OTHER BOOKS BY WILLIAM H. CROUSE

Automotive Mechanics
and five accompanying study guides:
WORKBOOK FOR AUTOMOTIVE CHASSIS
WORKBOOK FOR AUTOMOTIVE ELECTRICITY
WORKBOOK FOR AUTOMOTIVE ENGINES
WORKBOOK FOR AUTOMOTIVE SERVICE AND TROUBLESHOOTING
WORKBOOK FOR AUTOMOTIVE TOOLS

Everyday Automobile Repairs
AUTOMOTIVE ENGINES

Construction, Operation and Maintenance

SECOND EDITION

William H. Crouse
ABOUT THE AUTHOR

Behind William H. Crouse's clear technical writing is a background of sound mechanical engineering training as well as a variety of practical industrial experiences. He spent a year after finishing high school working in a tinplate mill, summers, while still in school, working in General Motors plants, and three years working in the Delco-Remy Division shops. Later he became Director of Field Education in the Delco-Remy Division of General Motors Corporation, which gave him an opportunity to develop and use his natural writing talent in the preparation of service bulletins and educational literature. During the war years, he wrote a number of technical manuals for the Armed Forces. After the war, he became Editor of Technical Education Books for the McGraw-Hill Book Company. He has contributed numerous articles to automotive and engineering magazines and has written several outstanding books: *Automotive Mechanics, Electrical Appliance Servicing, Everyday Automobile Repairs, Everyday Household Appliance Repairs, and Understanding Science.*

William H. Crouse's outstanding work in the automotive field has earned for him membership in the Society of Automotive Engineers and in the American Society for Engineering Education.

AUTOMOTIVE ENGINES

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THE MAPLE PRESS COMPANY, YORK, PA.
How to study this book

THIS IS one of a series of five books covering in detail the construction, operation, and maintenance of automobiles. The five books are designed to give you the complete background of information you need to become an automotive mechanic. Furthermore, the comprehensive coverage of the subject matter in the books should make them a valuable addition to the library of anyone interested in any phase of automobile engineering, manufacturing, sales, service, and operation.

GETTING PRACTICAL EXPERIENCE

Of course, these books alone will not make you an automotive mechanic, just as books alone do not make an airplane pilot or a dentist or an architect the expert he is. Practice also is required, practice in handling automotive parts and automotive tools and in following automotive servicing procedures. The books will give you the theoretical background you need, but you should seek out means of getting practice, also. If you are taking a regular course in automotive mechanics, you will get practical experience in the school automotive shop. But if you are not taking a regular course in a school, you may still be able to make use of the facilities of any nearby school with an automotive shop. Perhaps you will meet others who are taking an automotive mechanics course and can talk over any problems you have. This often clears up difficult points. A local garage or service station is a good source of practical information. If you can get acquainted with the automotive mechanics there, so much the better. Watch them as they work; notice how they do things. Then go home and think about it. Perhaps the mechanics will let you handle various parts and possibly even help with some of the servicing jobs.
How to Study This Book

SERVICE PUBLICATIONS

While you are in the service shop, try to get a chance to study the various publications they receive. Automobile manufacturers, as well as suppliers of parts, accessories, and tools, publish shop manuals, service bulletins, and parts catalogues. All these are designed to help service personnel do a better job. In addition, numerous automotive magazines are published which deal with the problems and methods of automotive service. All these publications will be of great value to you; study them carefully.

These various activities will help you gain practical experience in automotive mechanics. Sooner or later this experience, plus the knowledge that you have gained in studying the five books in the McGraw-Hill Automotive Mechanics Series, will permit you to step into the automotive shop on a full-time basis. Or, if you are already in the shop, you will be equipped to step up to a better and a more responsible job.

CHECKING UP ON YOURSELF

Every few pages in the book you are given the chance to check the progress you are making by answering a series of questions. There are two types of tests, progress quizzes and chapter check-ups. Each progress quiz should be taken just after you have completed the pages preceding it. The quizzes allow you to check yourself as you finish a lesson. On the other hand, the chapter checkups may cover several lessons since they are review tests of entire chapters. Since they are review tests, you should review the entire chapter by rereading it or at least paging through it to check important points before trying the test. If any of the questions stump you, reread the pages in the book that will give you the answer. This sort of review is very valuable and will help you fix in your mind the essential information you will need when you go into the automotive shop. Do not write in the book. Instead, write down your answers in a notebook.

KEEPING A NOTEBOOK

Most of the questions require a written answer. It would be well for you to keep a notebook and for you to write the answers in the [vi]
**How to Study This Book**

notebook. Also, you can write down in the notebook important facts that you pick up from reading the book or from working in the shop. As you do this, you will find that the notebook will become a valuable source of information to which you can refer. Use a looseleaf, ring-binder type of notebook so that you can insert or remove pages and thereby add to and improve your notebook.

**GLOSSARY AND INDEX**

There is a list of automotive terms in the back of the book, along with their definitions. Whenever you have any doubt about the meaning of some term or what purpose some automotive part has, you can refer to this list, or Glossary. Also, in the back of the book you will find an Index. This Index will help you look up anything in the book that you are not sure about. For example, if you wanted to refresh your mind on how some component works, you could locate the explanation quickly by looking in the Index to find what pages the information is on.

**AUTOMOTIVE TOOLS**

Notice that the Automotive Engines book has a chapter on automotive tools. This chapter is an important one and should be studied along with any of the books in the McGraw-Hill Automotive Mechanics Series. In other words, the information in this chapter on tools applies to all service operations on the car, and not just to engine service.

**McGRAW-HILL AUTOMOTIVE MECHANICS SERIES**

The five books in the McGraw-Hill Automotive Mechanics Series, of which this is one, are designed to be a complete library in automotive mechanics. Their purpose is to supply the technical background needed by anyone entering the field of automotive servicing. Although the five books are closely correlated, each is complete in itself and can serve as a text in the particular specialty it covers. There are, unavoidably, some slight duplications in the books; these were necessary to make each book a complete text in itself. The duplications will serve as a review for the student and will thus help him remember essential points on the construction and operation of automotive engines.
And now, good luck to you. You are engaged in the study of a fascinating, complex, and admirable mechanism—the automobile. Your studies can lead you to success in the automotive field, a field where opportunities are great. For it is the man who knows—the man who can do things—who moves ahead. Let this man be you.

William H. Crouse
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RAPID technological developments in the automotive field, as well as advancements in educational methods required to keep pace with these new developments, have made advisable a new edition of Automotive Engines. This revision includes material on the new automotive equipment introduced in the past three years and related servicing techniques. Insofar as possible, this new material has not been appended to the old; instead, it has been integrated into the pattern of the text so that the student sees the new material as part of the complete presentation.

The comments and suggestions of teachers and students who have used the earlier edition have been carefully analyzed and acted upon where possible during the revision of the text. Reports of their experience in the actual use of the text for classroom and home study have been of paramount importance to the author in his efforts to make the book of maximum usefulness. Improvements that have been made in the present edition, therefore, should be credited to these users, and acknowledgment of their helpful suggestions is herewith gratefully extended.

WILLIAM H. CROUSE
Acknowledgments

DURING the several years that the five books in the McGraw-Hill Automotive Mechanics Series (of which this is one) were in preparation, the author was given invaluable aid and inspiration by many, many people in the automotive industry and in the field of education. The author gratefully acknowledges his indebtedness and offers his sincere thanks to these many people. All cooperated with the aim of providing accurate and complete information that would be useful in the training of automotive mechanics. Special thanks are due to the following organizations for information and illustrations that they supplied: AC Spark Plug Division, Buick Motor Division, Cadillac Motor Car Division, Chevrolet Motor Division, Delco Products Division, Delco-Remy Division, Detroit Diesel Engine Division, Frigidaire Division, Oldsmobile Division, Pontiac Motor Division, Saginaw Steering Gear Division, and United Motors Service Division of General Motors Corporation; Allen Electric and Equipment Company; American Exporter's Automotive World; Akron Equipment Company; American Motors Corporation; Barrett Equipment Company; Bear Manufacturing Company; Bendix Products Division of Bendix Aviation Corporation; Black and Decker Manufacturing Company; Carter Carburetor Company; Chrysler Sales Division, De Soto Division, Dodge Division, and Plymouth Division of Chrysler Corporation; Clayton Manufacturing Company; Henry Disston and Sons, Inc.; Eaton Manufacturing Company; E. I. du Pont de Nemours & Company, Inc.; Electric Auto-Lite Company; Federal-Mogul Corporation; E. Edelmann and Company; Federal Motor Truck Company; Ford Motor Company; Gemmer Manufacturing Company; B. F. Goodrich Company; Greenfield Tap and Die Corporation; Hall Manufacturing Company; Jam Handy Organization, Inc.; Hercules Motors Corporation; Hobart Brothers; Hotpoint, Inc.; Houde Engineering Division of Houdaille-Hershey Corporation; International Harvester Company; Kaiser Motors Corporation; K-D Manufacturing Company; Kelsey-Hayes Wheel Company; Kent-Moore Organization, Inc.; Johnson Bronze Company; King-Seeley Corporation; Lincoln-Mercury Division of Ford Motor Company; Linde Air Products Com-
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pany; Mack-International Motor Truck Corporation; Metalizing Com­pany of America; Alexander Milburn Company; Monmouth Products Company; Monroe Auto Equipment Company; Muskegon Piston Ring Company; New Britain Machine Company; North American Electric Lamp Company; Perfect Circle Company; Ramsey Accessories Manu­facturing Company; Bottler Boring Bar Company; A. Schrader's Son Division of Scovill Manufacturing Company, Inc.; Sealed Power Cor­poration; South Bend Lathe Works; Spicer Manufacturing Corporation; Standard Oil Company; Storm Manufacturing Company, Inc.; Stude­baker-Packard Corporation; Sun Electric Corporation; Sunnen Products Company; Thompson Products Inc.; United Specialties Company; United States Rubber Company; Van Norman Company; Warner Electric Brake Manufacturing Company; Waukesha Motor Company; Weaver Manufacturing Company; Wilkening Manufacturing Company; and Zenith Carburetor Company.

Special thanks are also due to the staff and instructors at General Motors Institute; they supplied the author with much excellent in­formation and gave him great assistance during certain phases of the work on the McGraw-Hill Automotive Mechanics Series. To all these organizations and the people who represent them, sincere thanks!

William H. Crouse
1: Fundamental principles

THIS CHAPTER discusses the fundamental principles that enter into the operation of the automotive engine. It offers explanations of heat and combustion and discusses the meaning of such terms as energy, work, power, torque, and friction. All these terms are used to describe the actions in the automotive engine. As you read the chapter, you will come to understand what they mean and how they are related to engine operation.

§1. Purpose of this book

You are interested in automobile engines. If you were not, you would not be reading this book. We hope to tell you a great deal about automobile engines in the pages that follow. We will describe how various engines are constructed, how they operate, and how to service and repair them. Such information will be of value to you regardless of what job you have, or hope to have, in the automobile industry. The automotive mechanic, the automotive engineer, the man working at the higher level in automotive manufacture, sales, service, or operation, should have a good understanding of the facts discussed in this book. Thus, no matter what your present position in the automotive industry, the knowledge in this book should enable you to do your job better; it will help to prepare you for a bigger job in the future.

§2. What our universe is made of

You may think it strange for us to start a book on automobile engines by talking about the universe and what it is made of. But by doing this, we can very quickly explain some of the puzzling aspects of engine operation. For example, when a gallon of gasoline is burned in the engine, more than a gallon of water is produced. Why? You'll find the answer on a following page. It is important to know about such things, because water in an engine can be very damaging to the engine. You will want to know not only how the water is formed, but also how the engine manages to get rid of it. You will find out about this, and
§3. Automotice Engines

many other interesting aspects of engine operation, in the pages that follow.

§3. Atoms We can look around us and count thousands of different substances and materials, from wood to steel, glass to cloth, gasoline to water. We can see that the world is made of a tremendous variety of things. Yet, the amazing fact is this: all these things are made up of only ninety some types of basic “building blocks” called atoms. And the atoms, in turn, are made up of various quantities of only three basic particles.

<table>
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<tr>
<th>Name</th>
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<th>Approximate atomic weight</th>
<th>Electron arrangement</th>
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<td>Ca</td>
<td>20</td>
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<td>C</td>
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<tr>
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<td>Cu</td>
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<td>63.6</td>
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<td>Fe</td>
<td>26</td>
<td>56</td>
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<td>Mg</td>
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§4. Size of atoms. Individual atoms are far too small for us to see, even with the most powerful microscope. There are billions upon billions of atoms in a single drop of water. However, even though no man has ever seen an atom, we have fairly definite ideas of how atoms are constructed. But before we discuss construction, let's first talk about size. To get a rough idea of how small atoms are, let's talk about the simplest atom of all, the atom of the gas hydrogen. We will start with a cubic inch of hydrogen gas (at 32°F and atmospheric pressure). This cube (Fig. 1-1) contains about 880,000,000,000,000,000 (880 billion billion) atoms. Suppose we were able to expand this cube until it was large enough to contain the earth. That means each edge would measure 8,000 miles. If the atoms were expanded in proportion, then each atom would measure about ten inches in diameter on this tremendously enlarged scale.

Note: You might think that the atoms would be closely packed together, since there are so many of them; but this is not so. The distance between atoms is considerably greater than the diameter of the atoms.
§5. The hydrogen atom

The hydrogen atom is the simplest of all atoms. It is made up of two particles (Fig. 1-2). One of these particles is at the center, or nucleus, of the atom; the other is whirling around the first particle at tremendous speed. The center or nuclear particle is called a proton (it has a tiny charge of positive electricity). The outer particle whirling around the proton is called an electron (it has a tiny charge of negative electricity).

Note: Positive charge is indicated by a plus (+) sign. Negative charge is indicated by a minus (−) sign.

The electron is kept whirling in its path (or orbit) around the proton by a combination of forces. One force is the attraction that two particles of opposite electric charge have for each other. (Positive attracts negative and negative attracts positive.) This attrac-
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tion tends to pull the electron in to the proton. But balancing this is the tendency that the electron has to move in a straight line and fly away from the proton. This is somewhat similar to the balancing of forces you have when you swing a ball attached to a rubber band in a circle (Fig. 1-3). As you swing the ball, the rubber band stretches because the ball tends to fly away from your hand. But the rubber band (the attracting force) keeps the ball moving in a circle around your hand.

§6. Helium The next element above hydrogen, as we go from the simplest to the more complicated atoms, is helium, another gas. The helium atom has two protons (+ charges) in its nucleus and two electrons (− charges) circling the nucleus (Fig. 1-4). In addition to the two protons, the helium nucleus contains two other particles which are electrically neutral (have no charge) and are thus called neutrons. The two neutrons seem to have the ability to hold the two positively charged protons together in the nucleus. If it were not for the neutrons, the two protons would fly apart. For just as two opposing electric charges (positive and negative) attract each other, so do similar electric charges repel each other. A positive charge repels a positive charge. A negative charge repels a negative charge.

§7. More complex atoms The next element above helium in complexity is lithium, a very light metal. The lithium atom (Fig. 1-5) has a nucleus with 3 protons and 4 neutrons. Three electrons, one for each proton, circle the nucleus.
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Next comes beryllium with 4 protons, 5 neutrons, and 4 electrons; boron with 5 protons, 5 neutrons, and 5 electrons; carbon with 6, 6, and 6; nitrogen with 7, 7, and 7; oxygen with 8, 8, and 8; and so on. Note that each atom normally contains the same number of electrons as there are protons. This makes the atom electrically neutral (since negative charges equal the positive charges).

CHEMICAL REACTIONS

§8. Molecules

Nearly everything around you, as well as your own body, is made up of combinations of different elements. It is rare that we see an element in its pure form. Whenever the atoms of different elements combine, molecules are formed. A molecule of common table salt is made up of two atoms, one atom of sodium and one atom of chlorine. A molecule of water is made up of one atom of oxygen and two atoms of hydrogen. These are simple molecules. Many molecules are very complicated and contain many atoms. For example, the molecule of serum albumin (found in blood plasma), contains upwards of ten thousand atoms.

The formation of molecules from atoms, or from other molecules, is called chemical reaction. During a chemical reaction there is a sharing, or interchange, of electrons between the atoms involved as the atoms combine into molecules. The nuclei of the atoms remain unchanged.

§9. Combustion

Combustion, or fire, is a common chemical reaction in which the gas oxygen combines with other elements such as hydrogen or carbon. One type of combustion process occurs in the automobile engine. In the engine, air and fuel (gasoline vapor) are mixed, compressed, and then ignited, or set on fire (Chap. 3, “Engine Fundamentals,” explains this sequence in detail). The air (our atmosphere) contains oxygen; about 20 percent, or one-fifth, of the air is oxygen. Gasoline is made up essentially of hydrogen and carbon (thus, gasoline is called a hydrocarbon). Let’s see what happens when the air-fuel mixture burns.

An oxygen atom has 8 protons and 8 neutrons in its nucleus, and 8 electrons circling the nucleus in two separate paths, or orbits (Fig. 1-6). The inner orbit has 2 electrons while the outer orbit carries 6 electrons. The outer orbit can carry, or hold, 8 electrons; it will, in fact, accept 2 additional electrons if free electrons move...
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close enough to the atom. The hydrogen atom has 1 electron, as already mentioned.

When gasoline burns in the engine, it splits up into hydrogen and carbon. Then these two elements combine with the oxygen in the air. For instance, let us look at what happens when the hydrogen combines with oxygen. During this action, two hydrogen atoms lose their electrons to one oxygen atom as shown in Fig. 1-7. These two electrons enter the outer electron orbit of the oxygen atom, thereby "filling up" or "satisfying" this orbit. However, this gives the oxygen atom a negative electric charge. Also, the two hydrogen atoms that have lost their electrons have a positive electric charge. The result of all this is that the two hydrogen atoms are attracted to the one oxygen atom. The three atoms form a molecule which has the chemical symbol H<sub>2</sub>O and the common name water.

At the same time that this is going on, the carbon atoms, released when the gasoline splits into hydrogen and carbon, are also combining with oxygen. A carbon atom has 6 protons and 6 neutrons.
in its nucleus, with 6 electrons circling the nucleus in two orbits (Fig. 1-8). In the combustion process, the 4 electrons in the outer orbit are "snatched" by two oxygen atoms somewhat as shown in Fig. 1-9. This gives the oxygen atoms a negative electric charge. As a result, the carbon atom attaches to two oxygen atoms to form a molecule of carbon dioxide, or CO₂ gas.

Now see what we have. In the combustion process, oxygen in the air unites with hydrogen and carbon in the gasoline to form water and carbon dioxide. Since the combustion is accompanied with high temperatures (temperatures may be above 4000°F), the water is in the form of vapor, or steam. It therefore goes out the exhaust with the carbon dioxide. Interestingly enough, more than a gallon of water is formed for every gallon of gasoline that is burned (that [8]
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is, it would measure more than a gallon if it were cooled enough to return to liquid form). You see, when the hydrogen part of the gasoline burns (or unites with oxygen), it is actually picking up the oxygen from the air. That is why we get more than a gallon of water (H₂O) when we burn a gallon of gasoline.

Note: When the engine is cold, some of the water condenses on cold engine parts. This water then works its way down into the crankcase where it mixes with the engine oil to form sludge. You will find more on this subject in §170.

HEAT

§10. The nature of heat If someone asked you to define heat, you might say that it is something that keeps a person warm, that raises the temperature, that makes water boil or iron melt. It is true that heat produces all these effects, but scientists look at heat in a somewhat different way. They say that heat is simply the rapid motion of the atoms and molecules of a substance.

You might think that the atoms and molecules in a piece of iron or wood or any other solid substance are motionless. However, they are in motion even though they do move in rather restricted paths. But the higher the temperature, the more violently and the faster they move. The atoms in a piece of hot iron are moving faster than the atoms in a piece of cold iron.

§11. Change of state It may seem strange to say that heat is simply an indication of the speed of atomic motion. Yet, as we discuss change of state, this idea will become clear.

If we were to place a pan of ice cubes over a fire, the ice cubes would soon melt, or turn to water. Presently, the water would become hot, and would boil, or turn to vapor (Fig. 1-10). Almost every substance can exist in any
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of three states: as a solid, as a liquid, or as a gas or vapor. When a substance changes from one state to another, it is said to undergo a change of state.

A change in the speed of molecular motion, if great enough, will cause a change of state. For example, in ice, the water molecules are moving relatively slowly and in fairly restricted paths. But as the temperature is increased, the molecules move faster and faster. Presently, at the melting point of ice (32°F), the molecules are moving so fast that they begin to break out of their restricted paths. The ice turns to water. As the molecular speed is increased still more (temperature continues to rise), the boiling point of water is reached (212°F). At this point, the molecules are moving so rapidly that great numbers of them actually fly out of the water in the form of steam. The water boils.

§12. Producing change of state

Let us take another look at the pan of ice cubes held over a fire (Fig. 1-10). We have already noted that combustion, or fire, is a chemical reaction in which atoms of oxygen combine with atoms of other elements such as hydrogen and carbon. But how can this produce the increase in molecular speed, that is, heat? A simple explanation is that during the chemical reaction, the newly formed molecules (H₂O and CO₂, for example) are set into extremely rapid motion. They bombard the bottom of the pan from the outside. This bombardment knocks the molecules of metal in the pan into more rapid motion. These metal molecules, in turn, begin to bombard the ice molecules that are in contact with the pan on the inside. The water molecules are thus "hammered" into more rapid motion. As this continues, the ice melts. Then, as the bombardment continues, the water molecules are set into such rapid motion that they are knocked clear out of the water; the water boils.

§13. Light and heat radiations

The above is only a partial description of what takes place in a fire. In addition to the swiftly moving molecules that the fire produces, it produces radiations.

These radiations we see as light and feel as heat. They are produced by interesting actions that take place inside the atoms of fuel and oxygen as they combine to form molecules during combustion. Scientists do not fully understand these actions, but they believe that during combustion, electrons jump between the orbits [10].
in the atoms. These jumps are accompanied by tiny flashes (or emissions) of radiant energy. These emissions we see as light and feel as heat.

§14. Expansion of solids due to heat When a piece of iron is heated, it expands. A steel rod that measures exactly 10 feet in length at 100°F will measure 10.07 feet in length at 1000°F (Fig. 1-11). In other words, the steel rod will expand nearly an inch (0.84 inch to be more accurate) as the steel rod is heated from 100 to 1000°F.

The reason for this is that as the material becomes hotter, the molecules move faster and faster. If the steel is heated enough, it will actually melt, or undergo a change of state. But before this happens, the steel will begin to expand a little. This is because as the molecules move faster and faster, they need more room. They "push" adjacent atoms away so that the atoms, in effect, spread out, causing expansion.

§15. Expansion of liquids and gases due to heat Not only solids like iron, copper, or aluminum, but also liquids and gases expand when heated. If you had a cubic foot of water at 39°F and heated it to 100°F, you would find that its volume had increased to 1.01 cubic foot. If you had a cubic foot of air at 32°F and increased its temperature to 100°F, meanwhile holding pressure constant, you would find that its volume had increased to 1.14 cubic feet. These expansion effects result from more rapid molecular motion which tends to push the atoms and molecules further apart so that they "spread out" and take up more room.

§16. Increase of pressure with temperature A different sort of effect results if the volume is held constant while the cubic foot of air is heated from 32 to 100°F. If we started with a pressure of 15 psi...
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(pounds per square inch), we would find that the pressure had increased to about 17 psi at 100°F. This can be explained by the

Fig. 1-12. Gas pressure in a container is the result of the ceaseless bombardment of the inner sides of the container by the fast-moving molecules of gas. This "bombardment" is shown on only one side of the container for simplicity. It actually takes place against all the inner sides. The molecules are shown tremendously enlarged. There are, of course, almost countless billions of molecules in action instead of a few as shown.

molecular theory of heat we have been discussing (§§10 to 12). But first let us examine the term "pressure" more closely. Actually, gas or air pressure in a container is due to the unending bombardment of the sides of the container by the fast-moving molecules of gas or air (Fig. 1-12). Of course, a single molecule bumping against the sides of the container would have little effect. Since, however, there are billions upon billions of molecules bumping the walls, their combined "bumps" do add up to a definite "push" or pressure.

As temperature increases, the molecules and atoms of air are moving faster. They bump the walls of the container harder and more often, thus registering a stronger "push" or a higher pressure.

In a similar way, when the molecules are pushed closer together (that is, when the air is compressed in the container), then the molecules bump into each other, and into the walls of the container, more often. This more intense bombardment causes a greater pressure to be registered.

Note: Not only pressure, but temperature as well, is increased when a gas is compressed. When the molecules are moved closer together (or the gas is compressed), they bump into each other and into the container walls more often. This means that they are set into more rapid motion as compression takes place. That is,
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temperature goes up. As an example of this action, the air drawn into a diesel-engine cylinder is compressed to as little as a sixteenth of its original volume. During this compression, the temperature of the compressed air goes up to as much as 1000°F.

§17. The thermometer as an application of the expansion effect

The ordinary glass-stemmed thermometer (Fig. 1-13) is a familiar application of the expansion of liquids with increasing temperature. The liquid, usually mercury or a special form of alcohol, is largely contained in the glass bulb at the lower end of the thermometer. As temperature increases, the liquid expands. Since it now needs more room, part of it is forced up into the hollow glass stem. The higher the temperature, the farther the liquid is forced up into the stem. The stem is marked off to indicate the temperature in degrees.

§18. The thermostat as an application of the expansion effect

Different metals expand different amounts with increasing temperature. For instance, aluminum expands twice as fast as iron as their temperatures go up. This difference in expansion rates is used to advantage in thermostats. These devices are temperature-sensitive and can be made to do various jobs as temperature changes. For instance, the thermostat in your home heating system turns the furnace on when the temperature goes down and turns it off when the temperature comes up to the shutoff point. Various thermostats are used in the automobile to open and close electric circuits, to control the engine cooling system, to control heating of the ingoing air-fuel mixture, and to do various other jobs. One type of thermostat is shown in Fig. 1-14. It consists of a coil made of two strips of different metals, brass and steel, for example, welded or otherwise fastened to each other. When the coil is heated up, one metal expands faster than the other. If the faster-expanding metal is on the inside of the strip, the coil will attempt to straighten out and unwind. On later pages of this book we shall come across various types of thermostats and shall learn the various jobs they do in the automobile.
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CHECK YOUR PROGRESS

Progress Quiz 1

The following questions will help you find out how well you are remembering what you are reading. If you have any trouble answering any of the questions, you should reread the past few pages. Most students make a practice of reading and rereading their lessons several times in order to make sure that they understand them. Do not be discouraged if you cannot answer all the questions at once. Just keep in mind that the material you have been reading is not quite so easy to remember as the plot of a story or of a movie you may have seen. So, if you run into trouble as you take the quiz below, just reread the past few pages and try the questions again. As you do this, you will begin to learn how to pick out the important facts you should remember. After you have done this a number of times in the next few sections of the book, you will find that it will become much easier to read and retain the essential facts. This means that you are becoming an expert student. And the expert student, the man who can remember the facts, is headed for success in his chosen line of work.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. A substance made up entirely of only one type of atom is called
   a particle a molecule an element

2. The hydrogen atom is made up of two particles which are called
   proton and neutron proton and electron proton and nucleus

3. In the chemical reaction known as combustion, each oxygen atom acquires
   one electron two electrons two protons

4. Gasoline is called a hydrocarbon because it is made up essentially of
   carbon and hydrogen carbon and oxygen hydro-
   gen and oxygen

5. When gasoline burns, two of the compounds that are formed are
   oxygen and hydrocarbon water and carbon dioxide water
   and oxygen

6. One way of looking at heat is to say that with increasing tem-
   perature, the molecules move faster molecules move
   slower molecules evaporize
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7. Most substances can exist in any of three states: solid, gas, or vapor; liquid, gas, or vapor; solid, liquid, or gas.

8. As a piece of iron is heated, the more rapid movement of the molecules cause the iron to expand, shrink, or increase in pressure.

9. If you heated a closed container of air, you would find that, inside the container, the volume would increase, pressure would increase, or pressure would decrease.

10. The thermostat is a device that produces mechanical movement as the temperature changes, pressure changes, or volume changes.

PHYSICAL PRINCIPLES RELATED TO ENGINE OPERATION

§19. What is meant by “physical principles”? By “physical principles” we mean the rules or “laws” that govern the different conditions that exist, and the actions that take place, in the world around us. When we release a stone from our hand, it drops to the ground. When a vacuum exists in an engine cylinder, air rushes in to “satisfy” the vacuum. When a car goes around a curve too fast, it skids. These things happen because of certain conditions that exist in the physical world around us: these “conditions” are physical principles, or physical laws. Let us discuss those physical principles that help to explain how and why an engine operates.

§20. Gravity Gravity is the attractive force that exists between all objects. When we release a stone from our hand, it falls toward the earth because of the gravitational pull of the earth. The stone also exerts a gravitational attraction on the earth. However, because the stone is so much smaller, the stone moves; the earth does not. If the stone and the earth were the same size (had the same mass), then the two would move toward each other and would meet at a halfway point. When a car is being driven up a hill, a considerable part of the power developed by the engine is used in overcoming gravity (that is, in raising the car against gravitational attraction). Likewise, a car can coast down a hill with the engine turned off because of the gravitational attraction of the earth on the car.

We normally measure gravitational attraction in terms of weight. We put an object on a scales and note that it “weighs” 10 pounds, for example. What we mean by this is that the object has sufficient
mass for the earth to register that much pull on it. It is gravitational attraction, or the pull of the earth, that gives an object its weight.

§21. Atmospheric pressure. We do not usually think of the air as having any weight. But the air is an "object," and it has weight (is pulled toward the earth by gravitational attraction). At sea level and average temperature, a cubic foot of air weighs about eight-hundredths (0.08) of a pound, or about 1 1/2 ounces. This does not seem to amount to much. But we must consider that the blanket of air (or the atmosphere) surrounding the earth is many miles thick. This means that there are, in effect, many thousands of cubic feet of air piled one on top of another, all adding their weight. Actually, we find that the total weight, or downward push, of this air amounts to about 15 psi at sea level. This means that the pressure of the air (or atmospheric pressure) is about 2,160 pounds on every square foot. This is more than a ton per square foot (2,000 pounds = 1 ton). Since the human body has a surface area of several square feet, the body is sustaining a total atmospheric pressure of several tons!

When a person first reads this, he is apt to wonder why all this tremendous pressure he is holding up doesn’t crush him. The reason is that the internal pressures of our body balance this external pressure of air. Fish have been found thousands of feet down in the ocean, where the pressures are more than 100,000 psi. The fish can live because their internal pressures balance these tremendous external pressures.

Atmospheric pressure is not constant. It changes with weather. It also changes as you move from sea level up into the mountains or, by plane, into the sky. In the next article, on vacuum, we shall find out how men measure changing atmospheric pressure and use these measurements to predict changing weather. For instance, lowering of the atmospheric pressure may mean a storm is coming. The reason that changing weather and changing atmospheric pressure are related is that the air expands and becomes lighter as it is heated (and contracts and becomes heavier as it cools). A cubic foot of air at 0°F weighs about 0.085 pound. A cubic foot of air at 100°F weighs only about 0.070 pound. This means that as the air is heated or cooled on sunny or cloudy days, it becomes lighter or heavier. Atmospheric pressure, therefore, decreases or increases.
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Atmospheric pressure decreases as you climb a mountain or fly upward in a plane. The reason for this is that the higher you go, the more of the total blanket of air, or atmosphere, you put below you where it cannot press down on you. For example, at 30,000 feet above the earth's surface, the air pressure is less than 5 psi. At 100,000 feet altitude, the air pressure is no more than 0.15 psi. A man could not live at this height unless he were in a sealed and pressurized airplane, or unless he wore a "space suit" which sustained a pressure around him and kept him supplied with oxygen.

§22. Vacuum  Vacuum is the absence of air or other matter. If we could journey far above the earth's surface, hundreds of miles, we should find practically no atmosphere at all. That is, at this height there are only a few widely scattered atoms of air. This is a vacuum.

But we do not need to leave the earth to find a vacuum. We can create a vacuum any place on earth with a long glass tube, closed at one end, plus a dish of mercury (a heavy metal that is liquid at normal temperatures). To produce a vacuum, we completely fill the tube with mercury, and then close the end tightly. Next, we turn the tube upside down, put the end into the dish of mercury, and open this end. When we open the end, some of the mercury will run down out of the tube, leaving the upper end of the tube empty (Fig. 1-15). Since no air can enter, the upper part of the tube is actually a vacuum.

The device shown in Fig. 1-15 is called a barometer, or a device to measure atmospheric pressure. You might wonder why not all the mercury runs out of the tube when it is turned upside down, since mercury is so heavy. The reason is that the atmospheric pressure won't let it run out. The air presses down on the surface of the mercury in the dish, and this pressure holds the mercury up in the tube (Fig. 1-16). This is somewhat like putting your hand, palm down, into soft mud. As you push down on the mud, the downward pressure causes some of the mud to squirt up between your fingers.

You can prove that it is air pressure that holds the mercury up in the tube by opening the top end of the tube. Now, air pressure will be admitted above the column of mercury in the tube. This air pressure will force the mercury in the tube down to the level of the mercury in the dish.

The barometer (Fig. 1-15) is a very useful device since it indi-
cates air pressure. When air pressure goes up, the air pushes harder
on the mercury and forces it higher up into the tube. But when air
pressure goes down, there is a weaker push on the mercury and the
mercury settles to a lower level in the tube. The barometer can
foretell the coming of a storm. A storm is normally accompanied
by lowered atmospheric pressure (brought on by the presence of
heated, and lighter, air). Thus, when the barometer "drops" (mer­
cury goes down in the tube), chances are a storm is coming.

There are, of course, many methods of producing a vacuum be­
sides using a tube of mercury. Pumps of various types produce
vacuum. The automobile engine is, in one sense, a vacuum pump.

That is, it produces a partial vacuum in its cylinders; atmospheric
pressure then pushes the air-fuel mixture into the cylinders. We'll
go into that in more detail on a later page.

§23. Work The engineer does not define the term "work" the way
we do in ordinary everyday life. You may say you are "working"
when you stand holding a package. You "work" a problem, or
"work" by sitting at a desk in an office. But the engineer doesn't
agree with you on these definitions. When he says "work," he means
changing the position of an object against an opposing force.
"Work" in this sense means that an object must be moved by the
application of a force (a push, a pull, a lift). For example, when a
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weight is lifted from the ground, work is done on the weight. It is lifted, or moved, against the force of gravity. In a similar way, when a coil spring is compressed, work is done on the spring (Fig. 1-17). A force (or push) is exerted through a certain distance.

Work is measured in terms of distance and force. For example, if a weight lifted from the ground weighs 5 pounds and it is lifted 1 foot, then the work done on the weight will be 5 foot-pounds (or $1 \times 5$). If the 5-pound weight is lifted 2 feet, the work done will be 10 ft-lb (foot-pounds). As another example, if you push down on a spring (Fig. 1-17) with an average force of 25 pounds and your hand moves a distance of 6 inches (or $\frac{1}{2}$ foot) in compressing the spring, then you have done 12.5 ft-lb ($\frac{1}{2} \times 25$) of work on the spring.

![Fig. 1-17. When a spring is compressed, work is done on that spring and energy is stored in it.](image1)

![Fig. 1-18. When the spring is released, it can do work on another body, lifting a weight against the force of gravity, for example.](image2)

Note: Work can also be measured in other units such as inch-pounds, inch-ounces, and so forth. However, in engineering work the foot-pound is the most commonly used measurement of work.

§24. Energy Energy is the capacity or ability to do work. When work is done on an object, energy (or ability to do work) is stored in that body. For example, when the spring is compressed (Fig. 1-17), work is done on the spring and energy is stored in it. If the spring is released (Fig. 1-18), the stored energy can do work on another body. It can, for instance, lift a weight against the force of gravity. Energy is also stored in a weight when it is lifted from the earth. If a 10-pound weight is lifted 5 feet, the work required is 50 ft-lb. This amount of work is, in effect, stored in the weight.
The weight has the ability to do 50-ft-lb of work. If it were released and allowed to drop on a stake being driven into the ground, it would do that much work on the stake.

Energy is the measure of ability. Work is the application of this ability to produce motion.

§25. **Power**  Work can be done slowly, or it can be done rapidly. You can lift a weight off the floor slowly, or you can lift it very quickly (if it is not too heavy). The speed with which work is done is measured in terms of power. A machine that does a great deal of work in a comparatively short time is called a *high-powered machine*. A machine that takes a much longer time to do the same amount of work is a comparatively *low-powered machine*.

Power, then, is the rate, or speed, at which work is done.

§26. **Horsepower**  Engine performance is measured in terms of power—*horsepower*. A horsepower is the power of one horse, or a measure of the speed at which a horse can work. It may seem somewhat strange that in this modern day, we still compare the power of engines with the speed at which a horse can work.

Years ago, when engines were first being developed, men realized that they had to use some sort of measuring stick so they could compare the power of different engines. Since the horse was then the most common source of power, it was natural that the power of engines should be measured in terms of the power of horses, that is, in horsepower. If men had harnessed cats instead of horses to do their work for them, we should probably be referring to engines in terms of “catpower.”

![Fig. 1-19. One horse can do 33,000 ft-lb of work a minute.](image-url)
It was found that an average horse can raise a weight of 200 pounds a distance of 165 feet in 1 minute. Figure 1-19 shows a simplified version of the method by which this test was made. The horse walks 165 feet in 1 minute, and the cable, running over the pulley, raises the 200-pound weight 165 feet in that minute. The amount of work done is 33,000 ft-lb (foot-pounds). The length of time it takes to do this amount of work is one minute. The amount of power required is one horsepower. In other words, this is the amount of work one horse can do in one minute.

On the above basis, if 400 pounds were to be raised 165 feet in 1 minute, 2 horses would be required (1 for each 200-pound weight). The amount of work required would be 66,000 ft-lb (165 X 400). When this amount of work is done in 1 minute, then 2 hp is required. Similarly, if 33,000 ft-lb of work is done in 2 minutes, then only ½ hp is required since work is being done at the rate of 16,500 ft-lb per minute. The formula for horsepower is

\[ Hp = \frac{L \times W}{33,000 \times t} \]

where
hp = horsepower

L = length, in feet, through which W is forced

W = push, in pounds, that is exerted through distance L

t = time, in minutes, required to force W through L.

Problem: You have a heavy box loaded with sand and want to drag it 500 feet across a level lot in 2 minutes. You find that it requires an average pull of 2,000 pounds to pull the box. How much horsepower would be required?

Solution: Substituting in the formula

\[ Hp = \frac{L \times W}{33,000 \times t} = \frac{500 \times 2,000}{33,000 \times 2} = 15.15 \text{ hp} \]

Problem: You are asked to select a gasoline engine capable of raising a coal-mine elevator, which weighs 3,000 pounds, 220 feet in 1 minute. Ignoring friction and all other power losses, what would be the minimum horsepower that you could select?

Solution: Substituting in the formula

\[ Hp = \frac{L \times W}{33,000 \times t} = \frac{220 \times 3,000}{33,000 \times 1} = 20 \text{ hp} \]
§27. Inertia

Inertia is a characteristic of all material objects. It causes them to resist any change of speed or direction of travel. A motionless object (zero speed) tends to remain at rest. Furthermore, it resists any attempt to make it move. But once it is in motion, it resists any attempt to change its direction, to hurry it up, or to slow it down.

Consider the automobile. When it is stationary, its inertia must be overcome by the application of force before the car will move. To increase its speed, further force must be applied. To decrease its speed the brakes must be applied. The inertia of the car resists any speed reduction; the brakes must overcome this inertia. To say it in another way: the car has a certain energy content, stored in the form of speed. The brakes must absorb this energy (turning it into heat energy as the brake shoes press against the brake drums). In a similar manner, when the car goes around a curve, its inertia tries to keep it moving in a straight line. The friction of the tires on the road must overcome this tendency, or else the inertia of the car will send it into a skid.

The car may be thought of as a container in which energy is put. Application of power to the wheels overcomes car inertia; the car moves and energy is stored in it. The higher the speed, the more energy is stored. The torn and twisted wreckage of two cars that have collided at high speed is ample and tragic evidence of the amount of energy stored in cars when they are moving at high speed.

§28. Torque

Torque is twisting or turning effort. When you reel in a fish, you are applying torque to the reel crank. You apply torque to the steering wheel of an automobile to guide it around a curve. You apply torque to the top of a screw-top jar when you loosen the top (Fig. 1-20).

Torque should not be confused with power or with work. Torque is the rotary or twisting force that the engine applies, through shafts and gears, to the car wheels. Power is something else—it is the rate at which the engine works. Work is the energy expended, or the product of force and distance. Both work and power imply motion. Torque does not; it is merely a turning effort and may or may not result in motion.

Torque is measured in pound-feet (do not confuse this with foot-
pounds of work). For instance, if you pushed on a windlass crank with a 20-pound push, and if the crank were 1½ feet long (from center to handle), you would be applying a torque of 30 lb-ft (pound-feet) to the windlass crank (Fig. 1-21).

§29. Friction Friction is the resistance to motion between two objects in contact with each other. If you put this book on a table top, and then pushed the book across the table, you would find it took a certain amount of push. If you put a second book on top of the first book, you would find you had to push harder to push the two books together across the table top. Thus friction, or resistance to motion, increases with the load. The higher the load, the greater the resistance to motion (that is, the greater the friction). In the automobile engine the bearings are heavily loaded. Some bearings sustain loads of well above 1,000 psi. With such heavy loads the friction would be tremendous if it were not for the lubricating oil. However, the oil, in effect, floats the rotating journal so that actual metal-to-metal contact is avoided. The friction is then between moving layers of oil, rather than between solid objects. This friction is relatively low. Friction has been classified into three types: dry, greasy, and viscous.

1. Dry friction. This is the friction between two dry objects, a board being dragged across a floor, for instance. If the board and the floor are rough, the friction is relatively high. If the board and floor are smooth, the friction is lower. You can think of dry friction
as an interference to motion between two objects caused by surface irregularities that tend to catch on each other. Even objects that have been machined to a very smooth finish still have very small irregularities; they offer resistance to relative motion.

2. Greasy friction. This is the friction between two objects thinly coated with oil or grease. It can be assumed that the thin film tends to fill in the low spots in the surfaces. This reduces the tendency for the surface irregularities to catch on each other. However, high spots will still catch and wear as the two surfaces move over each other. In an automobile engine, greasy friction may occur in an engine on first starting. Most of the lubricating oil may have drained away from the bearing surfaces, and from the cylinder walls and piston rings. When the engine is started, only the small amount of oil remaining on these surfaces protects them from undue wear. Of course, the lubricating system quickly supplies additional oil, but before this happens, greasy friction exists on the moving surfaces. The lubrication between the surfaces where greasy friction exists is not sufficient to prevent wear. That is the reason that automotive engineers say that initial starting and warm-up of the engine is hardest on the engine and wears it the most.

3. Viscous friction. "Viscosity" is a term that refers to the tendency of liquids, such as oil, to resist flowing. A heavy oil is more viscous than a light oil and flows more slowly (has a higher viscosity or higher resistance to flowing). Viscous friction is the friction, or resistance to relative motion, between adjacent layers of liquid. In an engine bearing supplied with sufficient oil, layers of oil adhere to the bearing and journal surfaces. In effect, these clinging layers of oil are carried around by the rotating journal and wedged under the journal (Fig. 1-22). The wedging action lifts the

![Fig. 1-22. Shaft rotation causes layers of clinging oil to be dragged around with it, so that oil moves from the wide clearance A and is wedged into the narrow clearance B, thereby supporting the shaft weight W on an oil film.](image)

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Fundamental Principles

journal so that the oil itself supports the weight, or load. Now, since the journal is supported (or "floats") on layers of oil, there is no metal-to-metal contact. However, the layers of oil must move over each other, and it does require some energy to make them so move. The resistance to motion between these oil layers is called *viscous friction*.

CHECK YOUR PROGRESS

**Progress Quiz 2**

Here is your chance to check up on yourself again to find out how well the facts you have been reading about have stuck with you. The past few pages discuss some important physical principles that will give you a better understanding of engine design, construction, and operation. Engine operation is based on these principles; when you know them, you know the "why" as well as the "what," and this will help you in your work in the shop or office. Reread the past few pages if any of the questions that follow stump you. Don't get discouraged. Just remember that most good students have to reread their lessons several times before they can remember the essential facts.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. At sea level, atmospheric pressure is about \(150 \text{ psi}\) \(1.5 \text{ psi}\) \(15 \text{ psi}\)
2. When air is heated, it expands and becomes heavier expands and becomes lighter contracts and becomes heavier
3. When there are only a few atoms of air, widely scattered, the condition is called a vacuum pressure of air storm pump action
4. Changing the position of an object against an opposing force is called energy power work torque
5. The capacity or ability to do work is called power energy torque
6. If you lifted a 10-pound weight 3 feet, you would be doing 3 ft-lb of work 30 ft-lb of work 300 ft-lb of work
7. An engine that could raise 16,500 pounds 100 feet in 1 minute would [25]
have to develop about 5 hp 10 hp 25 hp

8. The characteristic of an object which causes it to resist any tendency to change its direction of travel is called energy power inertia

9. Torque, which is twisting or turning effort, is measured in lb-ft ft-lb foot-pounds lb-ft per minute

10. The three types of friction are dry, greasy, and liquid dry, viscous dry, wet, and liquid

**CHAPTER CHECKUP**

Note: Since the following is a chapter review test, you should review the chapter before taking the test.

You have completed one chapter of the book, and have taken an important step forward into a better future for you. The chapter you have just finished may not be as interesting as the later chapters which deal directly with the engine. General principles are often harder to understand and remember than specific details. But these general principles are important to you. Once you do understand them, you will find that you can answer many puzzling questions about how and why engines operate. The following questions not only will give you a chance to check up on how well you understand and remember these principles, but also will help you to remember them better. The act of writing down the answers to the questions will fix the facts more firmly in your mind.

Note: Write down your answers in your notebook. Then later, when you have finished the *Automotive Engines* book, you will find your notebook filled with valuable information which you can refer to quickly.

**Physical Properties and Their Measurements**

Below is a list of several physical properties and a list of the units in which they are measured (not in order, however). Write down in your notebook the list of physical properties as it appears to the left, below. Then, next to each property, write the unit in which it is measured. For example, opposite “temperature” you would write “degrees” since temperature is measured in degrees.

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>torque</td>
<td>degrees</td>
</tr>
<tr>
<td>horsepower</td>
<td>pound-feet</td>
</tr>
<tr>
<td>work</td>
<td>pounds per square inch</td>
</tr>
<tr>
<td>atmospheric pressure</td>
<td>foot-pounds per minute</td>
</tr>
<tr>
<td>temperature</td>
<td>foot-pounds</td>
</tr>
</tbody>
</table>

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Fundamental Principles

Completing the Sentences

The sentences below are not complete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. The smallest particle into which an element can be divided is called a molecule an atom a hydrocarbon neutral electricity negative electricity

2. The electron has a tiny charge of positive electricity neutral electricity negative electricity

3. Atoms are held together in a molecule by electrical charges centrifugal force chemical reaction combustion

4. When you heat an object, you cause its speed to increase molecules to move faster molecules to vaporize

5. You cannot produce a change of state unless you change molecular speed molecular composition chemical composition

6. The reason the atmospheric pressure goes down when air temperature goes up is that heated air is heavier cold air is lighter

7. In the barometer, the mercury is held up in the tube by air pressure vacuum temperature

8. The rate, or speed, at which work is done is called energy power torque

9. A 100-hp engine, with a suitable mechanism (neglecting friction), can lift 100,000 pounds 16 feet in about 30 seconds 1 minute 2 minutes 10 minutes

10. If you were turning an 18-inch crank, and found that a 20-pound push was required, you would be exerting on the shaft of the crank a torque of 8 lb-ft 18 lb-ft 30 lb-ft 360 lb-ft

Problems

Work out the following problems in your notebook.

1. You weigh 150 pounds. You are carrying an object weighing 40 pounds and you walk up a flight of stairs that has a total measurement of 10 feet vertically and 12 feet horizontally. What is the total amount of work done?

2. You are pulling a cart that weighs 1,000 pounds along a level road and find that you must exert a pull of 55 pounds. After you have pulled it for 100 feet, you have done how much work on the cart?

3. How much horsepower would be required to pull the cart me-
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tioned in the preceding problem 100 feet in 10 seconds (\(\frac{1}{6}\) of a minute)?

4. You turn the crank of an egg beater and find that you must exert a force of 2 pounds on the crank handle. The handle is 3 inches (\(\frac{3}{4}\) foot) from the center of the shaft. What torque do you exert?

Definitions

In the following, you are asked to define certain terms. Write down the definitions in your notebook. Writing the definitions down will help you to remember them.

2. What is change of state? 7. Define power.
3. What is gravity? 8. What is a horsepower?
4. What is vacuum? 9. What is torque?
5. Define work. 10. Define friction.

Suggestions for Further Study

If you are interested in the basic principles discussed in the chapter you have just finished, you might like to study them further. Almost any up-to-date high school physics book will give you much additional information on the principles covered in the last few pages. Your local library probably has several physics books that you will find of interest. Also, if you have a chance, you could talk over various points that might not be clear to you with your local high school science or physics teacher. Teachers are almost invariably fine people who are sincerely interested in helping you to acquire more knowledge and thereby to better yourself.
2: Automobile components

THIS CHAPTER describes the various component parts of the automobile, aside from the engine, including such items as the frame, power train, and car body. This material will serve as background information so that you will have a better understanding of the relationship between the engine and the other automotive components.

§30. Components of the automobile  Before we begin our studies of the engine, let us first look at the complete automobile, examine its component parts, and find out how these parts work together with the engine. You will probably find that much of the information is already familiar to you. However, as you read the next few pages, you may find some new and interesting relationships between automobile components that might not have occurred to you.

The automobile can be said to consist of five basic components:

1. The engine, or power plant, which is the source of power.
2. The frame, which supports the engine, wheels, and body.
3. The power train, which carries power from the engine to the car wheels. It contains the clutch, transmission, propeller shaft, differential, and axles.
4. The car body.
5. The car-body accessories, which include lights, heater, radio, windshield wiper, convertible-top raiser, and so no.

Let us look at each of these further. Remember, the pages that follow in the rest of this chapter are "get-acquainted" descriptions. Later chapters in the book describe in full detail the construction, operation, maintenance and servicing of engines. Other books in the McGraw-Hill Automotive Mechanics Series discuss the other automobile components in similar detail.

§31. Frame and chassis  The engine must be mounted on, and supported by, a frame. This frame must also support the car body.
and other automobile components. The car wheels are attached to the frame so that they support the frame and the rest of the car. The frame is usually made of box, tubular, and channel members that are welded or riveted together (Fig. 2-1). Various cross members reinforce the frame and also provide supports for the engine, the wheels, and other parts. The frame is extremely rigid and strong so that it can hold up under the shock blows, twists, vibrations, and other stresses to which it is subjected on the road.

Some automobiles have a "unitized" frame-body construction. That is, the body shell and the underbody are welded into a single unit. The underbody, made up of floor plates, channel and box members welded into a single assembly, takes the place of the frame.

When the engine, wheels, power train, brakes, and steering system are installed on the frame, the assembly is called the chassis (Fig. 2-2). Let us see how these various parts are attached to the frame.

§32. Engine support The engine is usually supported by the frame at three or four places. A certain amount of vibration and noise is bound to result from engine operation. To keep this noise and vibration from the frame, the engine supports are usually insulated by rubber pads or washers. One type of engine mounting is shown [30]
in Fig. 2-3. Here, there are two biscuit-shaped rubber mounting pads at the front, and a single long, narrow rubber mounting pad at the back. The engine mounting lugs or brackets are supported on the rubber pads, and the mounting bolts pass through the rubber pads so that there is no metal-to-metal contacts. As a result, the rubber absorbs vibration and engine noise and prevents it from being carried into the metal frame and from there to the car body and passengers.

§33. Springs  The wheels are attached to the frame through springs (Fig. 2-4). The springs support the weight of the vehicle. They also allow the wheels to move up or down as the wheels meet holes or bumps in the road. Since the springs allow the wheels to move up and down independently of the frame, most of the jarring action, or up-and-down motion, is absorbed by the springs. Little of it is carried to the frame and body. The following types of springs are used in automobiles: coil (Fig. 2-4), leaf (Fig. 2-5), torsion bar or rod (Fig. 2-8), or air suspension.

Coil-spring action in a front-wheel suspension system is shown in Figs. 2-6 and 2-7. Car weight puts an initial compression on the
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spring. When the wheel encounters a bump in the road (Fig. 2-6), it will compress further. When the wheel meets a hole in the road (Fig. 2-7), it drops into the hole, causing an expansion of the spring.

![image](image)

(a)

(b)

Fig. 2-3. Engine supports, indicated by arrows. (a) One of the two biscuit-shaped mountings at front of engine. (b) Long, narrow mounting at rear of engine. (Studebaker-Packard Corporation)

The leaf spring has been made in a number of forms, but the one most commonly used is shown in Fig. 2-5. It consists of a series of flat steel plates (or leaves) of graduated lengths, assembled one on top of another. The assembly acts as a flexible beam; the two ends are attached to the car frame while the center is
FIG. 2-4. Passenger car front suspension using coil springs, frame, wheel, and other parts partly cut away to show suspension parts. Shock absorber is centered in coil spring. (Pontiac Motor Division of General Motors Corporation)

FIG. 2-5. Leaf spring and other suspension parts used at rear axle of an automobile. (Dodge Division of Chrysler Corporation)
attached to the axle or axle housing. When the wheel meets a bump, the spring bends upward to absorb the blow. When the wheel drops into a hole, the spring bends, or bows, downward.

§34. **Shock absorbers** Springs alone will not give a satisfactory ride; shock absorbers must be used with them. If you have a small coil spring, you can demonstrate why springs alone are unsatisfactory. Suspend a weight on the spring. Then lift the weight and let it drop. It will expand the spring as it drops. Then it will rebound, or move up. The spring, as it expands and contracts, will keep the weight moving up or down (or oscillating) for some time. On the car, a very similar action takes place when there is no shock absorber. For instance, when the wheel passes over a bump, the spring is compressed. After the bump is passed, the spring at-
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tempts to return to its original position. However, it overrides this position and expands too much. This action causes the car frame to be thrown upward. Now, having expanded too much, the spring compresses. Again it overrides and it compresses too much. As this happens, the wheel may be raised clear of the road, and the frame may drop. These actions, or oscillations, may be repeated many times whenever the wheel meets a bump or hole. Not only do these actions give a rough ride, but they also make it hard for the driver to control the car.

Shock absorbers (Fig. 2-4) prevent these spring oscillations. Figure 2-9 shows one type of shock absorber in sectional view. This is the direct-acting, or telescope, shock absorber. One end of the shock absorber is attached to the frame, the other either to the lower control arm (at front as shown in Fig. 2-4) or to the axle housing or spring (at rear). Thus, as a wheel moves up or down in relation to the frame, the shock absorber will shorten or lengthen (see Fig. 2-9). When the shock absorber shortens, the piston rod forces the piston down into the cylinder tube, thereby putting the fluid below the piston under high compression. The fluid is forced through small orifices, or openings, in the piston and into the upper part of the
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cylinder tube. On rebound, when the wheel moves downward after passing a bump or dropping into a hole in the road, the shock absorber is extended (Fig. 2-9). As this happens, the piston moves into the upper part of the cylinder tube, thereby forcing fluid from the upper into the lower part of the tube.

As the fluid is forced in one direction or the other, it must pass through small orifices. This slows the motion of the piston and tends to place restraint on the spring action. That is, the shock of the wheel meeting a bump or hole is absorbed. The orifices have spring-loaded valves which open varying amounts to allow varying speeds of fluid movement through the orifices. This permits rapid spring motion while still imposing a restraining action. At the same time, it prevents excessive pressure rise in the fluid that might otherwise occur when large bumps in the road are encountered by the wheels. Also, the restraining action prevents excessive oscillations of the wheel after it passes a bump or hole.

§35. Steering system The steering system permits the front wheels to be pivoted to the right or left so that the car can be steered. The steering wheel in front of the driver (Fig. 2-2) is mechanically linked to the wheels as shown in Fig. 2-10 to provide this steering
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control. The bottom end of the steering-wheel shaft has a worm gear which rotates as the wheel is turned.

The worm gear is part of the steering gear. One type of steering gear (Fig. 2-11) has a two-tooth sector, or gear, meshed with the worm gear. Rotation of the worm gear moves the sector toward one or the other end of the worm gear. This movement is carried through the sector shaft to the steering-lever arm, or pitman arm. Thus the pitman arm swings to one or the other side of the car. This, in turn, pushes or pulls on the steering-knuckle arms (through the tie rods), causing the wheels to pivot on their supporting king-pins. Figure 2-12 shows an actual steering system.
Fig. 2-12. Phantom view (top) and a disassembled view (bottom) of a typical steering mechanism and linkage. (Chevrolet Motor Division and Oldsmobile Division of General Motors Corporation)
Many cars are now equipped with a special hydraulic device which uses pressure on a fluid to reduce steering effort. This device is called power steering, and there are several varieties. All work in a similar manner. As the driver turns the steering wheel, a hydraulic mechanism comes into operation to supply most of the effort needed to turn the wheel. Details of power steering and other steering systems are covered in another book in the McGraw-Hill Automotive Mechanics Series (Automotive Chassis and Body).

§36. Brakes Brakes are necessary to slow or stop the car. Practically all cars use hydraulic brakes, that is, brakes actuated by pressure on a fluid. A typical hydraulic braking system is shown in Fig. 2-13. When the brake pedal is pushed down, a piston is pushed into a cylinder in the master cylinder. This forces brake fluid from the master cylinder through the brake lines, or tubes, into the brake wheel cylinders. A wheel cylinder is shown in assembled view in Fig. 2-15. It has two pistons which are forced outward as brake fluid is forced into the wheel cylinder. The outward movement of the pistons moves the brake shoes out. The brake shoes are of metal, with the outer curved surface lined with a tough asbestos material which can withstand wear and high temperature.
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As the brake shoes are forced outward, they come up against the curved inner surface of the brake drum (Fig. 2-15). The wheel is attached to the brake drum so that it and the drum rotate together. When the brake shoes are forced against the inner surface of the brake drum, the frictional drag on the drum tends to prevent the wheel from rotating. The car is thus slowed or stopped.

FIG. 2-15. Brake-shoe assembly (at left) and brake drum in place on assembly (at right). The drum is partly cut away to show shoe. (Oldsmobile Division of General Motors Corporation)

§37. Tires The tires support the weight of the car and transmit the driving or braking power from the wheels to the road. They also absorb a considerable part of the road shocks resulting from small bumps and holes so that these shocks are not felt in the car. The tire consists of two parts, the inner tube, which holds the air, and the outer casing, which takes the wear and tear of traveling over the road. The casing (Fig. 2-16) has an outer coating of rubber which is baked, or vulcanized, onto an inner structure of fabric. The fabric is built up in layers, or plies (a five-ply tire having five layers, for example). The tread, which is the thickest part of the
rubber coating, is supplied in a number of different patterns (Fig. 2-17). Different tread designs are used to provide good traction for various road conditions, and for operation in snow, in mud, and off the highway.

The inner tube retains the air pressure. The air is introduced into the tube through a valve (Fig. 2-18). The air inflates the tube against the inner surface of the casing, thus holding the casing in shape under the weight of the car. At the same time, the assembly
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is flexible enough to give when bumps or holes are encountered in the road. Many tires are now tubeless. The tire casing and wheel rim are leakproof so no separate tube is needed.

FIG. 2-18. Cross-sectional view of a typical tire valve. (A. Schrader’s Son)

§38. Body supports  The body is attached to the frame in several places. The supporting points may be rubber-insulated to absorb vibration. Figure 2-1, illustrating two frames, shows the frame brackets to which the body is attached.

CHECK YOUR PROGRESS

Progress Quiz 3

You have now moved into the actual study of the automobile. The automotive-component fundamentals you have just been reading about are of special interest to anyone working in the automotive field. Find out how well you remember what you have been reading by taking the quiz that follows. Don’t be discouraged if any of the questions stump you. Just reread the past few pages and try the questions again. Remember, even the best students usually reread their lessons several times.

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The combination of taking the quiz and of rereading the preceding pages will help you fix essential facts firmly in your mind.

Correcting Parts Lists

The purpose of this exercise is to enable you to spot the unrelated part in a list. For example, in the list, shoe, pants, shirt, milk, tie, coat, you would see that milk does not belong because it is the only thing named that is not something you wear.

In each of the lists, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. Parts of the chassis include the frame, engine, wheels, body, power train, brakes, steering system.
2. Parts of the suspension include the shock absorbers, coil springs, leaf springs, steering wheel.
3. Parts in the shock absorber include rebound piston, brake shoe, cam, arm.
4. Parts in the braking system include the master brake cylinder, wheel cylinder, engine support, brake shoes, brake drums.
5. Parts of the car include the power plant, frame, steering system, transmission, power train, car body.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. The title of this book is Automotive Mechanics Chassis Engines Electricity
2. The power plant or engine is the source of electricity power gravity effort
3. The engine and body are attached to the braking system frame steering power train
4. When the engine, wheels, power train, brakes, and steering system are installed on the frame, the assembly is called the automobile chassis car framework
5. The engine is usually supported by the frame at one or two places two or three places three or four places six or eight places
6. Car springs are of two types coil and leaf coil and extension leaf and flat coil and helical
§39. Power train The power that the engine develops must be carried to the car wheels so that the wheels will rotate. The power train (Fig. 2-19) does this job. Actually, the power train must do three things: it must provide varying gear ratios (explained in §41) between the engine and car wheels; it must provide a reverse gearing arrangement so that the car can be backed; and it must
provide a neutral, or disconnecting, arrangement so that the engine can be uncoupled from the wheels.

With the standard power train and transmission (not the automatic transmission) the power train contains a clutch, a manually operated transmission, a propeller shaft, and a final drive (or differential).

Note: There is no separate clutch on most of the cars equipped with automatic transmissions, although such transmissions contain, as part of their internal mechanism, multiple-disk clutches.

§40. Clutch The clutch shown in Fig. 2-20 is of the type used with standard transmissions (not automatic). Its purpose is to permit the driver to couple or uncouple the engine and the transmission. When the clutch is in the coupling (or normal running) position,
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power flows through it from the engine to the transmission. If the transmission is in gear (see §41), then power flows on through to the car wheels so that the car moves. Essentially, then, the clutch has the job of permitting the driver to uncouple the engine temporarily so that the gears can be shifted from one to another forward gear position (or into reverse or neutral). It is necessary to interrupt the flow of power (by uncoupling) before gears are shifted. Otherwise, gear shifting would be extremely difficult if not impossible.

The clutch (Fig. 2-20) contains a friction disk (or driven plate) about a foot in diameter. It also contains a spring arrangement and a pressure plate for pressing this disk tightly against the smooth face of the flywheel. The friction disk is splined to the clutch shaft. The splines consist of two sets of teeth, an internal set on the hub of the friction disk, and a matching external set on the clutch shaft. They permit the friction disk to slide back and forth along the shaft, but force the disk and the shaft to rotate together. External splines can be seen on the shaft in Fig. 2-20. Figure 2-28 shows both external splines (No. 8) and internal splines (No. 17).

The flywheel, which is attached to the end of the engine crankshaft, rotates when the engine is running. When the clutch is engaged (that is, in the coupling position), the friction disk is held tightly against the flywheel (by the clutch springs) so that it must rotate with the flywheel. This rotary motion is carried through the friction disk and clutch shaft to the transmission.

To disengage (or uncouple) the clutch, the clutch pedal is pushed down by the foot. This causes the clutch fork to pivot so the clutch throwout bearing is forced inward. As the throwout bearing moves inward, it operates release levers. The release levers take up the spring pressure and lift the pressure plate away from the friction disk. The friction disk is no longer pressed against the flywheel face and the engine can run independently of the power train. Releasing the clutch pedal permits the clutch fork to release the throwout bearing so that the springs once again cause the pressure plate to force the friction disk against the flywheel face. The two again revolve together.

§41. Transmission  The transmission provides a means of altering the gear ratio between the engine and car wheels. In the usual
standard three-speed transmission (not automatic) used in passenger cars, the three possible forward gear ratios cause the engine crankshaft to turn about four, eight, or twelve times for each car-wheel revolution. There is also a reverse gear in the transmission for backing the car. In addition, there is a neutral position in which no power flows through the transmission.

The different gear ratios are necessary since the engine does not develop much power at low engine speeds. It must be turning at a fairly high speed for it to deliver enough power to start the car moving. Thus, on first starting, and after clutch disengagement, the transmission is placed in low gear. Now, after the clutch is engaged, the engine crankshaft turns twelve times for each wheel revolution. Engine and car speed are now increased until the car is moving 5 or 10 mph (miles per hour). At this point, the engine may be turning 2,000 rpm (revolution per minute). The clutch is then disengaged and the engine speed reduced so that gears may be shifted in the transmission. Gears are then shifted to second and the clutch re-engaged. The ratio is now about 8:1 (eight to one) or eight crankshaft revolutions to one wheel revolution. When engine speed is again increased, car speed will be increased. For example, 2,000 engine rpm would give a car speed of possibly 20 mph. Next the gears are shifted into high, the clutch being dis-engaged and re-engaged for this operation. This gives a ratio of about 4:1.

In automatic transmissions, the varying ratios between the engine and the car wheels are achieved automatically; that is, the driver does not shift gears. Automatic controls in the automatic transmission select or supply the proper gear ratio to suit driving conditions. Such transmissions make use of a fluid coupling or a torque converter, as well as mechanical, hydraulic, and possibly electric controls. Another book in the McGraw-Hill Automotive Mechanics Series (Automotive Transmissions and Power Trains) discusses these transmissions in detail.

§42. Gears Before we talk about transmissions in detail, let us take a look at gear construction. When two meshing gears have the same number of teeth (Fig. 2-21), both will turn at the same speed. But when one gear has more teeth than the other (Fig. 2-22), then the smaller gear will turn faster than the larger gear. For instance,
if a 24-tooth gear is meshed with a 12-tooth gear, the smaller gear will turn twice as fast as the larger one. The gear ratio between the two gears is 24:12, or 2:1. If a 12-tooth gear were meshed with a 36-tooth gear, the gear ratio would be 36:12, or 3:1. The smaller gear would turn three times every time the larger gear turned once. If the larger gear were turning at 1,500 rpm, the smaller gear would be turning at 4,500 rpm.

§43. Operation of transmission

Essentially, the typical standard passenger-car transmission consists of three shafts and eight gears of various sizes. A simplified version of a standard transmission is shown in Fig. 2-23. Four of the gears are rigidly attached to the...
countershaft. One of the countershaft gears is permanently meshed with the clutch gear on the end of the clutch shaft. When the engine is running and the clutch is engaged, the countershaft is driven by the clutch gear. It turns in a direction opposite, or counter, to the rotation of the clutch gear (that is why it is called a countershaft). With the gears in neutral (Fig. 2-23) and the car stationary, the transmission main shaft is not turning. The transmission shaft is connected, through the propeller shaft, to the final drive (see Fig. 2-19). The two gears on the transmission main shaft may be shifted back and forth along the splines on the shaft by operation of the gearshift lever in the driving compartment. The splines permit endwise (axial) movement of the gears but cause the gears and shaft to rotate together. Note, in the illustrations that follow, that a floor-board shift lever is shown. This type of lever is shown since it illustrates more clearly the lever action in shifting gears. The transmission action is the same, regardless of whether a floor-board or a steering-column type of shift lever is used.

1. Low gear. When the shift lever is operated to place the gears in low (Fig. 2-24), the lower end of the shift lever enters a slot in
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the low-and-reverse shifter yoke. The shifter yoke is moved forward by the lever movement. This moves the large gear on the transmission main shaft (the low-and-reverse gear) along the shaft until it meshes with the small gear on the countershaft. The clutch is disengaged for this operation so that the clutch shaft and countershaft stop rotating. When the clutch is again engaged, the transmission main shaft is driven through the countershaft low gear and the low-and-reverse gear. Because the various gears are of different sizes, the countershaft turns more slowly than the clutch shaft. The transmission main shaft turns more slowly than the countershaft. This gives a gear reduction of about 3:1; that is, the clutch shaft turns about three times to turn the transmission main shaft once. Further gear reduction in the final drive (or differential) at the rear axles produces an over-all gear reduction of about 12:1 between the clutch shaft (or engine crankshaft) and the wheels.

2. Second gear. When the clutch is operated and the gearshift lever is moved to second (Fig. 2-25), the low-and-reverse gear on the transmission main shaft is de-meshed from the countershaft low gear. The second-and-high-speed gear is moved into mesh with the
countershaft second gear. Since these two gears are more nearly of equal size, the gear reduction from the clutch shaft to the transmission main shaft is about 2:1. With the gear reduction in the differential, this gives an over-all gear reduction of about 8:1 between the crankshaft and the wheels.

3. High gear. When the gears are shifted into high (Fig. 2-26), the second-and-high-speed gear is de-meshed from the countershaft second gear. The second-and-high-speed gear is then moved on along the transmission main shaft until teeth on the side of this gear mesh with teeth on the side of the clutch gear. These two gears now turn together so that the transmission main shaft turns at the same speed as the clutch shaft. There is now a 1:1 gear ratio between the two shafts. The differential gear reduction gives a gear ratio of about 4:1 between the crankshaft and the wheels.

4. Reverse gear. When the gears are placed in reverse (Fig. 2-27), the low-and-reverse gear is moved into mesh with the reverse idler gear. The reverse idler gear is always in mesh with the countershaft reverse gear. Interposing the idler gear between the countershaft reverse gear and the low-and reverse gear causes the low-and-
HIGH
Fig. 2-26. Transmission with gears in high.

REVERSE
Fig. 2-27. Transmission with gears in reverse.
reverse gear to be rotated in the reverse direction. Now, when the
clutch is engaged, the car will be backed.

§44. Other transmissions While the above description outlines the
basic principles of all transmissions, somewhat more complex trans­
missions are used in modern cars, trucks, and busses. These trans­
missions may use helical gears instead of the plain spur gears shown
in the illustrations. Also, synchromesh devices are used to simplify
gear shifting; these devices synchronize the gears that are about to
be meshed so that meshing teeth are moving at the same speed.
They therefore mesh without clashing.

Many cars now have automatic transmissions which use fluid
couplings or torque converters and gearing systems quite different
from the one described above. In one type of automatic trans­
mission, gear shifting is done automatically in accordance with
engine and car speed and throttle opening. In others, gear shifting
can be accomplished by throttle movement. In still others, no gear
shifting takes place, all gear reduction taking place in an oil-filled
coupling called a torque converter. These various types of auto­
namic transmissions, along with conventional transmission, are dis­
Series (Automotive Transmission and Power Trains).

§45. Propeller shaft The propeller shaft (Fig. 2-19) carries the
power from the transmission to the differential at the rear-wheel
axles. The propeller shaft is more than a simple line shaft; it is
connected at one end to the rigidly mounted transmission and at
the other end to the differential, which moves up and down with
wheel-spring movement. Two separate actions are produced by this
movement. First, the distance between the transmission and the
differential changes as the differential moves up and down. As the
springs compress and the differential moves up and down, the distance
decreases. As the springs expand and the differential moves down, the
distance increases. Secondly, the driving angle changes as the
differential moves up and down.

1. Slip joint. Since the propeller shaft tends to shorten and
lengthen with the up-and-down differential movement, a device
must be included to permit this action. The device used is called a
slip joint. It is located either at the front or at the rear of the
propeller shaft. A typical slip joint is shown in Fig. 2-19.
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of the externally splined slip yoke (No. 8 in Fig. 2-28) and the internally splined front shaft (No. 17). When assembled, the yoke enters the shaft. The two must turn together because of the splines. However, the yoke can slip in the shaft to shorten or lengthen the effective length of the propeller shaft.

2. Universal joints. To take care of the differences in the angle of drive as the differential moves up and down, the propeller shaft has one or more universal joints. A universal joint is shown in assembled view in Fig. 2-28. A simplified drawing of a universal joint is shown in Fig. 2-29. It is essentially a double-hinged joint through which the driving shaft can transmit power to the driven shaft, even though the two shafts are somewhat out of line with each other.

Each of the two shafts has a Y-shaped yoke on the end. Between the yokes is a center member shaped like a cross. The four arms of this cross member are assembled in bearings in the ends of the shaft yokes. The bearings permit the cross-member arms to turn.

**Fig. 2-28.** Propeller shaft and support bearing partly disassembled so that the slip joint can be seen. External splines are on universal-joint yoke (8) and internal splines are in shaft (17). (Studebaker-Packard Corporation)

| 6. Lock washer | 12. Lock plate |
in the yokes. The driving shaft causes the cross member to rotate with it. At the same time the cross member causes the driven member to rotate.

§46. Differential If the car were driven in a straight line without turning, no differential would be necessary. However, when the car rounds a turn, the outer wheel must travel farther than the inner wheel. For example: when a right-angle turn is made with the inner wheel turning on a 20-foot radius, this wheel will travel about 31 feet (Fig. 2-30). The outer wheel, being nearly 5 feet from the inner wheel, turns on a radius of about 25 feet. It therefore travels nearly 39 feet. This is 8 feet more than the distance the inner wheel travels.

If the propeller shaft were geared rigidly to both wheels so that both wheels had to turn together, then each wheel would have to skid an average of 4 feet to make the turn discussed above. On this basis tires would not last long. Furthermore, the skidding would make the car very hard to handle on turns; it would probably go completely out of control. The differential prevents these difficulties; it allows the wheels to rotate different amounts when turns are made.

To study the construction and operation of the differential, let us build up, in effect, a simple differential (Fig. 2-31). The two rear wheels are mounted on separate axles. Each axle has a bevel gear that drives it (Fig. 2-31a). There is a differential case assembled to
one axle which encases the two bevel gears (Fig. 2-31b). The differential case has a bearing that permits it to turn independently on the axle. Inside the case there is a shaft that supports a third bevel gear, called the differential pinion gear (Fig. 2-31c). This gear meshes with the two axle bevel gears. Thus when the differential case is rotated, both axle gears rotate and both wheels turn. The differential case is rotated through a ring gear attached to it which is driven by the drive pinion on the end of the propeller.
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shaft (Fig. 2-31d). The propeller shaft turns the drive pinion; the
drive pinion turns the ring gear and the differential case.

If one of the wheel axles, with its bevel gear, were held stationary
while the differential case is rotating, then the differential pinion
gear would also rotate as it "runs around" on the stationary bevel
gear. It would be forced to do this since it is mounted on a shaft
that is carried around when the differential case rotates. As the
differential pinion gear rotates, it carries rotary motion to the
other axle bevel gear, causing it, and the wheel, to rotate.

In actual operation, when the car is on straight road, the ring
gear, differential case, differential pinion gear, and the two axle
bevel gears rotate without any relative motion. They turn as a unit.

[57]
However, when the car goes around a curve, the differential pinion
gear rotates on its shaft. This action permits the outer wheel to turn
more rapidly than the inner wheel.

The actual differential is more complicated than the simplified
unit shown in Fig. 2-31. An actual differential, in cutaway view,
is shown in Fig. 2-32. Driving power enters through the drive
pinion (No. 8) on the end of the propeller shaft. The drive pinion
is meshed with the ring gear (No. 5). The differential pinion-gear
shaft (No. 15) is mounted in the differential case, and two dif­
ferential pinion gears (No. 6) are mounted on this shaft. There is
an axle bevel gear (No. 12) on each axle shaft (No. 11). The other

§47. Body
The body (Fig. 2-33) contains and protects the pas­
sengers as well as the engine and other car components. It is made
up of a basic framework of rigid members to which the sheet-metal
body panels are attached.

§48. Accessories
The heater, lights, radio, windshield wipers, and
other such accessories, while not essential to the actual operation
of the car, do contribute to the comfort and safety of the passengers.
These various accessories are discussed in other books in the Mc­

[F8]
CHECK YOUR PROGRESS

Progress Quiz 4

When the battery man in an automotive shop has a battery on charge, he checks it periodically to see how it is taking the charge. Likewise, in this book, you stop periodically to check your progress and see how you are "taking the charge" of information. The following questions will help you find out how well you remember what you have just read. You may have some difficulty answering the questions. But don't be discouraged, just reread the past few pages and try the questions again. Most good students reread their lessons several times. Rereading the pages and rechecking the questions will help you learn how to pick out the important facts to remember. This is good practice; before you finish the book you will find your ability to remember essential information greatly improved. This ability will be of great help to you in your work.

Correcting Parts Lists

The purpose of this exercise is to enable you to spot the unrelated part in the list. For example, in the list, shoes, pants, shirt, milk, tie, coat, you would see that milk does not belong because it is the only thing named that you could not put on and wear.

In each of the lists, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. Parts in the power train include the clutch, steering wheel, transmission, propeller shaft, differential.
2. Parts in the clutch include the friction disk, flywheel, pistons, clutch pedal, throwout bearing.
3. Parts in the transmission include the clutch gear, tires, countershaft, reverse idler gear, main shaft.
4. Parts in the propeller shaft include the pitman arm, universal joint, slip joint.
5. Parts in the differential include the drive pinion, shaft, ring gear, clutch, bevel gear.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.
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1. The power train contains the clutch, transmission, propeller shaft and frame chassis differential body.
2. There is a double-faced friction disk splined to a shaft in the transmission differential propeller shaft clutch.
3. Two meshed gears have a gear ratio of 4:1. This means that while the large gear is turning five times, the small gear will turn\[\frac{4}{5}\text{ times} \quad \frac{5}{4}\text{ times} \quad 5\text{ times} \quad 10\text{ times} \quad 20\text{ times}\]
4. In the transmission, the countershaft drive gear is meshed with the reverse idler gear clutch gear second-and-low high-speed gear.
5. In low gear, the countershaft low gear is meshed with the second-and-high-speed gear low-and-reverse gear second-and-low gear reverse idler gear.
6. In high gear, the transmission main shaft turns at the same speed as the countershaft reverse idler gear shaft clutch shaft.
7. To take care of the difference in driving angle as the differential moves up and down, the propeller shaft has one or more slip joints shaft joints universal joints.
8. To take care of the lengthening and shortening of the propeller shaft with differential movement, the propeller shaft has a slip joint shaft joint universal joint.
9. In the differential, the drive pinion meshes with the ring gear differential pinion gear axle bevel gear drive gear.
10. The differential pinion gear meshes with the ring gear axle bevel gear drive gear pinion gear.

CHAPTER CHECKUP

Note: Since the following is a chapter review test, you should review the chapter before taking the test.

Now that you have completed another chapter in the book, you will want to test your knowledge of the subjects covered in the chapter. The questions that follow have two purposes. One is to test your knowledge. The second purpose is to help you review the chapter. It may be that you will not be able to answer, offhand, all the questions. If this happens, turn back into the chapter and reread the pages that will give you the answer. For instance, under Listing Parts you are asked to list the parts in the differential, besides bearings, that are in motion when the car is moving. If you cannot remember them all, turn back to the illustration of a differential in the chapter and refer to it when writing your list. The act of writing down the names of the parts will help you to remember them.
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Note: Write down your answers in your notebook. Then later, when you finish the book, you will find your notebook filled with valuable information to which you can quickly refer.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. The major part that must be added to make the chassis a complete automobile is the engine frame body wheels brakes
2. The purpose of the shock absorbers is to damp spring oscillations improve rigidity of spring mountings strengthen frame permit use of coil springs instead of leaf springs
3. The pitman arm in the steering gear is linked to the front wheels through the worm steering wheel tie rods steering shaft
4. The brake shoes are curved to conform to the inner diameter of the wheel tire brake drum pedal master cylinder
5. The power train transmits power from the engine to the crankshaft rear wheels front wheels steering gear power plant
6. The clutch part that is between the pressure plate and the engine flywheel is called the throwout bearing clutch fork friction disk pedal
7. The gear that is always in mesh with the countershaft drive gear in the transmission is called the second-and-high-speed gear clutch gear reverse idler gear low-and-reverse gear
8. The propeller shaft has one or more idler gears universal joints synchromeshes ring gears
9. The total number of pinions and gears in the standard differential is two three six nine
10. In the differential, the ring gear is attached to the differential case bevel gears rear axles propeller shaft

Listing Parts

In the following, you are asked to list parts that go into various automotive components discussed in the chapter. Write down this list in your notebook.
1. List five major components of the chassis.
2. List two types of springs used in automobile chassis.
3. List five parts in a steering system.
4. List five parts used in a hydraulic braking system.
5. List the four major components of the power train.
6. List five parts in a clutch.
7. List six gears used in a typical transmission.
8. List two types of joints used in a propeller shaft.
9. List the parts in the differential, aside from bearings, that are in motion when the car is moving.
10. List several body and body-accessory parts.

Purpose and Operation of Components

In the following, you are asked to write down the purpose and operation of certain components of the automobile discussed in the chapter. If you have any difficulty in writing down your explanations, turn back in the chapter and reread the pages that will give you the answer. Then write down your explanation. Don’t copy; try to tell it in your own words. This is a good way to fix the explanation firmly in your mind. Write in your notebook.

1. What is the purpose of the car frame?
2. What is the purpose of the car springs?
3. What is the purpose of shock absorbers?
4. Briefly, how does a shock absorber work?
5. How does the steering system work?
6. How does the hydraulic brake system work?
7. What happens in the clutch when the clutch pedal is depressed?
8. What happens in the transmission when the gears are shifted into second speed?
9. What is the purpose of the universal joints in the propeller shaft?
10. What happens in the differential when the car turns a corner?

Suggestions for Further Study

If you would like to do some further studying of the engine chassis, brakes, differential, transmission, clutch, and so forth, there are several things you can do. First, you can read the Automotive Chassis and Body book and the Automotive Transmissions and Power Trains book, which are other books in the McGraw-Hill Automotive Mechanics Series. Also, you can inspect your own and your friends’ cars. We do not suggest that you get out your tool kit and start tearing them down, however. You are not quite ready for that yet. You can go into your school automotive shop or to a friendly service shop where repair work on all these parts is done.
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By watching what goes on in a service shop you will learn a great deal about the various automobile components, how they are put together, and how the parts look.

You may be able to borrow shop repair manuals from car-dealer service shops or from your school automotive shop library. These manuals are sometimes available, for a price, from the car manufacturers. Your school automotive shop may have cut-away parts on exhibit which are used as teaching aids. Studying these will help you understand how these parts are constructed and how they work.
3: Engine fundamentals

THIS CHAPTER discusses fundamentals of engine construction and operation. In addition, it describes briefly the engine accessories that are necessary to the operation of the engine. These accessories include the fuel system, lubrication system, electric system, and cooling system. These accessories are, in fact, part of the engine itself. However, since this book deals primarily with the engine

![Typical six-cylinder engine partly cut away to show internal construction.](image-url)
itself, the accessories are not described in full detail. They are discussed only to the extent that they enter into the actual operation of the engine. Other books in the McGraw-Hill Automotive Mechanics Series cover the accessories in a comprehensive manner. The electric system is described fully in Automotive Electrical Equipment. The Automotive Fuel, Lubricating, and Cooling Systems book covers those accessories.

§49. The engine cylinder The engine (Fig. 3-1) is the source of power that makes the wheels go round and the car move. It is usually referred to as an internal-combustion engine. This is because the fuel (gasoline) is burned inside the engine—within the engine cylinders or combustion chambers. The combustion, or burning, of the gasoline creates high pressure. The high pressure thus produced.
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causes a shaft to turn or rotate. The rotary motion is carried to the car wheels by the power train so that the wheels rotate and the car moves.

Most automotive engines have either six or eight cylinders. Since similar actions take place in all cylinders, let us concentrate on one cylinder. Figure 3-2 shows the construction of a single cylinder of an engine with the cylinder and piston sliced in half. Figure 3-3

FIG. 3-3. Cutaway view of an eight-cylinder V-type engine. (Mercury Division of Ford Motor Company)

FIG. 3-4. A typical piston with rings in place. When piston is installed in cylinder, the rings are compressed into the grooves in the piston.
is a cutaway view of another engine. In this picture, the cylinder is cut away but the piston is shown complete. Essentially, the cylinder is nothing more than a cylindrical air pocket, closed at one end and open at the other. A movable piston fits snugly into the open end of the cylinder. The piston is made of aluminum or other suitable metal. It is a snug fit, but it is still loose enough to slide easily up and down inside the cylinder. There are grooves cut in the side of the piston, with piston rings fitted into these grooves (Fig. 3-4). The rings fit tightly against the cylinder wall and provide such a good seal that very little air can escape between the piston and cylinder wall. Thus, when the piston is pushed up in the cylinder, the air in the cylinder is trapped above the piston and is compressed.

Figure 3-5 shows this action very simply. In Fig. 3-5a, the piston is shown below the cylinder. The cylinder is drawn as though it
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were transparent so the piston can be seen as it moves up into the cylinder (Fig. 3-5b). The air above the piston is compressed as it is pushed up into the cylinder. (Neither the piston rings, nor the means of pushing the piston up into the cylinder, are shown.) If we could put some gasoline vapor into the compressed air, and if we were able to apply a lighted match or a spark to the air-vapor mixture, it is obvious what would happen. The gasoline vapor would burn. High pressure would be created and the piston would be blown out of the cylinder as shown at Fig. 3-5c. Actually, this, in a modified form, is what happens in the cylinder. A mixture of gasoline vapor and air enters the cylinder, the piston is pushed up into the cylinder, the mixture is ignited, and the piston is pushed down and outward from the cylinder.

§50. Reciprocating to rotary motion  The up-and-down movement of the piston is called reciprocating motion. The piston moves in a [68]
straight line. This straight-line motion must be changed to rotary, or turning, motion in order to make the car wheels rotate. A crank and a connecting rod (Figs. 3-6 and 3-7) change the reciprocating motion to rotary motion.

The crank is an offset section of the crankshaft. It swings around in a circle as the shaft rotates. The connecting rod connects between the crankpin of the crank and the piston (Fig. 3-7). The crank end of the connecting rod is attached to the crankpin by fastening the rod bearing cap to the connecting rod with the rod-cap bolts (Fig. 3-7). The cap and rod have bearings which permit

![Diagram of engine components and motion sequence]

the crankpin to rotate freely within the rod. The piston end of the rod is attached to the piston by the piston pin, or wrist pin. The piston pin is held in two bearings in the piston. A bearing in the piston-pin end of the connecting rod (or bearings in the piston) permits the rod to swing back and forth on the piston pin.

**Note**: The crank end of the connecting rod is sometimes called the rod “big end” while the piston end is called the rod “small end.”

Now, let us see what happens as the piston moves up and down in the cylinder (Fig. 3-8). As the piston starts down, the connecting rod tilts to one side so the lower end can follow the circular path of the crankpin. If you follow the sequence of action as shown in
Fig. 3-8 (or steps numbered from 1 to 8), you will note that the connecting rod tilts back and forth on the piston pin while the lower end moves in a circle along with the crankpin.

§51. The Valves There are two openings, or ports, in the enclosed end of the cylinder, one of which is shown in Fig. 3-3. One of the ports permits the entrance of the mixture of gasoline vapor and air into the cylinder. The other port permits the burned gases, after combustion, to exhaust, or escape from the cylinder.

The two ports have valves assembled into them, and these valves close off one or the other port, or both ports, during various stages of the action taking place in the cylinder. The valves are nothing more than accurately machined metal plugs that close the openings when they are seated (that is, have moved down into the opening). Figure 3-9 shows a valve and a valve seat of the type used in the engine illustrated in Fig. 3-3. This type of valve is called a poppet.
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downward. The valve lifter, in turn, pushes up on the valve stem, forcing the valve to move up, or open. After the cam lobe moves out from under the valve lifter, the valve spring forces the valve down on its seat again. Figure 3-10 shows an L-head valve mechanism. There are other types (see §83).

Figure 3-11 shows a typical camshaft. It has a cam for each valve in the engine, or two cams per cylinder. The camshaft is driven by gears, or a chain, from the crankshaft, and it turns at one-half crankshaft speed. The cam lobes are so positioned on the camshaft as to cause the valves to open and close in the cylinders at the proper time with respect to the activities taking place in the cylinders.

§52. Engine operation The activities taking place in the engine cylinder can be divided into four stages, or strokes. "Stroke" refers to piston movement; a stroke occurs when the piston moves from one limiting position to the other. The upper limit of piston move-
ment (position 1 in Fig. 3-8) is called top dead center or TDC. The lower limit of piston movement is called bottom dead center or BDC. A stroke is piston movement from TDC to BDC, or from BDC to TDC. In other words, the piston completes a stroke each time it changes direction of motion.

Where the entire cycle of events in the cylinder requires four strokes (or two crankshaft revolutions), the engine is called a four-stroke-cycle engine, or a four-cycle engine. The term "Otto cycle" is also applied to this type of engine (after Friedrich Otto, a German scientist of the last century). The four piston strokes are intake, compression, power, and exhaust. (Two-stroke-cycle engines are also in use; in these, the entire cycle of events is completed in two strokes, or one crankshaft revolution.)

Note: For the sake of simplicity in the following discussion, the valves are considered to open and close at TDC and BDC. Actually, they are not timed to open and close at these points, as is explained in a later chapter. Also, the illustrations showing the four strokes (Figs. 3-12 to 3-15) are much simplified and show the intake and exhaust valves separated and placed on either side of the cylinder so that both can be seen.

1. Intake (Fig. 3-12). On the intake stroke, the intake valve has opened. The piston is moving down, and a mixture of air and vaporized gasoline is being “drawn” into the cylinder through the valve port. The mixture of air and vaporized gasoline is delivered to the cylinder by the fuel system and carburetor (discussed in §56).

Note: Actually, the piston does not “draw” the air-fuel mixture into the cylinder. As the piston moves down, a partial vacuum is produced in the cylinder, and atmospheric pressure (or pressure of the air) outside the engine pushes air into the engine cylinder. This air passes through the carburetor, where it picks up a charge of gasoline vapor, and then through the intake manifold and intake-valve port. For a comprehensive discussion of vacuum and atmospheric pressure, see Automotive Fuel, Lubricating, and Cooling Systems, another book in the McGraw-Hill Automotive Mechanics Series.

2. Compression (Fig. 3-13). After the piston reaches BDC, or the lower limit of its travel, it begins to move upward. As this happens, the intake valve closes. The exhaust valve is also closed, so the
cylinder is sealed. As the piston moves upward (pushed now by the revolving crankshaft and connecting rod), the air-fuel mixture is compressed. By the time the piston reaches TDC, the mixture has been compressed to as little as one-seventh of its original volume, or even less. This compression of the air-fuel mixture increases the pressure in the cylinder. Or, to say it another way, the molecules that compose the air-fuel mixture have been pushed closer together. They therefore bump into the cylinder walls and piston head more often. The increasing frequency of the bumps means a stronger "push" is registered on the walls and head; the pressure is higher. The molecules, being pushed closer together, also collide with each other more frequently. This, in turn, sets them into more rapid motion. We know that more rapid motion and increased temperature mean the same thing. Therefore, when the air-fuel mixture is compressed, not only does the pressure in the cylinder go up, but the temperature of the mixture also increases.
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3. Power (Fig. 3-14). As the piston reaches TDC on the compression stroke, an electric spark is produced at the spark plug. The spark plug consists essentially of two wire electrodes, electrically insulated from each other. The ignition system (part of the electric system discussed later in this chapter) delivers a high-voltage surge of electricity to the spark plug to produce the spark. The spark ignites, or sets fire to, the air-fuel mixture. It now begins to burn very rapidly, and the cylinder pressure increases to as much as 600 psi (pounds per square inch) or even more. That means the hot gases are pushing against every square inch of the combustion chamber and the piston head with a pressure of 600 pounds or more. For example, a piston 3 inches in diameter with a head area of about 7 square inches would have a pressure on it of over 2 tons.

This terrific push against the piston forces it downward, and a power impulse is transmitted through the connecting rod to the crankpin on the crankshaft. The crankshaft is rotated as the piston is pushed down by the pressure above it.

Let us take a look at the activities we have just described from [74]
the molecular point of view. That is, let us see how the increased pressure can be explained by considering the air-fuel mixture as a vast number of molecules. We have already noted, in the previous paragraph, that compressing the mixture increases both its temperature and pressure. The molecules move faster (higher temperature) and bump the cylinder walls and piston head more often (higher pressure). Then, when combustion takes place, the hydrocarbon molecules of gasoline are violently split apart into hydrogen and carbon atoms. The hydrogen and carbon atoms then unite with oxygen atoms in the air (see §9 on combustion). All this sets the molecules into extremely rapid motion (still higher temperature which may momentarily reach 4500°F). The molecules begin to bombard the cylinder walls and piston head much harder and more often. In other words, the pressure goes up much higher.

It may be a little difficult, at first, to visualize a 2-ton push on the piston head as resulting from the bombardment of molecules far too small to be seen. But remember that there are billions upon billions of molecules in the combustion chamber, all moving at speeds of many miles a second. Their combined hammering on the piston head adds up to the high pressure that is registered.

4. Exhaust (Fig. 3-15). As the piston reaches BDC again, the exhaust valve opens. Now, as the piston moves up on the exhaust stroke, it forces the burned gases out of the cylinder through the exhaust-valve port. Then, when the piston reaches TDC, the exhaust valve closes and the intake valve opens. Now, a fresh charge of air-fuel mixture will be drawn into the cylinder as the piston moves down again toward BDC. The above four strokes are continuously repeated during the operation of the engine.

§53. Multiple-cylinder engines A single-cylinder engine provides only one power impulse every two crankshaft revolutions and is delivering power only one-fourth of the time. To provide for a more continuous flow of power, modern engine use four, six, eight, or more cylinders. The power impulses are so arranged as to follow one another, or overlap (on six- and eight-cylinder engines). This gives a more nearly even flow of power from the engine.

§54. Flywheel Even though the power impulses in a multicylinder engine follow each other, or overlap, to provide a fairly even flow of power, additional leveling off of the power impulses is desirable.
This would make the engine run still more smoothly. To achieve this, a flywheel is used (Fig. 3-16). The flywheel is a fairly heavy steel wheel, attached to the rear end of the crankshaft.

To get a better idea of how the flywheel does its job, let us look at a single-cylinder engine. This engine delivers power only one-fourth of the time—during the power stroke. During the other three strokes it is absorbing power—to push out the exhaust gas, to "pull in" a fresh air-fuel charge, to compress the charge. Thus, during the power stroke, the engine tends to speed up. During the other strokes, it tends to slow down. Any rotating wheel, including the flywheel, resists any effort to change its speed of rotation (this is due to inertia—see §27). When the engine tends to speed up, the flywheel resists it. When the engine tends to slow down, the flywheel resists it. Of course, in the single-cylinder engine, there would still be some speed-up and slowdown. But the flywheel minimizes it. In effect, the flywheel absorbs power from the engine during the power stroke (or speed-up time), and then gives it back to the engine during the other three strokes (or slow-down time).

In the multicylinder engine, the flywheel acts in a similar manner to smooth out further the peaks and valleys of power flow from the engine. In addition, the flywheel forms part of the clutch as already explained (§40). The flywheel also has teeth on its outer diameter that mesh with the electric cranking-motor drive pinion when the engine is being cranked to start it. This is explained in more detail in §60.
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CHECK YOUR PROGRESS

Progress Quiz 5

The following quiz will help you check yourself on the progress you have been making in the book. If you have difficulty with the questions, reread the past few pages. Remember, most students reread their lesson several times, so don’t be discouraged if you don’t remember everything the first or second time. Notice that the questions usually refer to the most important facts, the most essential details, in the pages you have read. The questions spotlight these important details and help you to remember them. These questions are put here for your own benefit to enable you to check up on yourself. If you are not sure about the answer to any question, reread the pages in the book first, before attempting to give the answer.

Correcting Parts Lists

The purpose of this exercise is to give you practice in spotting unrelated parts in a list. For example, in the list, cylinder, piston, rings, brake shoe, connecting rod, you can see that brake shoe does not belong because it is the only part named that does not belong in an engine.

In each of the lists, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. The four piston strokes are intake, exhaust, reverse, compression, and power.
2. To operate, the engine requires a fuel system, lubrication system, cooling system, braking system, and electric system.
3. Engine parts include the piston, piston pin, connecting rod, crankshaft, clutch, and rod cap.
4. The valve system includes the camshaft, valve lifter, poppet valve, flywheel, valve spring, and valve guide.
5. Engine parts include the cylinder block, cylinder head, pistons, crankshaft, connecting rods, differential, camshaft, and valves.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. The connecting rod is attached to the piston by the rod cap piston pin cap bolts big-end bearing
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2. In the standard engine, each cylinder has one valve, two valves, three valves, or four valves.

3. The four strokes in an Otto-cycle engine are, in order, intake, power, exhaust, and compression. These are also known as intake, exhaust, compression, and power.

4. The two types of engine valves are intake and port, intake and inlet, intake and exhaust.

5. The valve is opened as the cam lobe on the cam raises the valve lifter, bearing, piston pin, valve guide, camshaft, piston pin, rod big end.

6. The rod bearing cap attaches the connecting rod to the crankpin, camshaft, piston pin, rod big end.

7. During combustion, the pressure in the cylinder may increase to as much as 60 psi, 600 psi, or 6,000 psi.

8. During the power stroke, the intake and exhaust valves are respectively, closed and opened, opened and closed, or closed and closed.

9. The camshaft has a separate cam for each engine valve.

10. The device for smoothing out the power impulses from the engine is called the crankshaft, camshaft, flywheel, or clutch.

§55. Engine accessories The engine requires four separate mechanisms, or accessory systems, for its operation. These are the fuel system, the lubricating system, the electric system, and the cooling system. In addition, an exhaust system is provided to carry away the burned gases exhausted from the engine cylinders. These various systems are actually essential parts of the complete engine. However, they are discussed separately since each system has a definite and individual job to do. Brief descriptions of these systems follow. Later chapters describe the systems in greater detail.

§56. Fuel system The gasoline-engine fuel system (Fig. 3-17) has the job of supplying the engine with a combustible mixture of fuel and air. It consists of a tank in which liquid gasoline is stored, a fuel pump, a carburetor, an intake manifold, and connecting fuel lines (metal tubes). The fuel pump pumps the liquid gasoline from the fuel tank and delivers it to the carburetor. The carburetor mixes the gasoline with air and delivers the mixture to the intake manifold. From there, it passes the intake valve ports (when valves are open) and enters the engine cylinders. The carburetor varies...
the proportion of fuel and air to suit different operating conditions. For example, a rich mixture of about nine pounds of air for every pound of gasoline is delivered for starting, initial warm-up, and accelerating. A relatively lean mixture of about fifteen pounds of air for every pound of gasoline is delivered for normal over-the-road operation.

1. **Fuel tank.** The fuel tank is essentially a sheet-metal tank with a filler tube for filling it and an outlet near the bottom to which the fuel line is attached.

2. **Fuel pump.** The fuel pump (Fig. 3-18) pumps gasoline from the fuel tank and delivers it to the carburetor. It contains, as the essential working parts, a rocker arm, a flexible diaphragm, and two valves. The pump is mounted on the side of the cylinder block. The rocker arm enters an opening in the block and rests on an eccentric on the camshaft. The eccentric is an offset ring on the camshaft. As the camshaft rotates, the eccentric causes the rocker arm to rock, or move back and forth. This movement causes the diaphragm in the pump to fluctuate down and up, alternately creating vacuum and pressure. When vacuum is created, the inlet valve is lifted off its seat, allowing gasoline to be drawn from the fuel tank, through the fuel line, and into the pump chamber. On the return stroke the diaphragm is released and the diaphragm spring

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*Fig. 3-17. Fuel system on automobile chassis. Dotted line shows alternate fuel-line location.*
forces it upward. This creates pressure in the pump chamber. The inlet valve is closed by the pressure and the outlet valve is opened. Gasoline is forced from the pump through a fuel line to the carburetor. The rocker-arm spring keeps the rocker arm in contact with the eccentric on the camshaft. The diaphragm spring maintains pressure on the diaphragm and on the fuel in the pump chamber during the return stroke.

FIG. 3-18. Sectional view of a fuel pump with inlet valve to right and outlet valve to left. (AC Spark Plug Division of General Motors Corporation)

3. Carburetor. The gasoline is delivered through an inlet to a bowl on the side of the carburetor (Figs. 3-19 and 3-23). The bowl serves as a sort of constant-level gasoline reservoir. It contains a float that operates a needle valve. When the proper level of gasoline in the bowl is reached, the float has risen enough to force the needle valve into the opening, thus sealing it off. Now, no further gasoline can be delivered. However, when the gasoline level falls in the bowl, the float drops down enough to allow the needle valve to open, and gasoline can enter the float bowl. In actual operation, the float positions the needle valve so that gasoline entering just balances gasoline being withdrawn by the carburetor.
Aside from the float bowl, the carburetor contains three essentials: an air horn with a venturi (or constriction), a fuel nozzle, and a throttle valve (Fig. 3-20). The air horn is a passageway for air as it moves from outside the engine toward the engine cylinders. An air cleaner, mounted on the air horn, filters dirt and dust particles from the entering air. This action prevents such particles from getting into the engine where they could damage engine bearings, cylinder walls, and piston rings. After the air passes through the air horn (where it picks up a charge of fuel), it enters the intake manifold on which the carburetor is mounted. The intake manifold (Fig. 6-5) is essentially nothing more than a series of passages leading from the carburetor to the engine cylinders. These passages are as short and as straight as possible (minimum of bends) so the air-fuel mixture will not be excessively restricted, or held back, on its way to the cylinders.

When the engine is running, air is moving constantly through the carburetor air horn and intake manifold to the engine cylinders. Each time a piston moves down on an intake stroke, a partial vacuum is produced in that cylinder. Atmospheric pressure (or pressure of the air) then pushes air through the air horn and intake manifold, and through the opened intake-valve port, into the cylinder.

As the air moves through the air horn, it picks up a "charge" of gasoline vapor as already mentioned. The fuel nozzle, which extends upward from the float bowl into the center of the air horn (Fig. 3-21), delivers gasoline to the passing air. Its upper end is
centered in a venturi, or constriction, in the air horn. When air is passing through a venturi, a partial vacuum is produced in it. This effect is shown in Fig. 3-22, which illustrates three dishes of mercury (a very heavy liquid) connected by tubes to an air horn with a venturi. The greater the vacuum, the greater the rise of the mercury in the tube. Note that the center tube, which opens into the venturi, shows the greatest mercury rise, or greatest vacuum effect.

Thus, when the engine is running and air is passing through the air horn, the vacuum at the venturi (or at the fuel nozzle) causes gasoline to be delivered from the float bowl into the passing air. Atmospheric pressure, acting through a vent or opening in the float bowl (Fig. 3-21), pushes the gasoline up through the fuel nozzle.
nozzle. It leaves the fuel nozzle in the form of a fine spray which rapidly turns into vapor as the droplets of gasoline evaporate. The more air that moves through, the faster it moves and the greater the amount of gasoline delivered.

The throttle valve (Fig. 3-20), controls the amount of air-fuel mixture moving through and being delivered to the engine cylinders. The throttle valve is a round disk mounted on a shaft. When the shaft is turned, the valve tilts more or less to open or close the air passage. When the valve is tilted only slightly from the horizontal the throttle is said to be closed. Only a small amount of air can get through. Only small amounts of air-fuel mixture are delivered to the engine cylinders and the engine runs slowly. It is "throttled down," or idling. When the throttle valve is opened, more air-fuel mixture gets through to the engine cylinders and engine speed increases.

Figure 3-23 shows an actual carburetor in sectional view. Note
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that the venturi arrangement is more complicated than that shown in the previous illustrations; it consists of three related venturis. This assures better fuel delivery and mixing. The actual carburetor has several circuits, or fuel passages, that provide balanced performance for different operating conditions. For instance, while accelerating, the accelerator is pushed down. A linkage to the accelerator pump (at left in Fig. 3-23) causes the pump piston to move down and to force a stream of gasoline into the carburetor air horn. This greatly enriches the air-fuel mixture so that the engine responds quickly. The idle circuit includes an idle port under the throttle valve which feeds gasoline when the throttle is closed. This assures satisfactory mixture richness for smooth idling.

Note: See Chap. 8, "Automotive-engine Fuels and Fuel Systems," for more details on fuel systems.

§57. Other fuel systems In addition to gasoline fuel systems, there are other systems in use for diesel and LPG (liquefied petroleum gas) engines. In diesel engines, air alone is compressed (§87) and fuel oil is injected into the cylinder at the end of the compression stroke. Thus, the diesel-engine fuel system is a sort of pumping system which meters and delivers the fuel in liquid form to the cylinders of the engine at the right time and in the right amounts. In the LPG engine, the fuel used is a gas, or vapor, at atmospheric pressure. It is kept under a relatively high pressure (anywhere between 20 to 225 psi) in a sealed tank; this holds it in liquid form. In operation the liquid fuel passes from the fuel tank into a pressure regulator which reduces the pressure on it to a few pounds per square inch (above atmospheric pressure). The fuel is then partly liquid and, in a second step, is subjected to a further reduction in pressure (down to atmospheric). This turns it completely into a vapor. The vapor now passes into the carburetor. The carburetor is essentially a mixing device that mixes air with the entering vaporized LPG. Since this fuel is a vapor at atmospheric pressure, there is no problem of vaporizing it as in the gasoline carburetor.

§58. Exhaust system (Fig. 3-24) After the air-fuel mixture burns in the engine cylinder, the exhaust valve opens and the upward-moving piston forces the burned gases from the cylinder on the exhaust stroke. The gases pass into the exhaust manifold (Fig. 6-5) [84]
and from there through a pipe (the exhaust pipe) into the exhaust muffler (Fig. 6-13). The exhaust muffler provides a series of passages and chambers through which the exhaust gases must pass before being discharged into the air. These passages and chambers muffle the exhaust noise, thus quieting the engine.

§59. Lubricating system When two metal parts move over each other, they will wear away rapidly unless the metal surfaces in contact are lubricated. Lubricating oil between moving metal surfaces acts to hold the surfaces apart. In effect, each surface slides on a film of oil. So long as the metal surfaces are held apart by the oil film, they cannot come into actual contact and therefore cannot wear each other. The action might be compared to a boat being pulled up a river. As long as the water is deep enough to float the boat, there is no appreciable wear on either the bottom of the boat or the bed of the river. But if the water level should fall so that the protective films of water are removed from between the bottom of the boat and the river bed, there is a different action. Now, dragging the boat along the river bed will cause "wear" on both the bottom of the boat and the river bed. In a like manner, depriving moving metal parts of lubricating oil will permit them to slide on each other and wear rapidly.

The lubricating system used in the automotive engine is designed to supply oil to all moving parts. In a sense, these parts "float" in a film of oil which prevents actual metal-to-metal contact. In the engine, oil is supplied to crankshaft and camshaft journals rotating in their supporting bearings. Oil is supplied to the cylinder walls so the pistons and rings will slide easily and smoothly without undue piston, ring, or wall wear. In a like manner, other moving engine parts are supplied with oil.
Automotive-engine lubricating systems are of several types that splash or force (or both splash and force) oil onto the sliding and rolling metal surfaces in the engine. Figure 3-25 illustrates the full-pressure system. In this system, holes are drilled through the crankshaft and connecting rods, and oil is forced through these holes by an oil pump. The oil is fed onto the bearing and journal surfaces and is then thrown off in a fine spray. This spray effectively covers the cylinder walls. In addition, oil is forced through drilled leads to the camshaft bearings and valve mechanisms. The oil drains off the various engine parts and returns to the oil pan in the bottom of the engine. From there, it is picked up by the oil pump and recirculated through the engine.

In addition to providing lubrication, the oil also carries away some of the heat from the moving engine parts. The oil picks up heat, becomes hotter, and then, when it returns to the oil pan, gives up heat, and cools off. The oil pan gives up heat to the passing air circulating around and under it.

Note: Further details of engine-lubricating systems are to be
§60. Electric system

The electric system (Fig. 3-26), includes the storage battery, cranking motor, generator, regulator, ignition distributor, coil, and spark plugs, as well as the wires and switches for connecting these various units. Lights, radio, heater, indicating gauges, and other electrically operated devices, while a part of the electric system, are usually considered accessory items since they are not absolutely essential to the operation of the car.
1. Storage battery. The storage battery is an electrochemical device, which means that its operation depends upon both chemical and electrical actions. The battery is a source of electric current when the engine is being cranked with the cranking motor. It also supplies current when the generator is not able to carry the electric load. When current is withdrawn from the battery, chemical actions take place to produce the flow of current. The chemicals in the battery are, in a sense, used up by this action. Thus, after a certain amount of current has been withdrawn for a certain length of time, the battery becomes "discharged." To "recharge" the battery, current from some external source, such as a generator or battery charger, must be forced through it in the reverse, or charging, direction.

2. Cranking motor. The cranking motor is a special direct-current electric motor that starts the engine by rotating the crankshaft when the cranking-motor switch is closed. Closing the switch connects the motor to the battery. There is a special gearing arrangement between the cranking-motor drive pinion and the engine flywheel that causes the flywheel and crankshaft to turn when the cranking motor operates.

3. Generator. The generator is a device that converts mechanical energy (from the automobile engine) into a flow of electric current. This current restores the battery to a charged condition when it has become run down, or discharged. It also operates electrical devices, such as the ignition system, lights, radio, and so forth. The generator is usually mounted on one side of the engine (or between the two banks of cylinders on some V-8 engines) and is driven by the engine fan belt.

4. Regulator. Under some conditions, the generator could produce too much current, and this would damage the various connected electrical devices. To prevent such damage, a generator-output regulator is used. The regulator controls the amount of current the generator produces, allowing the generator to produce a high current when the battery is in a discharged condition and electrical devices are turned on. When the battery becomes charged and electric units are turned off, the regulator cuts down the current produced to the amount needed to meet the operating requirements of the system.

5. Lights, heater, radio, indicating devices. The lights and heater add to the flexibility, comfort, and convenience of the car, while [88]
the indicating devices keep the driver informed as to the engine temperature, oil pressure, amount of fuel in the tank, and the battery charging rate.

6. Wiring and switches. The wiring (Fig. 3-26) connects the various electric units and switches and serves as a path through which the electric current can flow from one to another unit. Switches placed in these circuits are forms of valves that can close or open the circuits to permit or prevent the flow of current. The wires are made up of conducting materials, such as copper, that freely conduct current between the electric units. Some materials, such as rubber and glass, are nonconductors or insulators; they will not allow current to flow through them. Such substances are used to cover and insulate the wires so that the current will be kept within the proper circuits and paths (and will not short-circuit.) Note that the automotive wiring system shown in Fig. 3-26 is a one-wire system. That is, the electric units are normally connected to each other by one wire. The return circuit is through the car frame and engine block. This return circuit is also called ground; all the electric units are connected to it.

7. Ignition system. The ignition system (Fig. 3-27) provides the
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high-voltage surges, or electric sparks, that ignite the compressed air-fuel mixture in the engine cylinders. After the fuel system has delivered the air and gasoline vapor mixture to the engine cylinder, and the mixture has been compressed by the piston compression stroke, it must be ignited. The ignition system does this job by producing sparks at the spark-plug gap in the engine cylinders. The sparks set the compressed mixture on fire so that it burns and creates the high pressure that drives the piston down on the power stroke. The following articles describe the operation of the ignition system in detail.

§61. Operation of ignition system
The ignition system consists of the source of electric energy (battery or generator), ignition switch, ignition coil, ignition distributor, spark plugs, and wiring (Fig. 3-28). The ignition system might be said to have two jobs. First, it must take the low voltage (6 or 12 volts) from the battery, and step it up to the several thousand volts needed to produce the igniting sparks at the spark plugs in the engine cylinders. Secondly, it must deliver the "sparks" to the proper cylinders at the proper time. That is, the ignition system must deliver a high-voltage surge (or spark) to cylinder 1 just as piston 1 nears TDC on the compression stroke. Then, a moment later, it must deliver another spark to cylinder 5 (or whichever cylinder is next in order of firing) when it is ready to fire, and so on.

The voltage step-up job is done by the ignition coil and the distributor contacts and breaker cam. The breaker cam is mounted on the distributor shaft (which is driven from the engine camshaft at camshaft speed) and rotates with it. As the cam turns, lobes on the cam open and close the contacts. When the contacts are closed, they connect the ignition coil to the battery. Current then flows through the coil and the coil, in effect, becomes "loaded" with electric energy. Then, a moment later, as the cam turns further, a lobe on the cam opens the contacts. The coil then unloads its energy in the form of a high-voltage surge.

NOTE: An ignition condenser (or capacitor) is connected across the contacts in order to prevent a high-voltage surge from jumping across the contacts as they separate. If this should happen, the energy in the coil would be wasted, and the contacts would be burned, by the arc between the contacts. There would be insufficient
electric energy to produce sparks in the cylinders, where they are needed to ignite the compressed air-fuel mixture.

The high-voltage surge that the coil produces as the contacts separate must be delivered to the proper cylinder. The distributor cap and rotor and the ignition wiring do this job. The high-voltage surge is led from the coil to the center terminal of the distributor cap by a high-tension lead. From there it passes to the distributor rotor. The rotor is mounted on the distributor cam and turns with it. It connects between the center terminal of the cap and the several outer cap terminals, in turn, as it rotates. Each outer terminal is connected by high-tension wires to a spark plug in one of the cylinders. Thus the rotor, as it turns, connects the ignition coil to the several cylinder spark plugs, one after the other. As each high-voltage surge is "manufactured" (by the closing and opening of the
contacts), it is delivered through the cap and rotor to the cylinder that needs it; that is, it is delivered to the cylinder that is ready to fire (piston nearing end of compression stroke).

§62. Operation of ignition-advance mechanisms When the engine is idling, the sparks are timed to appear in the engine cylinders just before the pistons reach TDC on their compression strokes. But at higher speeds, the air-fuel mixture has less time to ignite and burn. If ignition still took place just before TDC on the compression stroke, the piston would be up over the top and moving down before the mixture was well ignited. This means that the piston would be moving away from the pressure rise; much of the energy in the burning fuel would be wasted. However, if the mixture is ignited earlier in the compression stroke (at high engine speed), the mixture will be well ignited by the time the piston reaches TDC. Pressure will go up and more of the fuel energy will be used.

1. Advance based on speed. To ignite the mixture earlier at high speed, a spark-advance mechanism is used. This mechanism is incorporated in the ignition distributor. One type consists of a centrifugal device that pushes the breaker cam ahead of the distributor shaft as engine speed increases. Figure 3-29 shows the parts of this mechanism. The breaker cam is attached to an oval-shaped advance cam and this assembly sets down on a plate attached to the drive shaft. Two crescent-shaped advance weights are also assembled on the plate as shown in Fig. 3-30. Figure 3-30 also shows how the mechanism operates to move the breaker cam ahead as engine speed increases. With increasing engine speed, the advance weights move out against the weight-spring tension. This movement pushes the breaker cam ahead so that the cam lobes close and open the contacts earlier. The sparks thus occur earlier; the spark is advanced so that ignition occurs earlier in the compression stroke.

Different engines require different amounts of spark advance at various speeds. Typical advance curves are shown in Fig. 3-31. In curve A, the spark is timed to occur just a few degrees of crankshaft rotation before TDC, during idle. Then, as engine speed is increased, the spark moves ahead, or advances until it reaches a maximum of 28 degrees at 2,900 rpm. Curve B is a little more complicated. It “dog-legs,” or changes slope, at 1,500 rpm. A curve is [ ]
worked out for each engine so that the advance at any particular speed will provide best performance. The mechanism is then built to provide this advance.

Figure 3-32 illustrates a distributor that achieves spark advance with increasing speed by a different method. In this unit, the contacts are mounted on a movable breaker plate. The plate is linked to an airtight diaphragm. Movement of the diaphragm will cause the plate to rotate a few degrees and carry the contacts around with
Fig. 3-30. Centrifugal-advance mechanism showing initial- and maximum-advance positions. (Delco-Remy Division of General Motors Corporation)

Fig. 3-31. Typical centrifugal-advance curves.

It. This movement causes the contacts to be closed and opened earlier so that a spark advance is produced. The plate rotation results from the vacuum-line connection between the airtight diaphragm on the distributor and an opening in the carburetor venturi. We have already noted that vacuum increases in the carburetor venturi with increasing engine speed (§56). The greater the vacuum (or the greater the engine speed), the further the
Fig. 3-32. Top and sectional views of a full-vacuum-control distributor showing vacuum connections to carburetor with which it is used. (Ford Motor Company)
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diaphragm is moved, and the more the plate moves to advance the spark.

2. Advance based on intake-manifold vacuum. With a partly closed throttle valve, there is a partial vacuum in the intake manifold. Less air-fuel mixture gets into the engine cylinders and it is therefore less highly compressed. This means that the mixture burns more slowly. An additional spark advance, under these conditions, will allow the mixture ample time to burn and give up its energy to the piston. Spark advance, based on intake-manifold vacuum, is achieved by an airtight diaphragm linked to a movable breaker plate. This type of arrangement is shown in Fig. 3-32. A vacuum connection is made to an opening just above the edge of the throttle plate (B in Fig. 3-32) in the carburetor. Whenever the throttle is opened, its edge moves past the opening, thus introducing intake manifold into the tube. This vacuum then causes diaphragm and breaker plate movement. The spark is advanced. Note that advance is based, in this arrangement, on manifold vacuum, which is part-throttle vacuum. When the throttle is opened wide, there is no appreciable manifold vacuum and thus there will be no vacuum advance from this effect.

§63. Cooling system The burning of the air-fuel mixture in the engine cylinders produces a great deal of heat. Temperatures of several thousand degrees Fahrenheit are generated in the cylinders as the mixture burns. Some of this heat is carried out of the engine by the lubricating oil. Some of its escapes in the hot exhaust gases. Some of it is absorbed by the evaporating fuel entering the cylinders in the air-fuel mixture.¹ The cooling system (Fig. 3-33) carries away most of the remainder of the excess heat. This prevents the engine from becoming too hot. Excessive engine temperature would damage or ruin the engine. At excessive temperature the lubricating oil would lose its effectiveness so that wear would increase very rapidly. High temperatures would also damage various engine parts.

¹You will recall that when a liquid evaporates (undergoes a change of state), it absorbs heat as explained in §§11 and 12. This action utilizes some of the heat developed in the engine and provides a certain amount of cooling as the fuel evaporates. In aircraft engines this effect is of great importance, and the pilot, under certain circumstances, requiring maximum power, may enrich the mixture in order to keep engine temperature down.
Circulating water is used as the conducting medium in the cooling system. The combustion chambers of the engine are surrounded by pockets, or water jackets (Fig. 3-33), through which the water can flow. A water pump causes the water to be pumped from the bottom of the radiator, through the water jackets, and back to the radiator again (Fig. 3-34). As the water passes through the water jackets, it absorbs heat and becomes hot. Then, as it enters the top of the radiator, it starts to cool off. The radiator has numerous water passages through which the water flows. Around these small water passages are numerous air passages. The engine fan pulls air through these air passages, thus removing heat from the radiator. Thus, as the water passes down through the radiator, it is cooled. The cooler water is then pumped back through the water jackets in the engine. The pump keeps the water in
continual circulation so that it continues to transfer heat from the engine to the air passing through the radiator.

**CHECK YOUR PROGRESS**

**Progress Quiz 6**

The following quiz allows you, once again, to check up on yourself. You have made a good start in reading the book, and if you have taken the previous progress quizzes, you know how well you have been absorbing the information you have been reading. Naturally, you are not going to be able to remember everything, but you probably do not have too much difficulty recalling the most essential facts. These essential facts are referred to in the questions below. Answering these questions helps you to fix the facts more firmly in your mind. If you find questions that stump you, turn back in the book to the pages that will help you answer them.

**Correcting Parts Lists**

The purpose of this exercise is to help you to spot unrelated parts in a list. For example, in the list, *distributor, coil, spark plugs, fuel pump*, [98]
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ignition switch, you can see that fuel pump does not belong since it is the only part that does not belong to the ignition system.

In each of the lists, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. Fuel-system parts include the carburetor, fuel pump, oil pump, fuel line, and fuel tank.
2. The carburetor contains a float bowl, accelerator pump, fuel pump, nozzle, throttle valve, and idle port.
3. The electric system includes the storage battery, cranking motor, generator, carburetor motor, regulator, ignition distributor, and coil.
4. The ignition system includes the ignition switch, distributor, spark plugs, coil, spark pump, wiring.
5. The cooling system includes the water pump, water jackets, radiator, water, and float bowl.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. The fuel system contains a fuel tank, fuel line, fuel valve and muffler pump and carburetor pressure gauge and valve vacuum gauge and carburetor
2. Air entering the engine cylinders must first pass through the carburetor float bowl high-speed circuit air horn exhaust manifold
3. When the carburetor is delivering a rich mixture, it means that the mixture has more gasoline than air proportion of gasoline is increased proportion of air is increased throttle opening is increased
4. A mixture of 15 pounds of air and 1 pound of gasoline is considered to be a relatively rich mixture a relatively lean mixture a relatively noncombustible mixture a good mixture for acceleration
5. When the engine is throttled down, the throttle is closed is opened is moved from closed to open position is held in open position
6. The ignition system supplies a high-voltage surge to the spark plug in the cylinder toward the end of the intake stroke compression stroke power stroke exhaust stroke
7. The high-tension terminal of the ignition coil is connected to the spark plug through the contact points through the distributor cap and rotor through the regulator circuit.

8. The ignition-distributor centrifugal-advance mechanism advances the spark as throttle opening changes as engine speed is reduced as engine speed is increased.

9. The distributor shaft is driven from the camshaft at crankshaft speed camshaft at camshaft speed crankshaft at camshaft speed.

10. In the cooling system, the water pump circulates water between the engine water jacket and the radiator water heater.

CHAPTER CHECKUP

Note: Since the following is a chapter review test, you should review the chapter before taking the test.

Once more, you will want to test your knowledge of the subjects covered in the chapter you have just completed. The questions that follow have two purposes. One is to test your knowledge. The second purpose is to help you to review the chapter and fix more firmly in your mind the facts covered. It may be that you will not be able to answer, offhand, all the questions. If this happens, turn back into the chapter and reread the pages that will give you the answer. For instance, under Listing Parts, you are asked to list the parts in the valve mechanism. If you cannot remember them all, turn back to the illustration of the valve mechanism in the chapter and refer to it while writing your list. The act of writing down the names of the parts will help you to remember them.

Note: Write down your answers in your notebook. Then later, when you finish the Automotive Engines book, you will find your notebook filled with valuable information to which you can quickly refer.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. The parts that must be added to the piston to assure a good seal with the cylinder wall are the piston pins connecting rods piston rings gaskets.

2. The part that tends to keep the valve closed is called the guide lifter spring cam retainer.

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3. The crankshaft has at one end a piston connecting rod camshaft flywheel cylinder head.

4. For each crankshaft revolution, the camshaft revolves one-half turn one turn two turns.

5. To bring gasoline from the fuel tank to the carburetor, the fuel system includes an accelerator pump a vacuum pump a fuel pump a float.

6. In the carburetor air horn, a vacuum is produced by the fuel nozzle venturi accelerator pump float.

7. The term "enriching the mixture" means adding more air adding greater air speed adding greater vacuum adding more gasoline.

8. In the ignition system, the high-voltage surge from the coil is directed to the proper cylinder spark plug by the distributor cam distributor rotor ignition switch camshaft.

9. At higher engine speed, the spark is timed to occur at the cylinder spark plug earlier in the exhaust stroke intake stroke power stroke compression stroke.

10. At part throttle the spark will be advanced (by properly equipped distributors) as a result of higher engine speed lower engine speed intake-manifold vacuum.

Listing Parts

In the following, you are asked to list parts that go into various automotive components discussed in the chapter. Write down these lists in your notebook.

1. List the four piston strokes in the four-cycle engine.
2. List the parts that move up and down in the engine cylinder.
3. List the parts in the valve mechanism.
4. List the parts through and past which the air moves as it passes from outside the engine into the engine cylinder.
5. List the most essential, or basic, parts of the carburetor.
6. List the major components of the fuel system.
7. List the major parts of the fuel pump.
8. List the major components of the electric system.
9. List the main parts in the ignition system.
10. List the parts through which the water moves in the cooling system.

Purpose and Operation of Components

In the following, you are asked to write down the purpose and operation of certain components of the automobile discussed in the
chapter. If you have any difficulty in writing down your explanations, turn back in the chapter and reread the pages that will give you the answer. Then write down your explanation. Don’t copy; try to tell it in your own words. This is a good way to fix the explanation firmly in your mind. Write in your notebook.

1. Briefly describe the actions that take place during the four piston strokes.
2. What is the purpose of the connecting rod?
3. Describe the action of the valve mechanism.
4. What is the purpose of the flywheel?
5. Describe the action of the fuel pump.
6. What is the purpose of the float and needle valve in the carburetor float bowl? Describe their action.
7. Describe briefly the action in the carburetor when the throttle valve is opened.
8. Describe the action of the lubricating system.
9. Describe the action of the ignition system.
10. Describe the action of the cooling system.

SUGGESTIONS FOR FURTHER STUDY

If you would like to study the engine, electric, cooling, lubricating, and fuel systems further, there are several things you can do. First, you can read the Automotive Fuel, Lubricating and Cooling Systems and the Automotive Electrical Equipment books, which are other books in this McGraw-Hill Automotive Mechanics Series. Also, you can inspect your own and your friends’ cars as well as cars in the school automotive shop. You can go to a friendly service garage where repair work on these parts is done. By watching what goes on in the ordinary work of the day you will learn much about these automotive components. Perhaps you can borrow shop-repair manuals from your school-automotive-shop library or from car-dealer service shops. You may also be able to buy some of these from the car manufacturers. In addition, your school automotive shop may have cutaway and working models on exhibit which are used as teaching aids. Studying these will help you to understand the construction and operation of the actual units.
4 Engine performance measurements

THIS CHAPTER describes various ways in which engine performance may be measured. An engine may be measured in terms of its cylinder diameter, length of piston stroke, and number of cylinders. It is also measured, performancewise, in terms of the torque and horsepower it develops, as well as its efficiency and its friction horsepower (or horsepower used in overcoming friction). Let us examine these in more detail.

§64. Bore and stroke The size of an engine cylinder is referred to in terms of the bore, or diameter, and the stroke, or distance the piston travels from BDC (bottom dead center) to TDC (top dead center) (Fig. 4-1). Note that the bore is always mentioned first, as a 3\(\frac{1}{4}\) by 3\(\frac{1}{2}\)-inch cylinder. This means the diameter, or bore, of the cylinder is 3\(\frac{1}{4}\) inches, and the stroke is 3\(\frac{1}{2}\) inches. These measurements are used to figure piston displacement.

§65. Piston displacement Piston displacement is the volume that the piston displaces as it moves from BDC to TDC. You can picture this volume as a cylinder the diameter of the engine cylinder, with the top and bottom being the piston head at the TDC and BDC positions. To calculate piston displacement, you use the bore \((D)\) and the length of stroke \((L)\). Thus, piston displacement of a 3\(\frac{1}{4}\)-by 3\(\frac{1}{2}\)-inch cylinder would be the volume of a cylinder 3\(\frac{1}{4}\) inches in diameter and 3\(\frac{1}{2}\) inches long, or

\[
\frac{\pi \times D^2 \times L}{4} = \frac{3.1416 \times 3.75^2 \times 3.5}{4} = \frac{3.1416 \times 10.5625 \times 3.5}{4} = 29.036 \text{ cu in.}
\]

If the engine has six cylinders, then the total displacement in the engine would be 29.036 times 6, or 174.216 cubic inches.
§66. Compression ratio

The compression ratio of an engine is the air volume in one cylinder with the piston at BDC divided by the air volume with the piston at TDC (Fig. 4-2).

Note: The air volume with the piston at TDC is called the clearance volume since it is the clearance that remains above the piston when it is at TDC.

The compression ratio is a measure of how much the air-fuel mixture will be compressed in the cylinder. For example, the engine of one popular car has a cylinder volume of 42.35 cubic inches at BDC (this is A in Fig. 4-2). It has a clearance volume of 6.05 cubic inches at TDC (this is B in Fig. 4-2). The compression ratio, therefore, is 42.35 divided by 6.05 or 7/1 (that is, 7 to 1). In other words during the compression stroke, the air-fuel mixture is compressed from a volume of 42.35 cubic inches to a volume of 6.05 cubic inches, or to one-seventh of its original volume.

§67. Effect of increasing compression ratio

In recent years, engineers have designed engines with higher and higher compression ratios. Increasing the compression ratio offers several advantages. When the compression ratio of an engine is increased, its power and economy also increase, without a comparable increase of engine size or weight. In effect, an engine with a higher compression ratio "squeezes" the air-fuel mixture harder (compresses it more) when this happens, the air-fuel mixture gives up more power or...
the power stroke. Here's why: a higher compression ratio means a higher initial pressure at the end of the compression stroke. This in turn means that, when the power stroke starts, higher combustion pressures will be attained: a harder push will be registered on the piston. The burning gases will also expand to a greater volume during the power stroke. It all adds up to this: there is more push on the piston for a larger part of the power stroke. More power is obtained from each power stroke.

Increasing the compression ratio does, however, introduce special problems. For one thing, as compression ratio goes up, the problem of detonation, or knocking, in the engine becomes more acute. There is a detailed discussion of knocking in Chap. 8, "Automotive-engine Fuels and Fuel Systems," §§150 and 151. But to summarize briefly, any particular fuel will stand a certain amount of "squeezing" without causing knocking. But if it is "squeezed" (or compressed) further as a result of a higher compression ratio, it will then cause knocking in the engine. This knock, or ping, robs the engine of power and, if severe, may even cause engine parts to break. Thus, as compression ratios of engines have been stepped up, the gasoline companies have had to supply new types of fuel that would operate in these higher-compression engines without knocking (see § 151).

Another factor to be considered in the higher-compression engines is the effect of carbon accumulations in the cylinders. Carbon results from incomplete fuel combustion; many engines will accumulate carbon, especially in city driving where the engine works much of the time at part throttle. When carbon accumulates in an engine, it has the effect of increasing the compression ratio. The carbon reduces clearance volume; the air-fuel mixture is therefore squeezed into a smaller volume. For example, one 8-cylinder engine with a compression ratio of 8.25:1 has a clearance volume of only about 5½ cubic inches. Suppose that a tablespoonful of carbon (about a cubic inch) accumulates. This reduces the clearance volume to about 4½ cubic inches, and thereby increases the effective compression ratio to about 10:1! The cylinder in which this took place would "knock its head off." Thus, with the higher-compression engines, more attention must be paid to engine maintenance. Further discussions on this matter follow in later chapters in the book.
§68. Delivery of air-fuel mixture

When the piston moves down on the intake stroke, a vacuum is produced in the cylinder. Atmospheric pressure (pressure of air) then pushes air into the cylinder. This air must first pass through the carburetor (where it picks up a charge of fuel), the intake manifold, and the intake-valve port. You might think that atmospheric pressure [15 psi (pounds per square inch) at sea level] would be great enough to push air through these passages and into the cylinder almost instantly. However, it does take air an appreciable time to move through any restricting passage. Anyone who has deflated a tire knows how long it takes for the air to escape after the valve core has been removed.

Thus, as the air moves through the carburetor, manifold, and intake-valve port, it must pass through constrictions and go around turns that, in effect, “hold it back.” It takes time for the air to get into the cylinder on the intake stroke. But even during engine idle, there isn’t much time available for the air to get into the cylinder. During idle [say at 350 rpm (revolutions per minute)] the entire intake stroke takes less than one-tenth of a second. At high speed, this time is reduced to less than a hundredth of a second.

It is therefore obvious that the vacuum in the cylinder (caused by the downward moving piston) is not going to be completely “satisfied.” That is, the air is going to be shut off by closing of the intake valve before the cylinder is “filled up.” The higher the engine speed, the less will be the amount of air-fuel mixture taken in during the intake stroke. This is one reason why an engine will not increase in speed and in power output indefinitely. There is a certain speed at which an engine will produce maximum power; above this speed power drops off.

§69. Volumetric efficiency

The amount of air-fuel mixture taken in by the engine on the intake stroke is a measure of the engine’s volumetric efficiency. If the mixture were drawn into the cylinder very slowly, it would be possible to get a full charge of air-fuel mixture into the cylinder. However, as mentioned in the previous section, the mixture must pass very rapidly through a series of restricting openings and bends in the carburetor and intake manifold. In addition, the mixture is subjected to heat (from engine and exhaust manifold), and it therefore increases in temperature. We know that when air is heated, it expands. The two conditions, rapid
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movement and heating, reduce the amount of mixture that can enter the cylinder on the intake stroke; a full charge of air-fuel mixture cannot enter because the time is too short.

Volumetric efficiency is the ratio between the amount of air-fuel mixture that actually enters the cylinder and the amount that could enter under ideal conditions. For example, a certain engine has an air volume (A in Fig. 4-2) of 47 cubic inches per cylinder (piston at BDC). If the cylinder were allowed to completely "fill up," it would take in 0.034 ounce of air (air at atmospheric pressure weighs about 1.25 ounces per cubic foot). However, suppose that the engine were running at a fair speed so that only 0.027 ounce of air could enter. This means that volumetric efficiency would be only about 80 percent (0.027 is 80 percent of 0.034). Actually, 80 percent is a good volumetric efficiency for an engine running at fairly high speed. As a matter of fact, volumetric efficiency of many engines drops to as low as 50 percent at high speeds. This is another way of saying that the cylinders are only "half-filled" at high speeds.

This is one reason why engine speed and output cannot continue to increase indefinitely. In effect, at higher speeds the engine has an increasingly hard time "breathing," or drawing in air. There comes a point where it begins to "starve" for air, and it is at this point in speed that the engine begins to "weaken" so that its power output drops off.

Modern engines are designed so that they can breathe more easily, and thus can develop a higher volumetric efficiency at high speed with a consequent higher power output. For example, intake valves have been made larger, and intake-manifold passages have been made larger and have been straightened and shortened as much as possible. Carburetors have been changed so as to permit more air to get through (some have extra circuits, or air passages, that open at high speed). Better breathing (and thus higher volumetric efficiency) helps engine performance.

§70. Engine power output

Power is the rate at which work is done. The rate at which an engine can do work is measured in horsepower (see §26). An engine that can deliver 33,000 ft-lb (foot-pounds) of work in 1 minute is a 1-hp (horsepower) engine. An engine that can deliver 660,000 ft-lb of work in 1 minute is a 20-hp engine. The power that the engine actually delivers is called [107]
brake horsepower (bhp). Automotive engines are usually rated in terms of bhp although the word “brake” is not always used. Thus, an engine that is rated as developing 160 bhp may be called a 160-hp engine.

§71. Determining brake horsepower The term “brake horsepower” came from the fact that a prony brake was one of the first devices used to measure engine horsepower output. The Prony brake (Fig. 4-3) contains a large brake drum around which a brake is clamped. A brake arm is attached to the brake at one end and rests on a scale at the other. The brake has a device (A in Fig. 4-3) that can be tightened so that the brake will exert a greater braking effect on the drum. The brake drum is driven by the engine. Thus when the brake is tightened, a greater load is imposed on the engine. At the same time, there is a greater push exerted through the brake and brake arm on the scales.

The Prony-brake test is made by running the engine (and brake drum) at a steady speed and gradually tightening the brake on the brake drum. As this is done, the load on the engine is increased and the throttle must be opened wider in order to maintain engine speed. Loading the engine in this way also increases the load, or weight, on the scales (W in Fig. 4-3). To find the maximum power that the engine can develop at any one speed, the load is increased [108]
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gradually (throttle being opened wider and wider at the same time to maintain speed), until the throttle is wide open. Further loading would then cause the engine speed (and power output) to drop off.

The maximum load on the scale is then used in the following formula to determine what horsepower the engine was developing:

\[ \text{Bhp} = \frac{2\pi RNW}{33,000} \]

where \( R \) = length of arm (from center of drum)
\( N \) = engine speed in rpm
\( W \) = load in pounds on scale

For example, let us suppose the arm is 3 feet long, the load on the scale (\( W \)) is 100 pounds, and \( N \) is 1,000 rpm. Substituting in the formula gives:

\[ \text{Bhp} = \frac{3 \times 1,000 \times 100}{5,252} = 57.12 \text{ bhp} \]

§72. Dynamometer rating of engine horsepower Instead of the Prony brake, many engine testers now use a dynamometer (Fig. 4-4). This device contains an electric dynamo, or generator, which is driven by the engine during the test. The amount of electric current that the dynamo produces during the test is a direct measure of the amount of power the engine is producing. Since the current can be very accurately measured, the dynamometer will very accurately report the horsepower output of the engine.

Another type of dynamometer makes use of a water brake. The water brake contains a rotating device with numerous blades, or vanes. When water is put into the device, the rotating member has a restriction put on it. The more water added, the more restriction and the more power needed to drive it. As can be seen, this device can apply a varying load on the engine as water is added to or removed from the rotating mechanism.

Many dynamometers test detached engines as shown in Fig. 4-4. Other dynamometers, called \textit{chassis dynamometers}, test the engine while it is in the car. On these, the rear wheels of the car are placed on rollers. The engine is started, and the transmission is placed in gear. The rollers are then driven by the engine. The rollers, in turn, are connected to the dynamometer so that engine
output can be measured. The use of the chassis dynamometer is becoming more common in the automotive servicing field since it can give a very quick report on engine condition (by measuring engine output at various speeds and loads). The chassis dynamometer is also valuable in testing and adjusting automatic trans-

missions since checks and adjustments can be made in the shop; no road test is necessary.

CHECK YOUR PROGRESS

Progress Quiz 7

Once again you have the chance to check up on yourself and find out if you are making good progress in your studies of the automotive engine. The material you have just covered is different from the material in previous chapters because it describes some of the ways in which engine performance is measured. You will readily appreciate that this is valuable information for you to have. Anyone interested in automotive engines should know how engine output is measured, what compression ratio [110]
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means, and so on. You can find out how well you have remembered this material by answering the questions below.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. The size of an engine cylinder is referred to in terms of its
   bore and length    bore and stroke    diameter and bore
2. Piston displacement is calculated from the
   bore and stroke    piston length and diameter    cylinder diameter and length
3. The air volume above the piston with the piston at TDC is called
   the compression ratio    clearance volume    piston displacement    bore
4. The air volume in the cylinder with the piston at BDC divided by
   the clearance volume is called the
   piston displacement    cylinder ratio    compression ratio
5. Two special problems to be considered in the higher-compression engines are
   air-fuel ratio and speed    ping and detonation    detonation and carbon accumulations
6. As carbon accumulates in a cylinder, it causes an increase in
   the clearance volume    effective compression ratio    piston displacement
7. The amount of air-fuel mixture taken in by the engine on the intake stroke is a measure of the engine's
   clearance volume    compression ratio    volumetric efficiency
8. A volumetric efficiency of 80 percent for an engine running at fairly high speed is
   good    fair    poor
9. The more easily an engine can breathe, the higher its volumetric efficiency
   piston displacement    compression ratio
10. The Prony brake is used to determine
   fhp    bhp    ihp

§73. Dynamometer test results

Dynamometer tests of engines, even with controlled laboratory conditions, will not usually show test results that will agree with the advertised horsepower ratings of the engines. For example, an engine advertised as being a "150-hp engine," might show only about 130-hp output maximum on the chassis dynamometer and possibly about 135-hp maximum on the engine dynamometer. One reason for this is that the advertised ratings are measured without such accessories as generators, air
cleaner, and exhaust system. Each of these cuts down the engine output 2 or 3 hp. In addition, on the chassis dynamometer there is a friction loss in the transmission, universal joints, and rear axles, of several horsepower.

Another difference is that the advertised rating has been corrected for both temperature and atmospheric pressure. Other factors being equal, the power output of an engine will go up with increased pressure and down with increased air temperatures (within certain limits, of course). Increased pressure increases the amount of air-fuel mixture forced into the engine cylinders. But increased temperature, which causes the air to expand, reduces the amount of air-fuel mixture entering the cylinders. Thus, in order to have a system that will give the same corrected ratings regardless of where the engine is being tested, engine testers have adopted a code that does this: After an engine is tested on the dynamometer, the test results are adjusted for actual air temperature and pressure. For example the test results would be adjusted upward if actual air temperature were too high or pressure were too low (either of these cause a power loss). The test results would be adjusted downward if the actual air temperature were too low or the air pressure too high. Actually, a single formula is used to make the corrections. This formula corrects the test results to a standard which corresponds to dry air at 60°F and at 15 psi (sea-level atmospheric pressure).

§74. Indicated horsepower

Another method of evaluating engines is by indicated horsepower (ihp). Indicated horsepower is based on the power actually developed inside the engine cylinders by the combustion process. A special indicating device (an oscilloscope) is required to determine ihp. This device measures the pressure (by electronic means) in the cylinder continuously throughout the four piston strokes (intake, compression, power, exhaust). It makes a graph of these pressures, relating them to the piston position in the cylinder during the four piston strokes. A graph of these pressures taken from a typical engine test might be as shown in Fig. 4-5. The four small drawings show the crank, rod, and piston positions as well as directions of motion, during the four strokes. Note that the pressure in the cylinder is about atmospheric at the beginning of the intake stroke. Then it falls a little below atmospheric.
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pheric as air-fuel-mixture delivery to the cylinder lags slightly behind piston movement (that is, volumetric efficiency is less than 100 percent). When the compression stroke begins (both valves closed), the pressure starts to increase as the piston moves upward in the cylinder. As it reaches a value of somewhat over 100 psi, and a little before the piston reaches TDC, ignition takes place (the graph shows an ignition-spark advance of about 20 degrees). Now, as the air-fuel mixture burns, pressure goes up very rapidly, reaching a peak around 680 psi at about 25 degrees past TDC on the power stroke. Pressure begins to fall off fairly rapidly as the power stroke continues, but there is still a pressure of about 50 psi at the end of the power stroke. When the exhaust stroke begins, the pressure falls off as the piston moves up, forcing the burned gases from the cylinder. At the end of the exhaust stroke, pressure has fallen to around atmospheric. Another intake stroke then begins.

From a graph such as is shown in Fig. 4-5, the average or mean effective pressure (mep) in the cylinder can be determined. The mep is the average pressure during the power stroke, minus the average pressures during the other three strokes. The mep is,
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in effect, the pressure that actually forces the piston down during the power stroke. From the mep, and other engine data, the following formula is used to calculate ihp:

\[ \text{ihp} = \frac{\text{PLANK}}{33,000} \]

where
- \( P \) = mean effective pressure in psi
- \( L \) = length of stroke in feet
- \( A \) = area of cylinder section in square inches
- \( N \) = number of power strokes per minute (or rpm/2)
- \( K \) = the number of cylinders

In operation, some of the power developed in the engine is used up in overcoming friction in the engine. Thus ihp (which is power developed in the engine) is always greater than bhp (which is power delivered by the engine). Frictional losses in an engine can be determined by subtracting bhp from ihp. Section 80 explains how bhp and ihp can be used to determine engine efficiency.

Friction horsepower

Friction losses in an engine are sometimes referred to in terms of friction horsepower (fhp). This expression means the amount of horsepower required to overcome friction losses in the engine. The fhp of an engine can be determined by driving the engine with an electric motor (the dynamo in an electric dynamometer can be used for this purpose). The engine is turned off (after a run to bring it up to operating temperature) with no fuel in the carburetor and the throttle wide open. Under these conditions the amount of power required to drive the engine at different speeds is determined. At low speeds an engine uses up a relatively small amount of power in overcoming friction. However, as engine speed increases, the fhp goes up rapidly. The graph (Fig. 4-6) shows this increase in a typical engine. Note that at about 1,000 rpm, the fhp is only about 4 hp. However, at 2,000 rpm the fhp is nearly 10 hp. At 3,000 rpm it has gone up to about 21 hp, while at 4,000 rpm it is about 40 hp.

One of the major causes of frictional loss (or fhp) in the engine is piston-ring friction. Under some conditions, the friction of the rings on the cylinder walls accounts for 75 percent of all friction losses in the engine. For example, Fig. 4-6 shows a fhp of 40 hp at 4,000 rpm. It could be that 75 percent of this total, or 30 hp, is
being used up by the rings in overcoming friction, under certain conditions. Understanding of this fact makes us realize more fully than ever the difficult job that the piston rings have to do in the engine.

![Friction-horsepower curve](image)

**Fig. 4-6.** Friction-horsepower curve, showing relationship of fhp to engine speed.

### §76. Relating bhp, ihp, and fhp

We have already mentioned that bhp is the power delivered by the engine, ihp is the power developed in the engine cylinders by the burning air-fuel mixture, and fhp is the horsepower required by the engine to overcome frictional losses. The relationship between the three is

\[
Bhp = ihp - fhp
\]

In other words, the horsepower delivered by the engine (or bhp), is equal to the horsepower developed in the engine, minus the horsepower losses resulting from friction.

### §77. SAE horsepower

The SAE (Society of Automotive Engineers) horsepower rating of engines is used to compare engines on a uniform basis (usually for tax purposes only). This formula is

\[
SAE \text{ hp} = \frac{D^2 \times N}{2.5}
\]

where  
- \(D\) = diameter of cylinders, or bore  
- \(N\) = number of cylinders

Note that this formula does not consider such factors as mep, length of stroke, rpm, and so forth.

### §78. Torque

Torque is turning effort (see §28). An example of torque was seen in the old days (before electric cranking motors), when the automobile engine had to be cranked by hand (Fig. 4-7). As the hand crank was turned, torque was being applied to...
the engine crankshaft. In like manner, when the piston is moving down on the power stroke, it applies torque to the crankshaft through the connecting rod and crank on the crankshaft (Fig. 4-7).

The harder the push on the piston, the greater the torque applied. Thus, the higher the combustion pressures in the engine, the greater the amount of torque the engine develops.

Torque should not be confused with engine power. Torque is the rotary or twisting effort that the engine applies through the crankshaft.

![Fig. 4-7. Torque applied to the hand crank of the old-time car rotates engine crankshaft. Likewise, piston and connecting rod impart torque to crank of crankshaft to cause crankshaft to rotate.](image)

Power is the rate at which the engine works. Of course, the two are related, but it must be remembered that power takes into consideration engine speed, or rpm, while torque does not. Torque is merely the force times the distance the force acts from the shaft center, or pound-feet (lb-ft). Torque can be applied without any motion at all; this is not, however, a normal condition in engine operation. The Prony brake (Fig. 4-3) can be used to measure engine torque.

**Example:** An engine under test on the Prony brake is found to provide a force of 110 pounds at 900 rpm with a 4-foot lever. The engine is therefore developing a torque of 440 lb-ft (110 \times 4).
This can be converted into horsepower (since the rpm is known) by use of the formula presented in §71.

\[
\text{Bhp} = \frac{\text{RNW} \times 4 \times 900 \times 110}{5,252} = 5252
\]

\[\Rightarrow \text{Bhp} = \frac{5252}{5252} = 75.3 \text{ bhp}\]

§79. Torque compared with brake horsepower

1. The torque that an engine can develop changes with engine speed. An engine develops more torque at intermediate speed (open throttle, of course), than at high speed. This is because, at the lower speeds (open throttle), there is more time for air-fuel mixture to enter the cylinder. In other words, in these speed ranges, the volumetric efficiency is high. This means that there will be a greater amount of air-fuel mixture to burn during the power stroke; higher combustion pressures will develop. This means, in turn, that greater torque will be applied to the crankshaft.

At higher speeds, there is less time for air-fuel mixture to enter the cylinder. Thus there will be less air-fuel mixture to burn. Pressures will not go so high, and torque will not be so great. Also, at high speed the piston is moving so much faster that it tends to "keep step" with the increasing pressure as combustion starts; less thrust is exerted on the piston. Figure 4-8 shows, graphically, how torque changes as engine speed changes. Note that at low speed (400 rpm) the engine can develop considerable torque (about 170 lb-ft). Torque goes up with engine speed until, in the

![Torque curve of an engine, showing relationship of torque to speed.](image)
range of 1,500 to 2,000 rpm, torque is at a maximum of around 215 lb-ft. Further increase of engine speed, however, results in a falling off of torque. This is due to the reduction in volumetric efficiency, or reduction of amount of air-fuel mixture that is able to get into the engine cylinder at the higher speeds.

Note: You will note that torque is somewhat lower at low speed than at intermediate speed, and this may seem contrary to what was said previously about volumetric efficiency being highest at very low speed. Actually, at idling speeds (which are not “very low speed”) the inertia effect of the air in the air cleaner, carburetor, and intake manifold has a retarding effect on air flow. It might be said that at the lower engine speeds the air is moving too slowly to “fill up” the cylinders efficiently during the intake strokes. However, when a somewhat higher engine speed is attained, then the air is moving through the carburetor and intake manifold at a much brisker pace. Now, when the intake valve opens, the air is already moving rapidly; this makes it possible for more air-fuel mixture to get in so that combustion pressures and developed torque will be greater.

2. Horsepower also goes up with engine speed (Fig. 4-9). It is obvious that this must be so because horsepower depends on rpm as well as on torque. Look at the brake-horsepower formula in §71. The \( W \) and \( R \) in the formula are pounds of force and distance in feet from the shaft center (or lb-ft torque), while \( N \) is rpm.
Thus, so long as torque and rpm go up, the horsepower output will also go up. Figure 4-9 illustrates this; this is the horsepower curve of the same engine for which the torque curve is given in Fig. 4-8. Note that at low speed (400 rpm) the brake horsepower (bhp) is small (only about 14 bhp). But bhp goes up steadily with increasing speed until a maximum of about 110 bhp is reached at around 3500 rpm. Then, bhp falls off rapidly. This tapering off results from the rapid decrease of engine torque in the higher-speed ranges as well as the rapid increase of friction horsepower (fhp) at the higher speeds. The relationships can be readily seen in Fig. 4-10, where the three curves are shown together. Note that the bhp continues to go up for some time even after the torque starts to drop. This is the effect of increasing engine speed. Soon, however, fhp is using up so much horsepower that bhp starts dropping off. Aiding in this bhp-curve drop is the torque-curve drop.

NOTE: The curves shown in Figs. 4-6 and 4-8 to 4-10 are for one particular engine only. Different engines have different torque, fhp, and bhp curves. Peaks may occur at higher or lower speeds, and the torque-bhp-fhp-speed relationships may not be as indicated.

§80. Engine efficiency The term "efficiency" means the relationship between the effort exerted and the results obtained. As applied to engines, efficiency is the relationship between the power delivered (bhp) and the power that could be obtained if the engine
operated without any power loss. Engine efficiency can be computed in two ways, as mechanical efficiency and as thermal efficiency.

1. Mechanical efficiency. Mechanical efficiency is the relationship between bhp and ihp:

\[
\text{Mechanical efficiency} = \frac{\text{bhp}}{\text{ihp}}
\]

EXAMPLE: At a certain speed, the bhp of an engine is found to be 116, and its ihp is 135. The mechanical efficiency would be

\[
\text{Mechanical efficiency} = \frac{116}{135} = 0.86, \text{ or } 86 \text{ percent}
\]

That is, 86 percent of the power developed in the cylinders is delivered by the engine (the remaining 14 percent or 19 hp being consumed as ihp).

2. Thermal efficiency. "Thermal" means of or pertaining to heat. Thermal efficiency of an engine is the relationship between the power output and the energy in the fuel burned to produce this power output. We have already noted that a considerable part of the heat produced by the combustion process is carried away by the cooling water and the lubricating oil. In addition, since the burned gases are still hot when they leave the engine, these exhaust gases carry away a considerable part of the heat produced by combustion. All these losses are heat (or thermal) losses that reduce the thermal efficiency of the engine; they do not add to the power output of the engine. The remainder of the heat, in causing the gases to expand, creates the high pressures that force the pistons down so power is developed by the engine. Because there is a great deal of heat lost during engine operation, thermal efficiency of the gasoline engine may be as low as 20 percent and is seldom above 25 percent. Practical limitations prevent higher thermal efficiencies.

§81. Over-all efficiency The gasoline enters the engine with a certain energy content, or certain ability to do work. At every step in the process, from the burning of the gasoline in the cylinders to the rotation of the car wheels, energy is lost. Figure 4-11 illustrates these losses as determined on one engine and car during a test run. Note that about 35 percent of the heat energy is carried away by the cooling water and lubricating oil. Another 35 percent is lost
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in the exhaust gases which are still hot after leaving the cylinders. Friction (engine and power train) accounts for another 15 percent. The amount of energy remaining, which may be as little as 15 percent of the energy contained in the gasoline, is actually responsible for propelling the car. This power is used to overcome rolling resistance and air resistance and to accelerate the car.

1. Rolling resistance. The rolling resistance results from irregularities in the road over which the wheels ride, as well as the flexing of the tires as the weight of the car bears on the various portions of the tire in turn.

2. Air resistance. Air resistance is the resistance the air offers to the passage of the car body through it. As car speed increases, so also does the air resistance. At 90 mph (miles per hour), for example, tests have shown that 75 percent of the power the engine develops is used up in overcoming air resistance. Streamlining the car body reduces power loss from air resistance.

3. Acceleration. Power is required to increase car speed. In effect, the power applied to accelerate the car overcomes the inertia of the car; energy in the form of car speed is built up, or stored in the car.

CHECK YOUR PROGRESS

Progress Quiz 8

Here is your chance to quiz yourself again to find out how well you are doing in your studies of the engine. You have covered more ground,
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in the past few pages, on engine performance measurements. Information
on this subject is very valuable to any person who has anything to do
with engines; it gives him a better understanding of engine performance,
design, and construction. Check your knowledge by answering the
questions below. If you have any trouble, reread the past few pages and
take the quiz again. Remember, the quiz is designed to help you
remember the important facts about engines.

Completing the Sentences

1. In comparison with the advertised horsepower rating of an engine,
the horsepower as determined by a chassis dynamometer will
be higher lower the same
2. The power actually developed inside the engine cylinders is called
ihp bhp hhp
3. The average pressure during the power stroke minus the average
pressures during the intake, compression, and exhaust strokes is
called the ihp bhp compression ratio mep
4. The power used in overcoming friction in the engine is called
ihp fhp bhp
5. One of the major causes of fhp in an engine is low volumetric
efficiency piston-ring friction excessive mechanical effi-
ciency
6. Ihp minus fhp equals bhp mep SAE hp
7. Engine torque is highest at low speed intermediate speed high speed
8. One reason why torque drops off at high speed is that, at high
speed, volumetric efficiency is lower engine breathes better fuel mixture is richer
9. Bhp divided by ihp is mechanical efficiency thermal effi-
ciency volumetric efficiency
10. The percentage of the energy in the gasoline burned in the engine
which is actually utilized in propelling the car may be as little
as 15 percent 25 percent 35 percent 70 per-
cent

CHAPTER CHECKUP

Note: Since the following is a chapter review test, you should review
the chapter before taking the test.

You are making good progress in your studies of the automobile
engine. The chapter you have just completed gives you a good back-
ground on the various ways in which engines and engine performance
are measured. When someone talks to you about piston displacement,
engine Performance Measurements

Compression ratio, or brake horsepower, you will know what he means. In order for you to be sure that you remember the important points covered in the chapter, the following checkup has been included in the book. Review the chapter before taking the test. If the questions seem hard to answer, review the chapter again. Remember, the good student may review his lesson several times in order to make sure that he has fixed the essential facts in his mind.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. Knowing the bore and stroke, you can calculate the compression ratio piston displacement volumetric efficiency
2. Knowing the clearance volume and the air volume in the cylinder with the piston at BDC, you can figure the compression ratio volumetric efficiency bhp ihp
3. Knowing the weight of air an engine cylinder could take in and the weight of air actually taken in under running conditions, you can figure compression ratio piston displacement volumetric efficiency
4. Knowing the speed at which an engine is running and the torque it is developing, you can figure bhp ihp fhp
5. In the advertised horsepower rating of an engine, the rating has been corrected for speed and pressure air pressure and temperature fhp ihp
6. If you know the engine speed, bore, stroke, number of cylinders, and mep in the cylinders, you can calculate bhp ihp fhp
7. Knowing the ihp and fhp of an engine, you can calculate SAE hp bhp rpm compression ratio
8. The SAE hp rating of engines is based on bore and number of cylinders engine speed and torque bhp and ihp fhp and fhp
9. To figure the mechanical efficiency of an engine under test, you need to know mep and ihp bhp and ihp mep and rpm
10. The ratio between power output of an engine and the energy in the fuel burned to produce that power is called thermal efficiency mechanical efficiency volumetric efficiency
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Problems

Work out the following problems in your notebook. Refer back to the formulas in the chapter if you are not sure of them.

1. What is the piston displacement in a 3- by 4-inch cylinder?
2. What is the compression ratio of an engine that has a clearance volume of 5.3 cubic inches (piston at TDC) and an air volume of 45.05 cubic inches with piston at BDC?
3. An engine has a compression ratio of 8/1. It has a clearance volume of 5 cubic inches and an air volume with piston at BDC of 40 cubic inches. Accumulations of carbon, after some months of adverse service, amount to an average of 1 cubic inch per cylinder. What is the average effective compression ratio?
4. An engine has an air volume (piston at BDC) of 47 cubic inches per cylinder. This means that at atmospheric pressure the cylinder could hold 0.034 ounce of air. In an actual running test at 3,000 rpm, the engine is found to take in only 0.024 ounce per cylinder on each intake stroke. What is the volumetric efficiency under these conditions?
5. In a Prony-brake test of an engine, where the brake arm is 4 feet long, the load on the scale was found to be 200 pounds at 1,250 rpm. What bhp is the engine developing?
6. Determine the ihp of an 8-cylinder 3- by 4-inch engine which, when running at 2,000 rpm, shows a mep of 360 psi.
7. Under certain test operating conditions an engine has a rating of 31 fup while developing 136 bhp. What is its ihp under these conditions?
8. What is the mechanical efficiency of the engine in problem 7 under the test conditions?
9. What is the SAE hp rating of an eight-cylinder 3- by 4-inch engine?
10. What torque is the engine described in problem 5 producing?

Suggestions for Further Study

There are a number of engineering books that supply additional information on engine measurements as well as details of how engine tests are run. If you are interested in learning more about these matters, go to your local library and have your librarian help you find the books containing this additional information. It is also possible that your local high school automotive mechanics teacher or physics teacher may be able to help you.
5: Engine types

THIS CHAPTER describes various ways in which engines are classified. All automotive engines are of the internal-combustion type; that is, combustion of the fuel takes place inside the engine (as opposed to steam engines, for instance, in which combustion of fuel takes place outside the engine). Engines are classified according to the type of fuel burned [gasoline, diesel fuel or LPG (liquefied petroleum gas)], arrangement of valves, number and arrangement of cylinders, and type of cooling.

§82. Cylinder arrangements While one- and two-cylinder engines are in use, their application is mostly confined to motorcycles, tractors, power mowers, and so forth. The smallest number of cylinders in use in American passenger car engines is four. Some European cars, however, use engines with fewer cylinders. The greatest number of cylinders now used in American passenger car engines is eight. In the past, some passenger cars were made with 12 and even 16 cylinders. However, the four-cylinder, six-cylinder, and eight-cylinder engines are the only ones in common use today.

1. Four-cylinder in-line engines. In the four-cylinder in-line engine, the cylinders are arranged in a line in a vertical position (Fig. 5-1). All cylinders are cast together in the cylinder block. The crankshaft is usually supported in three shaft bearings in the crankcase of the engine. All four crankpins on the crankshaft are in one plane, with the two outside crankpins and two inside crankpins having the same relative positions. Cylinders are numbered from the front to the back of the car, and the firing order (or order in which cylinders fire or produce power strokes) is either 1-3-4-2 or 1-2-4-3.

2. Six-cylinder in-line engines. The six-cylinder in-line engine has a construction that is very similar to the four-cylinder engine, except that two more cylinders have been added (Figs. 5-2 and 5-3).
1. Fan assembly
2. Water-pump bearing and shaft assembly
3. Water-pump seal washer
4. Water-pump seal assembly
5. Water-pump impeller
6. Piston
7. Wrist pin
8. Thermostat assembly
9. Water-outlet elbow
10. Thermostat retainer
11. Exhaust valve
12. Intake valve
13. Cylinder head
14. Exhaust-manifold assembly
15. Valve spring
16. Valve-tappet self-locking adjusting screw
17. Engine plate, rear
18. Camshaft
19. Flywheel ring gear
20. Camshaft-packing, rear end
21. Crankshaft-bearing rear drainpipe
22. Crankshaft-bearing rear, lower
23. Valve tappet
24. Camshaft
25. Oil pump and distributor gear drive
26. Connecting-rod cap bolt
27. Oil-float support
28. Oil-float assembly
29. Crankshaft bearing center, lower

Fig. 5-1. Four-cylinder automotive engine of the Otto-cycle type.
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The cylinders are arranged vertically and in line. The crankshaft is supported on three or four bearings, with the crankpins arranged in pairs 120 degrees apart. This provides good inherent balance. The cylinders are numbered from the front to the back of the car, and the firing order is either 1-5-3-6-2-4 or 1-4-2-6-3-5.

Note: There has been a good deal of development work done on a V-6 engine by various engine manufacturers. This type of engine has two banks of three cylinders each, placed at an angle to each other to form a V as in the V-8 engines (see Figs. 5-5 and 5-6). The V-6 arrangement, however, presents certain balancing problems that, to date at least, have not been easily and economically solved.

3. Eight-cylinder in-line engines. Eight-cylinder in-line engines are like six-cylinder engines, except that two cylinders are added. The cylinders are arranged vertically and in line (Fig. 5-4). The crankshaft is usually supported on five bearings, although a greater number may be used. The crankpins are arranged in pairs and in planes that are perpendicular (or at a 90-degree angle) to each other. Two general arrangements have been used. One consists, in effect, of placing two four-cylinder engine crankshafts end to end, with the cranks at a 90-degree angle to each other. Somewhat better balance is obtained by, in effect, cutting one crankshaft in half and placing the other shaft between the two halves at a 90-degree angle. The firing order in practically universal use on eight-cylinder in-line passenger-car engines is 1-6-2-5-8-3-7-4, although 1-4-7-3-8-5-2-6 could also be used.

4. V-8 engines. In the V-8 engine (Figs. 5-5 to 5-8) the cylinders
Automotive Engines

are arranged in two banks of four cylinders each, with the two banks set at a 90-degree angle (usually) to each other. This design permits a shorter and lighter but more rigid engine (rigidity is important in the higher-compression engines with the higher combustion pressures attained). This arrangement of the cylinders also permits the use of intake manifolding that assures relatively even distribution of air-fuel mixture to all cylinders, plus improved breathing characteristics.

The V-8 crankshaft crankpins may be arranged in one plane (as in the four-cylinder engine) or they may be arranged at 90-degree angles to each other. The latter design, which provides a better balance, is commonly used. Connecting rods from opposite cylinders are attached to the same crankpin, two rods being attached to each pin.

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FIG. 5-3. Partial cutaway of a six-cylinder L-head engine. (Studebaker Division of Studebaker-Packard Corporation)

FIG. 5-4. Sectional view of eight-cylinder in-line passenger-car engine with overhead valves. (Buick Motor Division of General Motors Corporation)
Fig. 5-5. (a) Side view and (b) sectional view from end of a V-8 engine. Note that this engine has overhead valves. (Cadillac Motor Division of General Motors Corporation)
Fig. 5-6. (a) Side sectional view and (b) sectional view from end of a V-8 engine. This is termed the Fire Dome engine by the manufacturer; the combustion chambers are hemispherical in shape. Note valve and push-rod arrangement. (DeSoto Division of Chrysler Corporation)
In recent years, there has been a great swing to V-8 engines. Such cars as Buick, Chrysler, De Soto, Dodge, Oldsmobile, Pontiac, Studebaker, and others have joined the ranks of those using V-8 engines. Cadillac, Ford, Lincoln, and Mercury have used V-8 engines for a number of years. Engineers have mentioned several reasons for the swing to V-8 engines. One is that the shorter engine is more rigid; this permits higher running speeds and higher output with less difficulty from flexing, or bending, of the crankshaft and cylinder block. Flexing, of course, throws the engine out of line, increases frictional losses, and may set up internal vibrations. Torsional vibration (explained in §101) is less with the shorter engine. Also, the shorter engine makes possible more passenger space on the same wheel base or a shorter wheel-base car. Most of
FIG. 5-8. (a) Front view and (b) end sectional view of a late V-8 engine. This is termed the *Fireball* engine by the manufacturer. Note arrangement of valves in vertical banks, and push rods. (*Buick Motor Division of General Motors Corporation*)
the V-8 engines, particularly the newer ones, use overhead valves (See §83).

5. **Twelve- and sixteen-cylinder engines.** Twelve- and sixteen-cylinder engines have been used in passenger cars, busses, and trucks and for industrial installations. With this number of cylinders, the cylinder arrangement may take various forms with two banks (V type or pancake type), three banks (W type), or four banks (X type), all working to a common crankshaft. The so-called “pancake engine” is essentially a flattened-out V engine. That is, the two banks are arranged in the same plane, but opposing, and work to the same crankshaft. This design provides an engine flat enough to be mounted under the floor of a bus, for example.

6. **Radial engine.** The radial engine (Fig. 5-9) has the cylinders radiating from a common center, like the spokes of a wheel. All connecting rods work to a common crankpin; the crankshaft has [134]
but one crankpin. The radial engine is air-cooled (§84) and is used mainly for aircraft applications. There is also the multiple-bank radial, which is essentially two or more radial engines, one mounted back of another, using a multiple-crankpin crankshaft.

§83. Valve arrangements The intake and exhaust valves in the engine can be arranged in various positions in the cylinder head or block; these arrangements have been termed L, T, I, and F (Fig. 5-10). Of these, the L, I, and F arrangements are in use in passenger cars. The I-head valve, or overhead-valve, arrangement is the most common; more and more engine manufacturers are changing from the L-head to the overhead-valve engine (usually accompanied with a change from an in-line to a V-8). One manufacturer (Willys-Overland Motors) is supplying a passenger car with an F-head engine.

1. L-head engine. In the L-head type of valve arrangement (Figs. 3-2 and 3-3) the intake and exhaust valves are located side
by side, with all valves for the engine in one line (except for the V-8 L-head engine, in which they would be in two lines as shown in Fig. 5-7). This arrangement permits the use of a single camshaft to operate all valves. Since all valve mechanisms are located in the cylinder block, removal of the cylinder head for major overhaul of the engine is relatively easy. Turbulence is reasonably good in this type of engine cylinder, since the shape of the combustion chamber helps set up a whirling motion of the charge as it enters and is compressed. The L-head engine, however, is not particularly adaptable to higher-compression engines. One reason for this is that the valves require a certain minimum amount of space to move up into when they open. This space, plus the minimum clearance required above the top of the piston, determines the clearance volume, or the volume in the combustion chamber when the piston is at TDC (top dead center). Since this volume cannot be decreased below a certain value, there are limitations to the top compression ratios that can be built into the engine. [Remember that compression ratio equals volume with piston at BDC (bottom dead center) divided by clearance volume.] On the other hand, the overhead-valve engine, which is of a more compact design, can be adapted to higher compression ratios, as explained in the following paragraphs.

2. I-head engine. In the I-head engine, usually known as the valve-in-head, or overhead-valve, engine, the valves are carried in the cylinder head. In in-line engines the overhead valves are in a single row as shown in Figs. 5-2, 5-3, and 6-8. In V-8 engines with overhead valves, the valves may be arranged in a single row in each bank as shown in Fig. 5-5, or they may be placed in a double row in each bank as shown in Fig. 5-6. Regardless of arrangement, a single camshaft is used to actuate all valves, with valve lifters, push rods, and rocker arms carrying motion from the cams to the valves.

The overhead-valve engine is somewhat more complex than the L-head engine, since the valve mechanism is more complicated. Also, the head requires additional cooling since heat enters the head not only from the combustion chamber and spark plugs but also from the valves. However, the overhead-valve engine has come into more widespread use in recent years, particularly on the high-compression engines. In an engine with overhead valves it is practical to reduce the clearance volume a proportionally greater amount.
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than in an L-head engine. Thus, higher compression ratios are practical from the design standpoint. A study of the illustrations of the various L-head and I-head engines will show you that the method of grouping the valves and piston close together permits a greater reduction of the clearance volume. In some I-head engines there are pockets in the piston heads into which the valves can move when the valves are open with the piston at TDC. In some engines the actual clearance between the piston and valves is only a few thousandths of an inch.

NOTE: Some types of commercial engines, racing engines, and aircraft engines with I-heads use an overhead camshaft. The camshaft is located above the cylinder head and is driven by a chain or by gears from the crankshaft. This arrangement shortens the valve train (between camshaft and valve) so that less variation will creep in due to heat expansion or motion lag in the system.

3. F-head engine. The F-head engine (Figs. 5-10 and 7-43) is, in a sense, a combination of an L-head and an I-head engine: one set of valves (intake, for example) is in the head and the other set is in the block. The F-head engine can be so designed as to utilize a single camshaft, with the in-head valves operated by push rods and rocker arms while the in-block valves are operated directly from the camshaft through valve lifters. It could also be designed to use two camshafts, one being an overhead camshaft to operate the in-head valves.

4. V-8 valve arrangements. The V-8 engine may use L heads or I heads, as has already been mentioned. Figures 5-5 and 5-6 illustrate V-8 engines with overhead valves while Fig. 5-7 shows a V-8 engine with L heads. In each, the valves are actuated by a camshaft placed directly above the crankshaft in the block. In the L-head V-8 engine the camshaft operates the valves directly through valve lifters. In the I-head V-8 engine the valves are operated from the camshaft through valve lifters, push rods, and rocker arms. The newer V-8 engines are all I-head.

§84. Cooling Engines are classified as air-cooled or liquid-cooled. All present-day American cars are liquid-cooled, although in the past air-cooled engines (such as the Franklin) were used in passenger cars. In the air-cooled engine the cylinders are separated so that air can circulate between them. Each cylinder barrel is [137]
equipped with metal fins that help to radiate the heat and thus prevent excessive operating temperatures. The liquid-cooled engine uses water as the cooling medium, circulating it between the water jackets that surround the cylinders and combustion chambers and a cooling radiator (§63).

**CHECK YOUR PROGRESS**

**Progress Quiz 9**

Here is your opportunity to check up on how well you are remembering the material covered in the past few pages. If some of the questions stump you, go back and reread the pages that will give you the answer.

**Completing the Sentences**

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. The smallest number of cylinders in use in American automobile engines is
   - two
   - four
   - six
   - eight

2. The six-cylinder crankshaft is usually supported on
   - one or two bearings
   - two or three bearings
   - three or four bearings
   - four or five bearings

3. The most common type of V engine is the
   - V-4
   - V-6
   - V-8
   - V-12

4. The crankpins on the six-cylinder crankshaft are arranged in pairs
   - 90 degrees apart
   - 120 degrees apart
   - 180 degrees apart

5. One firing order for six-cylinder engines is
   - 1-3-2-6-5-4
   - 1-4-3-6-2-5
   - 1-5-3-2-4-6

6. The crankshaft on the V-8 engine has
   - two
   - three
   - four
   - six

7. The engine in which the cylinders are arranged like the spokes of a wheel is a
   - spoke engine
   - radial engine
   - in-line engine
   - V-type engine

8. Four valve arrangements are
   - L, I, F, E
   - L, I, F, T
   - T, I, M, F

9. The type of engine using valve lifters, push rods, and rocker arms is a
   - V type
   - I-head type
   - L-head type
   - T-head type

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In regard to cooling, engines are classified as liquid-cooled and oil-cooled, water-cooled and liquid-cooled, and air-cooled.

§85 Classification by cycles Internal-combustion engines are classified according to whether they operate on the two-cycle or the four-cycle principle. We have already discussed the four-cycle (or four-stroke-cycle) engine in §52. In the four-cycle engine, the cycle of events requires four piston strokes (intake, compression, power, and exhaust). In the two-cycle engine, the intake and compression strokes, and the power and exhaust strokes, are so combined as to permit the engine to produce a power stroke every two piston strokes, or every crankshaft rotation.

The piston acts as a valve, clearing valve ports in the cylinder walls as it nears BDC (Fig. 5-11). A fresh charge of air-fuel mixture is forced into the cylinder under pressure as the intake port is cleared. The pressure on the incoming air-fuel mixture is produced by a supercharger, or blower. The shape of the piston head causes the incoming charge to be deflected upward; it rushes to the top of the cylinder, thereby forcing the burned gases out through the exhaust port. Then, as the piston starts upward, it moves past the valve ports and seals the charge in the cylinder (Fig. 5-12). When the piston nears TDC, the charge is ignited in the usual manner by an electric spark at the spark-plug gap. The piston is
FIG. 5-13. Two-stroke-cycle diesel engine with an exhaust valve in the top of the cylinder. (*Detroit Diesel Engine Division of General Motors Corporation*)

1. Exhaust-valve rocker
2. Exhaust valve
3. Cylinder head
4. Exhaust manifold
5. Blower
6. Piston
7. Air box
8. Cooling-water passage
9. Port admitting air to cylinder
10. Cylinder liner
11. Cylinder block
12. Camshaft
13. Push rod
14. Rocker cover
15. Hand-hole cover
16. Water manifold

forced downward by the pressure of the burning mixture, and as it clears the intake and exhaust ports, a fresh charge enters and the burned gases are exhausted from the cylinder, as already described.

Note that the two-cycle engine produces a power stroke every crankshaft revolution, while the four-cycle engine requires two crankshaft revolutions for each power stroke. From this, you might conclude that a two-cycle engine could produce twice as much...
horsepower as a four-cycle engine of the same size, running at the same speed. However, this is not true. In the first place, some power is used to drive the blower that forces the air-fuel charge into the cylinder under pressure. In addition, perfect clearing of the burned gases from the cylinder is not achieved. There is also apt to be less charge entering than would be the case in the four-cycle engine. This is because the intake-valve port is open a much shorter period of time (as compared with the four-cycle engine). These factors reduce the amount of power that the engine can produce under given conditions.

A variation of the two-cycle engine makes use of an exhaust valve in the top of the cylinder (Fig. 5-13). As the piston nears BDC and clears the intake ports, the exhaust valve opens. The charging air is forced in under pressure, causing the burned gases to be forced from the cylinder through the exhaust-valve port. Then, as the piston starts up on the compression stroke, the intake ports are sealed off and the exhaust valve closes. The engine shown in Fig. 5-13 is a two-cycle diesel engine.

§86. Classification by fuel Internal-combustion engines can be classified according to the fuel they use. Automobile engines use gasoline. Some bus and truck engines of the four-cycle Otto type are equipped to use liquefied petroleum gas (LPG). Both gasoline and LPG are discussed in Chap. 8, “Automotive-engine Fuels and Fuel Systems.” A third type of fuel, fuel oil (or diesel fuel oil), is used in diesel engines. The diesel engine may be of the two-cycle or of the four-cycle type.

§87. Diesel engine The diesel engine operates on a somewhat different principle from the Otto-cycle engine, since the fuel is not mixed with the air entering the cylinder during the intake stroke. Air alone is compressed during the compression stroke, and the fuel is injected or sprayed into the cylinder at the end of the compression stroke. In diesel engines the compression ratios used are as high as 15:1 and provide pressures of about 500 psi (pounds per square inch) at the end of the compression stroke. When air is rapidly compressed to this pressure, it will be heated to a temperature of approximately 1000°F. This temperature is high enough to ignite spontaneously fuel oil injected or sprayed into the cylinder at this instant. The combustion of the oil can be controlled by
the speed with which the oil is introduced into the cylinder. Thus in the diesel engine the combustion is not a rapid burning of the fuel already present in the cylinder, as in the gasoline engine, but a slower burning that produces an even increase of pressure. This allows a more complete utilization of the energy in the fuel.

The four-stroke-cycle diesel engine requires four piston strokes
for each power stroke, as in the gasoline engine. These are intake, compression, power, and exhaust (Fig. 5-14). On the intake stroke the piston moves downward and pulls air into the cylinder past the intake valve. The intake valve closes as the compression stroke starts, and the air is compressed. At the end of the compression stroke the fuel is sprayed or injected into the combustion chamber, where it burns and creates high pressure. The piston is pushed down during the power stroke, at the end of which the exhaust valve opens to allow the burned gases to escape during the exhaust stroke.

In the two-stroke-cycle diesel engine a blower or rotary-type pump is used to create an initial pressure on the incoming air (Fig. 5-15). The piston serves as a valve or valves, clearing on its
downward stroke the ports through which the air enters and ex­haust gases escape. The type shown in Fig. 5-15 has an exhaust valve in the top of the cylinder, through which the burned gases are forced when the valve opens and the piston clears the intake ports (Fig. 5-13). As the piston moves upward, it passes the intake ports, and the exhaust valve closes. The air thus trapped in the
cylinder is highly compressed, the fuel is sprayed into the cylinder, and the power stroke takes place.

The fuel oil used in diesel engines does not burn rapidly unless it is finely atomized and thoroughly mixed with the compressed air. To assure adequate mixing, particularly in the smaller engines, various shapes of combustion chamber are used. These special shapes produce turbulence, or whirling, of the compressed air; this
improves the mixing of the fuel with the air during the combustion process.

Figure 5-16 illustrates the turbulence chamber used in Hercules diesel engines. Toward the end of the compression stroke the air is being forced into the turbulence chamber at high velocity, so that it is whirling rapidly. The fuel is injected into the turbulent air and this produces a thorough mixing of the fuel and the air, so that better combustion is attained.

![Figure 5-17. Mack diesel-engine energy cell. (Mack Trucks, Inc.)](image)

Figure 5-17 illustrates the Mack diesel-engine energy cell. The combustion chamber in this engine is shaped like a figure 8 with the injection nozzle opposing the energy cell. When the injection of fuel starts at the end of the compression stroke, part of the fuel is sprayed into the energy cell. The combustion chamber and the energy cell are both filled with highly compressed air. The fuel in the combustion chamber and in the energy cell begins to burn. As the piston is forced downward, the fuel and the air in the energy cell stream out at terrific velocity, setting up a strong turbulence in the combustion chamber. This ensures good combustion of the fuel with a controlled rate of burning that provides
an even, strong thrust on the piston without sudden and excessive pressure.

§88. Gas turbine The gas turbine that is now making its appearance as an automotive power plant consists, in essence, of two sections: a gasifier section and a power section (Fig. 5-18). The compressor has a rotor with a series of blades around its outer edge. As it rotates, air between the blades is carried around and thrown out by centrifugal force. This action supplies the burner with air at relatively high pressure. Fuel is sprayed into the compressed air. The fuel used can be gasoline, kerosene, or oil. As the fuel burns, a further increase in pressure results. The high-pressure high-temperature gas then passes through the gasifier-nozzle diaphragm. A series of stationary blades directs this high-pressure gas against a series of curved blades on the outer edge of the gasifier-turbine rotor. The resulting high pressure against the curved blades causes the gasifier-turbine rotor to spin at high speed. Since the gasifier-turbine rotor

![Diagram of gas turbine](image-url)
and the compressor rotor are mounted on the same shaft, the compressor rotor is also spun at high speed. This action continues to supply the burner with an ample supply of compressed air. The action continues as long as fuel is supplied to the burner.

After the high-pressure high-temperature gas leaves the gasifier section, it enters the power turbine. Here it strikes another series of stationary curved blades which directs it against a series of curved blades on the outer edge of the power-turbine rotor. The resulting high pressure against these rotor blades spins the rotor at high speed. In some models, the turbine may turn faster than 30,000 rpm. This high rpm is reduced by a series of transmission gears before the power is applied to the vehicle wheels.

§89. Free-piston engine Instead of a compressor-burner section, some engineers propose the use of a free-piston engine to supply high-pressure gas to drive a power turbine. The free-piston engine (Figs. 5-19 to 5-22) contains a pair of piston assemblies that oppose each other in a cylinder. Each piston assembly consists of a relatively small power piston attached to a relatively large bounce piston. The principle of operation is this: the piston assemblies are driven in (or bounced in) to compress air between the power pistons. As the pistons complete their inward travel, fuel is injected into the combustion space between the pistons. At this instant, the engine functions like a diesel engine (see §87). The heat of com-
pression ignites the fuel and combustion takes place. The resulting high pressure drives the pistons apart. They clear exhaust and intake ports and fresh air enters the power cylinder. At the same time, the air back of the bounce pistons is compressed (in the bounce cylinders) and this pressure drives the piston assemblies toward each other again. The gas as it exhausts from the power cylinder still has sufficient pressure to drive a turbine (Fig. 5-22). This action continues as long as fuel is supplied to the engine.

The valves in the compression cylinders are spring loaded to open against pressure. Thus, when the bounce pistons are moving inward, air is compressed ahead of them and this forces the intake valves to open and admit this air to the air box. When the bounce pistons are moving outward, the pressure in the compression cylinders drops below atmospheric, and atmospheric pressure forces the intake valves open to admit air into the compression cylinders.

**CHECK YOUR PROGRESS**

**Progress Quiz 10**

Here is your progress quiz on the last half of Chap. 5. Find out how well the material you have just read has "stuck with you" by answering the questions below. If you are not sure about some of the answers, reread the past few pages and try the questions again.
Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete the sentence correctly.

1. There are two classifications of engine by cycle, one-cycle, two-cycle, three-cycle, four-cycle.

2. The two-cycle engine produces a power stroke every crankshaft revolution, every two crankshaft revolutions, every four crankshaft revolutions.

3. The two-cycle engine has valve ports in the cylinder walls, piston rings.

4. For fuel the diesel engine uses LPG, gasoline, fuel oil.

5. In the diesel engine, fuel is injected into the cylinder at the end of the intake, compression, power, exhaust stroke.

6. In the diesel engine rapid compression of the air to about 500 psi will produce an air temperature of about 100°F, 1000°F, 2000°F, 5000°F.

7. Compression ratios in the diesel engine are as high as 5:1, 10:1, 15:1.

8. The diesel engine is, compared with the gasoline engine, easier to start, about as easy to start, harder to start.

CHAPTER CHECKUP

Note: Since the following is a chapter review test, you should review the chapter before taking the test.

You have been making real progress in your studies of the automobile engine, and have covered in the past five chapters a great deal of necessary background information. This information will be of considerable help to you as you move on to the latter parts of the book which deal with such practical things as details of engine construction and servicing and maintenance procedures. To give you a chance to check up on your success in remembering the facts discussed in this chapter the following questions have been included.

Picking Out the Right Answer

Several answers are given for each of the questions below. Read each question carefully and decide which answer is the correct one. Then write down the question, with the right answer, in your notebook.
Automotive Engines

1. How many cylinders are used in American automobile engines?
   4, 8, and 12  4, 6, and 8  6, 8, and 12

2. What are the two most common valve arrangements in automotive engines?
   L-head and I-head  L-head and F-head

3. Which type of valve arrangement requires the use of rocker arms?
   I-head  T-head  L-head

4. Automobile manufacturers are swinging to what type of engine?
   L-head V-8  I-head V-8  L-head in-line  radial

5. What are three ways to classify automobile engines?
   by valve number, cylinder arrangement, and valve arrangement
   by cylinder ports, cylinder arrangement, and valve arrangement
   by number of cylinders, cylinder arrangement, and valve arrangement

Lists

In the following, you are asked to write down certain lists and also to make a couple of simple drawings. Write and draw in your notebook. As you write or draw, you are helping yourself remember, since the action of writing or drawing helps to fix the information in your mind. More than that, you are putting down the information in your notebook where you can quickly refer to it.

1. List the various cylinder arrangements given in the book.
2. List the various valve arrangements given in the book.
3. List differences between the two-cycle and the four-cycle engines.
4. List three types of internal-combustion-engine fuel.
5. List differences between Otto-cycle and diesel engines.
6. Make simple drawings (copy them from the book if you wish) of the I-head and the L-head valve arrangements.

Suggestions for Further Study

If you would like to learn more about diesel engines, you can probably find books about them in your local public or school library. In addition, your high school science or automotive mechanics teacher may have books or manuals on diesel engines. If a diesel-engine manufacturer has a branch or a dealership in your locality, you can probably find out a good deal about diesel engines from the people in the branch or dealership. Another place you might check would be the local truck or bus operator who is using diesel engines. You may also be able to obtain diesel-engine manuals for a modest sum by writing to the engine manufacturer. In writing, you should list specific engine numbers and explain why you need the manuals.
6: Engine construction and components

IN THIS chapter we consider in greater detail the construction of automotive engines with emphasis on the engine cylinder block and cylinder head. The next chapter (Chap. 7), which describes pistons and valve mechanisms, completes the analysis of construction details of the different automotive engines. These chapters supply you with the background information that will permit you to move on to the trouble-shooting and servicing sections in the latter part of the book.

§90. Engine construction
Thus far the engine has been considered from the operational point of view. We have seen how the mixture of fuel and air is compounded by the carburetor, drawn into the cylinders, compressed, ignited, and burned. We have noted that this combustion process creates a high pressure that forces the piston down, rotates the crankshaft, and thus moves the vehicle. The air-fuel mixture is admitted to the cylinder by the opening of the intake valve; the burned gases are exhausted through the exhaust-valve port when the exhaust valve opens. Let us now look at the engine from the constructional point of view and examine its various component parts.

§91. Engine cylinder block
The engine cylinder block (Figs. 6-1 and 6-2) forms the basic framework of the engine, and other engine parts are assembled into or attached to it. In automotive engines the cylinder block is usually cast in one piece from gray iron. The casting is normally rather intricate, since it contains not only the engine cylinders but the water jackets that surround them. In addition, passageways are provided to accommodate the valve mechanisms and, on L-head engines, the openings for the intake and exhaust ports. In L-head engines the intake-valve seats are
part of the cylinder block, but in many engines the exhaust-valve seats are made of special metal rings (Fig. 7-35) inserted into recesses in the block. Such exhaust-valve-seat inserts are used because they can better withstand the high temperatures of the burned gases passing through the exhaust ports. The lower part of the cylinder block contains the supporting bearings for the engine crankshaft (called the main bearings) so that the crankshaft, in

Fig. 6-1. Cylinder block of six-cylinder L-head in-line engine showing intake and exhaust valves of two cylinders removed. The screw driver is under a valve spring, prying it up and out. If a spring is removed in this manner, care must be used to keep it from flying and hurting someone. (Studebaker-Packard Corporation)

effect, is suspended from the bottom of the block (Figs. 6-2 and 6-3).

The upper halves of the crankshaft, or main, bearings are assembled directly into half-round sections in the cylinder block, while the lower halves of the main bearings are held in place by bearing caps that are attached to the cylinder block by bolts (Fig. 6-4).

The camshaft is supported in the cylinder block by bearings that fit into machined holes in the block (Figs. 3-11 and 6-3).
Fig. 6-2. (a) Top and (b) bottom views of a cylinder block from a V-8 overhead-valve engine. (De Soto Division of Chrysler Corporation)
Various other parts are attached to the cylinder block. The oil pan (Fig. 6-11) attaches to the lower part of the block to enclose and complete the crankcase. The oil pan serves as a reservoir and cooling device for the engine lubricating oil. The intake and exhaust manifolds, on L-head in-line engines, are attached to the side of the block (Fig. 6-5). On L-head V-8 engines the intake manifold is located in the "V" between the two banks of cylinders and is attached to each bank of cylinders in the block. The L-head V-8 engine has two exhaust manifolds, one on the outside of each bank. The manifolds are essentially passageways, or pipes, through which the air-fuel mixture can flow from the carburetor to the

![Diagram of L-head engine cylinder block showing crankshaft and camshaft bearings.](image)

Fig. 6-3. Upside-down view of L-head engine cylinder block showing crankshaft and camshaft bearings. This engine has three crankshaft and three camshaft bearings; other engines may have more. (American Motors Corporation)

On I-head engines the manifolds are attached to the cylinder head. The I-head V-8 engine has the intake manifold located between the two banks of cylinders and attached to the two cylinder heads. On the I-head V-8 engine there are two exhaust manifolds, attached to the outsides of the two cylinder heads. You can see the mounting studs or bolt holes for mounting the manifolds on an I-head V-8 engine cylinder head in Fig. 6-9.
 cylinders, and through which the burned gases can be conducted from the cylinders.

The water pump is attached to the front of the block (Fig. 6-6). The water pump is driven by a belt from a pulley on the engine crankshaft, and in operation it pumps water from the bottom of the radiator into the water jackets of the engine block. Also attached to the front of the block is a cover that encloses the timing gears or sprockets and chain on the crankshaft and camshaft. The camshaft is driven from the crankshaft through these gears or sprockets and chain.

The rear end of the crankshaft has the flywheel mounted on it (Fig. 3-16); the flywheel and clutch are enclosed in the clutch housing, which is attached to the rear of the block.

The ignition distributor is often mounted on the side of the block with the drive shaft extending into the engine to the camshaft. The distributor is driven off the camshaft by a set of gears. Usually these gears also drive the oil pump, which is mounted in

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**Fig. 6-4.** Crankshaft and related parts for a V-8 engine. (Ford Division of Ford Motor Company)
FIG. 6-5. Installation of intake and exhaust manifolds on the cylinder block of a typical L-head engine.

FIG. 6-6. Installation of the water pump on the cylinder block of a typical engine.
Chapter 9: Engine Construction and Components

§92. Cylinder-block materials and machining

In addition to gray iron, other materials have been used for cylinder blocks. Certain metals, such as nickel or chromium, may be mixed, or alloyed, with the iron to form denser, tougher, longer-wearing castings. Cylinder blocks have also been made of aluminum, since this material is approximately as strong as cast iron and is considerably lighter. Where aluminum cylinder blocks are used, cylinder liners consisting of thin sleeves of cast iron or steel are usually installed in the cylinders, since these materials withstand wear better than aluminum does.

The cylinder-block casting is made by pouring molten metal into a mold usually made of sand. The various openings in the casting, such as the water jackets, valve ports, and water passages, are obtained by placing sand cores of the proper size and shape in the mold before the metal is poured. These cores, as well as the mold, are broken up when the metal has cooled and hardened. The casting is then subject to a series of machining operations to bring the cylinders to size, smooth the top of the block, and prepare the casting for the attachment and installation of the crankshaft and other components.
camshaft bearings, manifolds, oil pan, cylinder head, and so forth. Of major importance is the machining of the cylinders, since they must be of proper dimensions, symmetrical, and nearly mirror smooth. Tool-steel cutters or reamers and grinding stones, or hones, are used in the cylinder-machining process.

§93. **Cylinder heads** The cylinder heads are usually cast in one piece, called the cylinder head, in a manner similar to the way the cylinder block is cast. Iron alloyed with various other metals is often used, the alloys adding such desirable characteristics as strength, toughness, and heat conductivity. Aluminum alloy is also used, since this material combines lightness with a high degree of heat conductivity. The latter characteristic is especially desirable because it assures that the heat of combustion will be rapidly carried away, preventing the formation of “hot spots,” which would cause preignition, or premature ignition, of the air-fuel mixture in the cylinder. Two types of cylinder head are in general use, the L-head type (Figs. 5-7 and 6-7) and the I-head, or overhead-valve, type (Figs. 6-8 and 6-9).

1. **L-head type of cylinder head.** The L-head type of cylinder head is a comparatively simple casting. It contains water jackets for cooling, which in the assembled engine are connected through openings to the water jackets in the cylinder block. Spark-plug openings are provided, along with pockets into which the valves operate (Fig. 6-7). Each pocket also serves as the top of the combustion chamber; the air-fuel mixture is compressed into the pocket as the piston reaches the end of the compression stroke. It will be noted that the pockets have a rather complex curved surface. This shape has been carefully designed so that the air-fuel mixture in being compressed into the pocket will be subjected to violent whirling, or turbulence. Turbulence assures a more uniform mixing of the fuel and air; this improves the combustion...
process and helps prevent local high-pressure, high-temperature areas that would cause detonation, or knocking.

2. I-head type of cylinder head. The I-head, or overhead-valve, type of cylinder head not only contains water jackets for cooling, spark-plug openings, and valve and combustion-chamber pockets,

![Fig. 6-8. Sectional view of I-head, or overhead-valve, type of engine. Note how the spark plugs, valves, valve mechanism, and manifolds are assembled to the head. (Buick Motor Division of General Motors Corporation)](image)

but also contains and supports the valves and valve-operating mechanisms (Figs. 6-8 and 6-9). It is obvious that this type of head is more complex than the L head. However, as we previously mentioned (§83), more and more automobile manufacturers are adopting the I-head engine (V-8 type) since this engine seems to offer the greater opportunity for increasing compression ratios. The I head, since it does carry the intake and exhaust valves, must have
Oil RETURN TO CRANKCASE HOLES

ROCKER BRACKET AND CYLINDER
HEAD BOLT HOLES
CORE HOLE PLUGS
EXHAUST VALVE GUIDES
SPARK PLUG HOLE
INTAKE VALVE GUIDES
ROCKER SUPPORT BRACKET ALIGNMENT HOLES

(a)

EXHAUST MANIFOLD MOUNTING STUDS
EXHAUST PORTS
SPARK PLUG HOLES
INTAKE VALVE GUIDES
OIL PASSAGE TO ROCKER ARMS
PUSH BOLT HOLES
WATER PASSAGE HOLES
WATER OUTLETS TO INTAKE MANIFOLD

(b)

Fig. 6-9. (a) Top and (b) bottom views of cylinder head from a V-8 overhead-valve engine. (De Soto Division of Chrysler Corporation)

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additional means of cooling. If you will examine the various engine illustrations in the book, you will note that the water jackets in the I heads are larger than those in the L heads.

§ 94. Gaskets. The joint between the cylinder block and the cylinder head must be tight and able to withstand the pressure and heat developed in the cylinders. It is not practical to machine the cylinder-block and cylinder-head surfaces flat and smooth enough to produce such a tight joint. Consequently, gaskets (Fig. 6-10) are used. Head gaskets are made of thin, soft-metal, or asbestos-and-metal sheets, cut out to conform with all water, cylinder, valve, and head-bolt openings in the block and the head. When they are placed in position between the block and the head, tightening of the head bolts squeezes the soft metal between the head and the
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cylinder block so that the joint is effectively sealed. Head gaskets are made of several materials. They may be of plain copper, of two thin copper sheets with asbestos between, of steel-and-copper sheets with asbestos between, or of crimped steel. In the last type the crimping is flattened out as the head bolts are tightened; this produces the sealing effect. As a rule, gaskets can be used only once. If removed and reinstalled, they cannot be further compressed to provide an effective seal. Gaskets are also used to seal joints between other engine parts, for example, between the oil pan and cylinder block and between the cylinder block and manifolds.

§95. Oil pan The oil pan, usually formed of pressed steel (Fig. 6-11), provides a sump, or reservoir, for the engine lubricating oil. The oil pan holds from 6 to 9 quarts of oil, depending on the engine. The oil pump in the lubricating system pumps oil from the pan to all working parts. The oil drains off and runs down into the pan, where the oil pump draws it up and sends it back through the lubricating system. The oil pan is attached to the underside of the cylinder block, with gaskets placed between the pan and the [162]
block to produce a tight seal. On many engines an oil strainer or filter is placed in the oil pan, and the oil must pass through it before entering the oil pump. The lubricating system, which includes the pump, strainer, and oil lines, is considered in detail in Chap. 10, "Automotive Lubricants and Lubricating System."

§96. Exhaust manifold The exhaust manifold (Fig. 6-12) is essentially a tube for carrying the burned gases away from the engine cylinders. On L-head in-line engines the exhaust manifold is bolted to the side of the cylinder block (Fig. 6-5). On I-head in-line engines the exhaust manifold is bolted to the side of the cylinder head (Fig. 6-8). On V-8 engines there are two exhaust manifolds, one for each bank of cylinders. The exhaust manifolds are bolted to the outsides of the two banks (to the block in L-head engines and to the cylinder heads in I-head engines). They are interconnected by a crossover pipe, and they exhaust through a common muffler and tail pipe. The exhaust manifold normally is tied in closely with the intake manifold. The purpose of this is to provide a certain amount of heat transfers from the exhaust manifold to the intake manifold during engine warm-up. This improves vaporization of the fuel and provides better initial engine performance just after the engine has been started (see §99).
Automotive Engines

§97. Exhaust system

As has already been mentioned, the exhaust system consists of the exhaust manifold, exhaust pipe, muffler, and tail pipe (Fig. 3-24). In-line engines normally have a single exhaust manifold and one exhaust pipe, one muffler, and one tail pipe. V-8 engines usually have two exhaust manifolds as mentioned in the previous section. The two exhaust manifolds are tied together by a crossover pipe to a common muffler and tail pipe. Some engines have two separate exhaust systems as described below.

1. Muffler. The muffler (Fig. 6-13) is located under the body and is connected into the exhaust line between the exhaust pipe and the tail pipe. It is designed to muffle the noise of the engine exhaust by gradually reducing the pressure of the exhaust gases as they leave the engine cylinders. Mufflers usually consist of a series of holes, passages, and resonance chambers that absorb and damp out the high-pressure surges introduced into the exhaust system when the exhaust valves open.

2. Dual exhaust system. The dual exhaust system as used on one V-8 engine is shown in Fig. 6-14. Each exhaust manifold exhausts into a separate exhaust pipe which, in turn, exhausts into its own muffler, resonator, and tail pipe. The resonators further reduce exhaust noises. They are, in effect, secondary mufflers. The use of two separate exhaust systems, one for each bank of cylinders, improves the "breathing" ability of the engine, allowing it to exhaust
Fig. 6.14. Dual exhaust system used with one V-8 engine, showing various attaching and supporting brackets.

(Cadillac Motor Car Division of General Motors Corporation)
more freely. This tends to reduce the amount of exhaust gas left in the cylinder at the end of the exhaust stroke, and thus improves engine performance.

§98. Intake manifold Essentially, the intake manifold (Fig. 6-15) is a tube for carrying the air-fuel mixture from the carburetor to

![Intake manifold](image)

Fig. 6-15. Intake manifolds for (a) an L-head in-line six-cylinder engine and for (b) an I-head V-8 engine. The white arrows in (b) show the air-fuel-mixture flow between the two barrels of the carburetor and the eight cylinders in the engine. The central passage connects between the two exhaust manifolds; exhaust gas flows through this passage during engine warm-up. (Studebaker Division of Studebaker-Packard Corporation)
Engine Construction and Components

the engine intake-valve ports. The carburetor is normally mounted in a central position on the intake manifold. The intake manifold is attached to the side of the cylinder block on L-head in-line engines, and to the side of the cylinder head on 1-head in-line engines. On 1-head V-8 engines the intake manifold is situated between the two banks of cylinders and is attached to each bank of cylinders in the block. On 1-head V-8 engines the intake manifold is also situated between the two banks of cylinders, but it is attached to the insides of the two cylinder heads. Figures 6-9 shows the intake ports on an L-head from a V-8 engine over which the intake manifold is attached. A gasket is used between the intake manifold and the mating surface of the block or head. Figure 6-15 (bottom) shows an intake manifold from an L-head V-8 engine. A two-barrel carburetor mounts on the intake manifold, each barrel supplying four of the eight cylinders with air-fuel mixture. The arrows indicate the pattern of air-fuel distribution from the two carburetor barrels to the eight cylinders of the engine. Note that each carburetor barrel supplies four cylinders. This arrangement permits a very even distribution of air-fuel mixture so that each cylinder receives its “share” and no cylinder is starved.

§99. Manifold heat control

On in-line engines the intake manifold is mounted close to and above the exhaust manifold. This causes heat transfer from the exhaust manifold to the intake manifold, which somewhat preheats the air-fuel mixture. This assures good vaporization of the fuel. During initial warm-up, just after the engine has been started, it is desirable to introduce additional heat into the intake manifold so that fuel vaporization will be improved; this permits better engine performance during warm-up. To get additional heat into the intake manifold, there is a close tie-in between the two manifolds at a point just below the carburetor (on in-line engines). At this place a thermostatically controlled butterfly valve, called the manifold heat-control valve, is built into the exhaust manifold.

Note: V-8 engines have a somewhat different arrangement, as will be described following the explanation of the in-line arrangement below.

1 A two-barrel carburetor is, in effect, two separate carburetors assembled together. Each barrel has its own venturi, throttle valve, and fuel nozzles. See Chap. 8, “Automotive-engine Fuels and Fuel Systems,” for more information on carburetors.
The thermostat is a coiled spring made up of two strips of different metals welded together. These two metals expand at different rates as temperature increases; this causes the thermostat to wind up. When the temperature decreases, the thermostat unwinds. This latter condition causes the butterfly valve to assume the position shown in Fig. 6-16 when the engine is cold. Thus, when the engine first starts, the hot exhaust gases circulate around through the jacket surrounding the intake manifold, quickly heating the intake manifold and assuring adequate vaporization of the fuel during the warm-up period of operation. An end view of this position is shown in the left-hand illustration in Fig. 6-17.

As soon as the engine begins to heat up, the thermostat, becoming hot, winds up, causing the heat-control valve to rotate into the position shown to the right in Fig. 6-17. This shields off the jacket surrounding the intake manifold, preventing any further flow of hot exhaust gases through it. Without such an arrangement, too much heat would be introduced into the intake manifold, producing an excessive expansion of the air-fuel mixture so that an

Fig. 6-16. Intake and exhaust manifolds for a six-cylinder engine. (Ford Division of Ford Motor Company)
insufficient quantity (by weight) would reach the engine cylinders (that is, volumetric efficiency would be too low).

In the V-8 engine the intake manifold is between the two banks of cylinders, while the two exhaust manifolds are mounted to the outsides of the two banks. In order to achieve additional heating of the intake manifold during engine warm-up, a different arrange-

Fig. 6-17. The two extreme positions, in the exhaust manifold, of the manifold heat-control valve, which controls the flow of exhaust gases through the intake-manifold jacket. (Chevrolet Motor Division of General Motors Corporation)

ment from that used in in-line engines is required. In the V-8 the intake manifold contains a special passage (shown in the center of the manifold illustrated in Fig. 6-15) that carries exhaust gas from one exhaust manifold to the other when a thermostatically controlled valve in one of the exhaust manifolds is closed. The exhaust gas is shunted through this special passage in the intake manifold, passing under the carburetor mounting pad. Extra heat is thus introduced into the intake manifold. Then, when the engine warms up, the thermostatically controlled valve opens to permit normal exhaust-
gas discharge through both exhaust manifolds; the exhaust gases no longer pass through the intake manifold passage.

CHECK YOUR PROGRESS

Progress Quiz II

Once more you have the chance to stop and find out how well you have been absorbing the material you have been reading on the engine. If anything in the quiz stumps you, turn back in the book and reread the pages to find the answer.

Correcting Parts List

The purpose of this exercise is to help you spot unrelated parts in a list. For example, in the list, head, oil pump, water pump, main bearing caps, differential housing, clutch housing, the only part that is not attached to the cylinder block is the differential housing. This part, therefore, does not belong.

In each of the lists, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. Parts in the engine exhaust system include the exhaust manifold, muffler, oil pan, heat-control valve, thermostat.
2. Parts attached to the cylinder block include the clutch housing, cylinder head, oil pan, water pump, timing cover, propeller shaft.
3. Openings in the cylinder block include the water jackets, cylinder bores, stud holes, water passages, connecting rods.
4. Parts of the engine lubricating system include the oil pan, pump, intake manifold, strainer, oil lines.
5. Parts driven off the camshaft include the oil pump, water pump, fuel pump, ignition distributor.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete the sentence correctly.

1. The oil pan, crankshaft, water pump, and cylinder head are attached to the car frame engine cylinder block manifolds.
2. The fastening device that is threaded at both ends is called a bolt stud screw lag.
3. The flat pieces that are put between the engine block and those [170]
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parts attached to the engine block are called

4. The water pump is attached to the

front  back  top

side

5. The most complicated head, considering the number of parts attached to it, is the

I head  L head  T head

V head

6. The part that carries the burned gases from the engine cylinders is called the

gas manifold  intake manifold  exhaust manifold  manifold control

7. The V-8 engine normally has

a single exhaust manifold  two exhaust manifolds  four exhaust manifolds

8. The device located in the exhaust system that reduces exhaust noise is called the

muffler  exhaust manifold  tail pipe

9. The V-8 engine normally has

a single intake manifold  two intake manifolds  four intake manifolds

10. The device in the exhaust system that causes increased heat transfer to the intake manifold during engine warm-up is called the

exhaust manifold  manifold heat-control valve  exhaust valve  distributor valve

§100. Crankshaft  The crankshaft is a one-piece casting or forging of heat-treated alloy steel of considerable mechanical strength (Figs. 3-16 and 6-18). The crankshaft, it will be remembered, takes the downward thrust of the piston during the power stroke. Pressure exerted by the pistons through the connecting rods against the crankpins on the crankshaft causes the shaft to rotate. This rotary motion is transmitted through the clutch and the power train to the car wheels. The problems of static and dynamic balance and torsional vibration must be considered in the design of a crankshaft. The cranks on the crankshaft, being offset from the center line of the shaft, naturally introduce an out-of-balance condition. This would set up serious vibration when the shaft rotates if it were not for counterweights that tend to place weights equal to the crank weights just opposite the cranks. The counterweights bring the crankshaft into practical balance. Crankshafts generally have drilled oil passages (Fig. 6-18) through which oil can flow from the main to the connecting-rod bearings (see §103 on bearing lubrication).

The flow of power from the engine is not smooth. While the power strokes from the various cylinders may overlap to some ex-

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tent in engines with six or more cylinders, there are periods when more power is being delivered to the crankshaft than at other times (Fig. 6-19). When more power is being delivered, the crankshaft tends to speed up; with less power, it tends to slow down. This would produce a roughly running engine if it were not for the fly-

Fig. 6-18. (a) Line drawing of a typical crankshaft showing names of parts and (b) cutaway view of a crankshaft for a V-8 engine. Note oil passages drilled to crankpins for lubricating rod bearings. (Johnson Bronze Company and Ford Motor Company)

wheel. The flywheel, a comparatively heavy wheel bolted to the rear end of the crankshaft, tends to resist any change of speed because of its inertia. Inertia, it will be recalled (§27), is the property that causes a body to resist any attempt to change its speed or direction of motion. The flywheel absorbs power during the intervals that the engine attempts to speed up. During the intervals when less power is being produced by the engine, the flywheel resists the engine's attempt to slow down by giving up part of its energy
of rotation. In addition to this function, the flywheel has gear teeth around its outer rim that mesh with the cranking-motor drive pinion when the cranking motor is operated to crank the engine for starting. The rear face of the flywheel also serves as the driving member of the engine clutch.

In the assembled engine the front end of the crankshaft carries three devices. One of these is a gear, or sprocket, that drives the camshaft (Fig. 7-27); the camshaft is driven at one-half the speed of the crankshaft. A second device is the vibration damper (see §101) which combats torsional vibration in the crankshaft. As a part of the vibration damper, there is a pulley with one or more
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V belts fit these grooves and drive the engine fan and water pump as well as the generator. There is an additional groove in the pulley on cars equipped with power steering; this additional groove is fitted with a V belt that drives the power-steering hydraulic pump. There may also be another groove for belt-driving the compressor in cars equipped with air conditioning.

§101. Vibration damper

The transmission of the power impulses to the crankshaft tends to set up torsional vibration in the crankshaft. When a piston moves down on the power stroke, it imparts considerable force to the shaft crank to which it is connected by the connecting rod. This force tends to twist the crankshaft; the shaft is actually twisted slightly. When the end of the power stroke is reached, the push against the crank is relieved so that the shaft, having been twisted, attempts to return to its original shape. It acts as a spring, however, and overrides this position, going beyond the original shape and twisting slightly in the opposite direction. It then returns, overriding in the other direction. This sets up an oscillating motion within the crankshaft, which is repeated every power stroke. If this torsional vibration were not controlled, succeeding power impulses would continue to add to the original oscillations of the shaft until, at certain speeds, the shaft might be broken by the excessive twisting it would undergo. To control this torsional vibration, devices variously called *vibration dampers*, *torsional balancers*, or *crankshaft-torque impulse neutralizers* are used. They are usually mounted to the front end of the crankshaft (Fig. 3-16) with the fan-belt pulley attached to them.

The vibration damper shown in Fig. 6-20 consists of a damper flywheel mounted to the fan-belt pulley by rubber cones. The fan-belt pulley is driven by the crankshaft and drives the damper flywheel in turn. The assembly acts in some respects like the shock absorbers used with automobile springs. The damper flywheel attempts to maintain a constant speed, and, by imposing a dragging force through the rubber cones and friction facing when the crankshaft attempts to oscillate, it damps out these oscillations in the crankshaft. For instance, if one part of the crankshaft is twisting in a forward direction because of torsional vibration, then it is moving faster than the damper (and the rest of the crankshaft). The damper imposes a drag that combats this speeding up. On the other
hand, if the crankshaft is untwisting, then the end is turning slower than the rest of the crankshaft. Here, the damper imposes its faster motion (it tends to turn uniformly) and thus combats the tendency for the crankshaft end to slow down. Note that the twisting and

untwisting (or torsional vibration) of the crankshaft is really of rather small dimensions. Yet unless some drag were imposed on it, the torsional vibration might build up sufficiently under certain conditions to cause actual breakage of the crankshaft, as has already

Fig. 6-20. (a) Sectional and (b) disassembled views of a typical vibration damper. (Studebaker-Packard Corporation)
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been noted. It would, at least, cause engine roughness unless checked by a vibration damper of some type.

Besides the type of damper illustrated in Fig. 6-20, dampers of a different design have been supplied which use a series of springs between the damper flywheel and the pulley. The springs act in a manner similar to the rubber cones.

In addition to the above method of eliminating torsional vibration, some engines have used a flywheel of the flexible, or damped, type. This type of flywheel has an outer rim attached to a hub on the crankshaft through flexible steel disks covered front and back by damping plate. Torsional vibration is absorbed by the plates.

§102. Engine bearings In the engine, there must be relative motion between the piston and connecting rod, between the connecting rod and the crankpin on the crankshaft, and between the crankshaft and the supporting bearings in the cylinder block. At all these points (as well as at other places in the engine) bearings must be installed (Figs. 6-21 and 6-22). The bearings are called sleeve
Fig. 6-22. Various bearings and bushings used in a typical engine. (Johnson Bronze Company)
1. Rocker-arm bushing
2. Valve-guide bushing
3. Distributor bushing, upper
4. Distributor bushing, lower
5. Piston-pin bushing
6. Camshaft bushing
7. Connecting-rod bearing
8. Clutch pilot bushing
9. Flanged main bearing
10. Starter bushing, drive end
11. Starter bushing, commutator end
12. Oil-pump bushing
13. Distributor thrust plate
14. Intermediate main bearing
15. Generator bushing
16. Connecting-rod bearing, floating type
17. Front main bearing
18. Camshaft thrust plate
19. Camshaft bushing
20. Fan thrust plate
21. Water-pump bushing, front
22. Water-pump bushing, rear
23. Piston-pin bushing

Fig. 6-23. Typical sleeve-type-bearing half. (Federal-Mogul Corporation)
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bearings because they are in the shape of a sleeve that fits around the rotating journal. Connecting-rod and crankshaft (or main) bearings are of the split or half type; that is, the bearing is split into two halves. Figure 6-23 illustrates a typical sleeve-type bearing half. With main bearings, the upper half is assembled into the counterbore in the cylinder block, while the lower half is held in place in the bearing cap. Figure 6-21 shows the lower bearing half and bearing cap. Figure 7-1 shows the bearings (Nos. 4 and 7) in disassembled and assembled views, used in a connecting rod. The big-end bearing is the split type, but the piston-pin bearing is not; it is the full-round or bushing type.

![Diagram of Sleeve-type Bearing](image)

**Fig. 6-24. Typical sleeve-type-bearing half with parts named. (Federal-Mogul Corporation)**

Figure 6-24 shows a sleeve-type bearing half with the various parts named. Note that it has a back to which a lining has been applied. The back, usually of steel or bronze, gives the bearing rigidity and strength. The lining is a thin layer of relatively soft material (the bearing material) only a few thousandths of an inch thick. The bearing material is a mixture of several metals—lead, tin, copper, and antimony, for example. The rotating journal is supported by this thin layer of bearing material. One reason for having the material soft is that when wear does take place, the bearing will wear rather than the more expensive engine part. When wear has gone beyond a certain point, the bearing, rather than the more costly engine part, can be replaced.

We noted in the previous paragraph that the bearing material "supports" the load of the rotating journal. Actually, the bearing...
surfaces are flooded with lubricating oil from the engine lubricating system so that the journals are, in effect, floated on films of oil (§29). It can be said, however, that the bearings support the films of oil, which in turn support the journals. So the bearings do, of course, "carry the load."

§103. Engine-bearing lubrication The engine bearings are flooded with oil by the lubricating system. For example, the bearing shown in Fig. 6-24 has an oil hole that aligns with an oil hole in the engine block. Oil feeds through this hole constantly, keeping the annular groove and the distributing grooves in the bearing filled with oil. Oil constantly feeds from these grooves onto the bearing surfaces. The oil works its way outward to the edges of the bearing. As it reaches the outer edges, it is thrown off and falls back into the oil pan. Thus oil is constantly circulating across the faces of the bearings in the engine.

One function of the oil is, of course, to provide lubrication; that is, it keeps the bearing and rotating journal separated by a film of oil so that there is no actual metal-to-metal contact. In addition, the oil helps to cool the bearing. The oil is relatively cool as it comes from the oil pan; as it spreads across the bearing and passes off the bearing edges, it warms up, thus removing heat from the bearing. This keeps the bearings at lower operating temperatures. A third function of the oil is to act as a flushing medium. It tends to flush out particles of dirt or grit that may have worked into the bearing (and on other engine parts). These particles are then carried back to the oil pan by the circulating oil and are removed from the oil by the oil filter or screen.

In addition to these functions, the "throwoff" of oil from the engine bearings helps to lubricate other engine parts. For instance, the cylinder walls, pistons, and rings are lubricated by the oil that is thrown onto the walls by the rotating crankshaft and connecting rods.

It is important to note that the oil, in order to function properly, must circulate through the bearing; it must flow. In order to permit this, the shaft-journal diameter is made somewhat smaller than the bearing diameter. The difference in diameters is called the oil clearance (Fig. 6-25). It is obvious that the greater this clearance, the faster the oil will flow through the bearing. Proper clearance
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varies somewhat with different engines, but 0.0015 inch would be a typical clearance. As the clearance becomes greater (from bearing wear, for instance), the amount of oil flowing through and being thrown off increases. With a 0.003-inch clearance (only twice 0.0015 inch), the oil throwoff increases as much as five times. A 0.006-inch clearance allows twenty-five times as much oil to flow through and be thrown off.

As bearings wear and oil flow-through and throwoff increase, more and more oil is thrown onto the cylinder walls. The piston and rings cannot handle these excessive amounts of oil; part of the oil works its way up into the combustion chambers, where it is burned and forms carbon on the piston, rings, and valves. This causes loss of power, increased engine wear, and other troubles (Chap. 12, "Diagnosing Engine Troubles"). It is also true that excessive oil clearance in some bearings may cause other bearings to be oil-starved so that they fail from lack of oil. The reason for this is that the oil pump can put out only so much oil. If the oil clearances of bearings are very large, most of this oil will pass through the oil clearances of the nearest bearings, and there won't be enough oil left for the more distant bearings. An engine with this trouble
usually has low oil pressure; the oil clearances are so great that the oil pump cannot build up normal pressures.

On the other hand, if oil clearances are not sufficiently great, then lubricating oil films in the bearing may not be thick enough to prevent metal-to-metal contact between bearing and shaft journal. Extremely rapid wear and early bearing failure will result. Furthermore, not enough oil will flow through and therefore oil throwoff will be insufficient to provide adequate lubrication of other engine parts such as the cylinder walls, pistons, and rings.

§104. Engine-bearing types  Early engines and some later-model heavy-duty engines used a "poured" bearing. This bearing was prepared by fitting a shaft-sized jig or mold into the counterbore where the bearing was to be, and then pouring molten bearing material into the space between the jig and counterbore. After the metal cooled, the jig was removed and the metal was then scraped or machined down to the proper size to fit the shaft to be installed. This was a laborious process.

Today bearing installation is much simpler. In the first place, the bearings are supplied as replaceable shells (Fig. 6-23) con-
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sisting of a hard back coated with a layer of the bearing material. Secondly, in many engines these bearings are so precisely made that they can be replaced without any machining or fitting of the bearing, counterbore, or shaft journal (provided that the journal is not unduly worn). These bearings are called precision-insert or precision-type bearings. On many engines using these bearings, main bearings can be replaced without removing the crankshaft; the old bearing is merely slipped out and the new bearing slipped in by use of a special tool (Fig. 15-3).

Some engines use semifitted bearings. These are approximately of the correct size but do have a few thousandths of an inch of extra bearing material that must be bored out after the bearings are installed: this establishes the proper fit and alignment with the shaft journals. The machining compensates for any slight irregularity in the alignment of the counterbores in the cylinder block and bearing caps. Figure 6-26 illustrates a semifitted crankshaft bearing of the thrust type. This illustration shows the “semifitted” principle, which requires removal of bearing stock for proper fit. It also illustrates the thrust faces found in the crankshaft thrust bearing. One of the main (or crankshaft) bearings in the engine is always a thrust bearing. The purpose of the thrust faces is to prevent excessive crankshaft end play. Whenever the crankshaft attempts to move endwise excessively, a flange on the crankshaft comes up against a thrust face and the crankshaft can move endwise no further. The center main bearing in the engine shown in Fig. 5-3 is of the thrust type, as is the rear bearing in the engine shown in Fig. 6-22.

§105. Bearing requirements Bearings must be able to withstand the varying loads imposed on them without being damaged or wearing with excessive rapidity. But bearings must have other desirable characteristics. Listed and described below (not necessarily in order of importance) are some of these characteristics.

1. Load-carrying capacity. Modern engines are lighter and more compact, yet more powerful, than were the engines of a few years ago. We have already noted that increased compression ratios and consequent increased combustion pressures have made it possible to step up horsepower output without increase in engine weight. These higher combustion pressures and horsepowers have brought
with them greater loading of the engine bearings. For example, only a few years ago connecting-rod bearings on many passenger-car engines sustained loads of 1,600 to 1,800 psi (pounds per square inch). Today, connecting-rod-bearing loads of 2,800 psi are not uncommon.

2. Fatigue resistance. When a piece of metal is repeatedly subjected to stress so that it flexes or bends (even slightly), it may harden and ultimately crack or break. An example of this is what happens when you repeatedly bend a piece of wire or sheet metal. Ultimately it will break. As far as bearings are concerned, they are subject to repeated and varying loads that tend to flex them. The bearing material must be able to stand this without any undue tendency to crack and break down.

3. Embeddability. The term “embeddability” refers to the ability of a bearing to permit foreign particles to embed in it. Despite air cleaners and oil filters and screens, particles of dirt and dust do get into the engine and some of them find their way to the engine bearings. A bearing protects itself by permitting particles actually to embed in the bearing-lining material. If the bearing material were too hard to allow this, the particles would simply lie on the surface of the bearing. They would soon scratch the shaft journal turning in the bearing and also gouge out the bearing. This in turn would cause overheating and rapid bearing wear so that the bearing and the journal would soon fail. There is a limit to the number of particles a bearing can embed, however. If too many particles are embedded, the bearing will become overloaded with them and will fail. Also, if particles are too large, they will not completely embed; they will scratch the shaft journal or gouge out grooves in the bearing. This also could lead to bearing failure.

4. Conformability. Conformability is associated with embeddability. It refers to the ability of the bearing material to conform to variations in shaft alignment or journal shape. For example, suppose a bearing is installed under a shaft that is slightly bent (or which bends as it is loaded). This causes a certain area of the bearing to be heavily loaded while other areas are very lightly loaded. If the bearing material has high conformability, it will “flow” slightly away from the heavily loaded area to the lightly loaded area. In effect, this redistributes the bearing material so that the bearing is more uniformly loaded. A similar action takes
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place when foreign particles are embedded in the bearing. As they embed, they displace material, thus producing a local high spot. However, the material flows away from the high spot, thus tending to prevent heavy local loading that could cause bearing failure.

5. Corrosion resistance. Certain acids appear in the oil as by-products of the combustion process and engine operation. Manufacturers of lubricating oil add certain compounds to their oils to combat the acids and prevent them from corroding engine bearings and other parts. These acids would otherwise attack certain types of bearing materials and cause them to fail rapidly.

6. Wear rate. The bearing material must be sufficiently hard and tough so that it will not wear with excessive rapidity. At the same time, it must not be so hard as to have poor embeddability and conformability, or to cause undue wear of the shaft journal it supports.

§106. Bearing materials

As has already been mentioned, the bearing back is usually steel or bronze. Steel is the more common backing material today; precision-insert bearings are steel-backed. The bearing material applied to the back is a mixture of several metals. For example, one bearing material is made of lead, tin, antimony, and copper. Another bearing material is made of lead, tin, mercury, calcium, and aluminum. Other combinations include copper, antimony, and tin; silver, copper, and cadmium; copper, lead, and silver. As can be seen, many combinations are possible. Actually, the bearing material is compounded of the proper metals to meet the operating requirements to which the bearing will be subjected. Each ingredient supplies certain characteristics. The engine designer selects the combination of ingredients that will best suit his engine.

§107. Bearing loading

We have already noted that the pressure in the engine cylinder varies from below atmospheric to several hundred pounds per square inch (Fig. 4-5). These varying pressures are transmitted through the piston and connecting rod to the crankpin; this imposes a varying load on the bearings. But there are other forces at work that also impose loads on the bearings. For example, let us analyze in detail the forces that act on the connecting-rod bearing (big-end bearing). In addition to the pressure loads, there are centrifugal loads and inertia loads. Centrifugal loads result from the centrifugal force on the rod big end that at-

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Attempts to throw it outward from the center line of the crankshaft (Fig. 6-27). This imposes a load on that part of the connecting-rod bearing which is toward the center of the crankshaft. The centrifugal load is constant for any particular speed, and increases as the speed goes up. It circles the bearing uniformly, and can be quite large. For example, let us assume that the crankpin is offset 2 inches and that the connecting rod weighs 2 pounds of which 1 pound (at the big end) is effective in producing centrifugal force. With these assumptions, we can calculate that the centrifugal force acting on the connecting-rod bearing at 4,000 engine rpm (revolutions per minute) would be more than 900 pounds.\(^3\) In other words, this is the bearing load produced by centrifugal force. This load is always on that section of the bearing which is toward the center of the crankshaft.

\[ \text{Centrifugal force} = \frac{W}{g} \left( \frac{2\pi N}{60} \right)^2 \approx \frac{1}{32.16} \left( \frac{2 \times 4,000}{60} \right)^2 \approx 914 \text{ lb.} \]

\(^3\) Federal-Mogul Corporation

![Diagram of forces acting on connecting rod bearing](image)

**Fig. 6-27.** The man swinging a pail of water in (a) illustrates one of the three forces acting on the connecting-rod bearing, (b). This is centrifugal force, which keeps the water in the pail by pushing it outward, just as centrifugal force pushes the connecting rod outward away from the center of rotation. This imposes a centrifugal load on the bearing in the direction shown in (c) by arrow C. Arrow P represents combustion pressure, acting along the connecting rod on the bearing. Arrow I is the inertia load which is acting in the opposite direction to P in the piston and rod position shown. R is the resultant load.

(Federal-Mogul Corporation)
Now, let's talk about inertia loads. Inertia, you will recall (§27), is that characteristic of all material objects that causes them to resist any change of speed or direction of travel. The piston and upper part of the connecting rod are constantly changing speed and direction of travel. At the end of each stroke [at TDC (top dead center) and BDC (bottom dead center)] the piston is brought to a complete stop. Then it is accelerated to the high speed it attains in the middle of each stroke. At 4,000 engine rpm, for example, the piston will accelerate from a “standing start” to about 88 feet per second (a mile a minute) in 0.00375 second. Then, in the next 0.00375 second, it has to slow down and stop again. Even though a piston may weigh only about a pound (cast-iron pistons weigh a little more), it takes a considerable force to stop the piston, start it again, accelerate it to high speed, and then stop it once more. This force, remember, is imposed on the connecting-rod big-end bearing and produces what are known as inertia loads. Inertia loads vary greatly from a minimum toward the middle of the stroke to a maximum at around TDC and BDC when maximum change of speed is taking place (or when the piston is brought to a stop and reversed in direction). For example, at 4,000 rpm, a 1-pound piston moving in a 4-inch stroke will impose a maximum inertia load of more than 700 pounds on the connecting-rod bearing. There is an additional load due to the inertia effect of the connecting rod, which is also brought to a stop and then moved in the opposite direction. Remember that this maximum load occurs as the piston passes through TDC or BDC, or during the time that the piston is brought to a stop and then started to moving in the opposite direction. Inertia loads increase with engine speed, just as centrifugal loads do.

§108. The effective bearing load The three different loads on the connecting-rod bearing sometimes add up, sometimes oppose each other, but generally they work at various angles to each other. You might compare this to two men pushing at angles on a box as shown in Fig. 6-28. As they exert force $A$ and force $B$ respectively,

\[ \text{Force} = ma = \frac{1}{32.16} \times 23,500 = 733 \text{ lb} \]

Assuming uniform acceleration of 23,500 ft/sec², based on formula $a = \frac{V_1 + V_2}{t}$.

Since $V_1$ is 0, and $V_2$ is 88 ft/sec, then $a = \frac{88}{0.00375} = 23,500$ ft/sec².
they work partly against each other, but part of their effort does add up to produce resultant force C. If they exerted different forces (as at force D and force E), then the resulting force would be to the right as shown (resultant force F). Note that, in the drawings, the lengths of the arrows are proportional to the forces exerted.

In a similar manner, as the bearing loads work at different angles to each other, they produce a resultant loading force that is, in effect, the same as a single loading force. For example, in Fig. 6-27, the small drawings to the right show the power, inertia, and centrifugal loads on the bearing at one certain engine speed and piston position on the power stroke. Note that the pressure load opposes

\[ \text{Force A-50 lb} \]
\[ \text{Force B-50 lb} \]
\[ \text{Force D-75 lb} \]
\[ \text{Force E-25 lb} \]

**FIG. 6-28.** Forces at angles to each other partly cancel each other out. At left, the two 50-pound forces give a resultant force of 70.7 pounds. At right, the 25-pound force and the 75-pound force give a resultant force of 79.4 pounds. Lengths of arrows are proportional to the loads. Thus arrow D (75 pounds) is three times as long as arrow E (25 pounds).

the inertia load; the inertia load partly cancels out the pressure load since it is in the opposite direction to the pressure load. The centrifugal load is at an angle.

The small drawing to the right shows how to combine the three loads to find out the resultant load R. The arrows are proportional in length to the forces exerted and they point in the directions in which the forces are exerted. After the three force arrows are drawn, the resultant arrow R is drawn in. Its length represents the strength of the resultant force while its direction indicates the direction that the force is exerted.

**§109. The bearing-load graph** Figure 6-29 is a graph of the resultant bearing loads (from pressure, centrifugal, and inertia loads) imposed on the connecting-rod bearing in a certain engine with a
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3½ bore and 4% stroke operating at 3,700 rpm. The small figures represent the degrees of crankshaft rotation; 0 to 180 degrees of crankshaft rotation represents the power stroke, 180 to 360 degrees the exhaust stroke, 360 to 540 degrees the intake stroke, and 540 to 720 (or 0) degrees the compression stroke. The distance from the intersection of the two straight lines to any point on the curved line represents the amount of bearing load imposed, while the direction in which the measurement is taken indicates the direction of loading. For example, at 90 degrees (or halfway through the power stroke), the bearing load is shown by arrow A, which scales at 2,100 pounds and is pointing down to the lower right. Then, at 270 degrees, which is halfway through the exhaust stroke, the bearing load is as shown by arrow B. This is almost horizontal to the left, and scales about 1,470 pounds. Arrow C indicates the bearing load at 420 degrees, or at a point 60 degrees after the intake stroke has begun. This scales at 1,480 pounds and is toward the upper right.

The graph in Fig. 6-29 provides a great deal of interesting information. For instance, under the running conditions at which the graph was compiled, at the beginning of the power stroke there is an almost zero bearing loading for a few degrees of crankshaft rotation (due to pressure load canceling the centrifugal and inertia loads). Moreover, in a matter of 15 degrees of crankshaft rotation, the load changes from about 2,000 pounds on the upper part of the bearing (at 0 degrees), to about 1,800 pounds on the lower part of the bearing (at 15 degrees). Note also how the load decreases after this due to pressure drop, and also swings up toward the right. Then, at about 45 degrees, the load again increases and swings downward. You might like to compare this graph of connecting-rod-bearing loading with the graph of cylinder pressures (Fig. 4-5).

It must be remembered that the graph (Fig. 6-29) shows only one set of conditions at one engine speed. The bearing loadings (and graph, of course) change with changed operating conditions. For example, Fig. 6-30 compares the bearing loads shown in Fig. 6-29, with bearing loads obtained at 1,000 rpm (with wide-open throttle) on the same engine. Note that under the latter conditions, an entirely different set of bearing loads is imposed, with the maximum coming early in the power stroke and amounting to 3,780 pounds. Note also how small the inertia and centrifugal loads are at 1,000 rpm (upper part of graph). As is obvious from the graph,
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this sort of operation is very hard on the bearings; it subjects them to periodic heavy shock loads. Bearings will have a relatively short life under such conditions.

We should also note that we have been discussing only connecting-rod bearings in the past few pages. However, other engine bearings (main, or crankshaft, piston pin, and so forth) also have varying loads imposed on them; somewhat similar bearing-load analyses could be made on these other bearings.

Fig. 6-29. Graph of resultant forces, or loads on connecting rod bearing, in a 3 1/4 by 4 1/2 in. engine operating at 3,700 rpm. The figures represent degrees of crankshaft rotation: 0 to 180 degrees is the power stroke, 180 to 360 degrees is the exhaust stroke, 360 to 540 degrees is the intake stroke, and 540 to 720 (or 0) degrees in the compression stroke. (Federal-Mogul Corporation)

Fig. 6-30. Comparison of graph of connecting-rod-bearing loads at 3,700 rpm (shown in dotted line) with loads at 1,000 rpm at wide-open throttle (shown in solid line). These graphs were compiled on the same engine. (Federal-Mogul Corporation)
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CHECK YOUR PROGRESS

Progress Quiz 12

Here is your progress quiz on the latter part of Chap. 6. You can find out once again how well you have understood and remembered the material you have been reading. This repeated checking up keeps you on your mental toes and also helps you review the material you have read. If any of the questions seem hard to answer, reread the pages that will give you the answer.

Correcting Parts Lists

The purpose of this exercise is to help you spot unrelated parts in a list. For example, in the list, connecting rod, piston, piston pin, main bearing, bearing cap, you would notice that main bearing does not belong since it is not a part of the connecting rod and piston assembly.

In each of the lists, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. Parts directly assembled on the crankshaft include the flywheel, vibration damper, piston, timing gear or sprocket.
2. Bearings assembled to the crankshaft include the main bearings, piston-pin bearings, connecting-rod bearings.
3. Desirable sleeve-bearing characteristics include embeddability, fatigue resistance, conformability, convertibility, corrosion resistance.
4. Materials for sleeve bearings mentioned in the text include lead, tin, copper, antimony, carbon.
5. The three loads acting on the connecting-rod bearing include pressure loads, depression loads, centrifugal loads, inertia loads.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. There is an overlapping of power impulses on four- and six-cylinder engines four- and eight-cylinder engines six- and eight-cylinder engines
2. Twisting and untwisting of the crankshaft is called torsional balance torsional vibration power impulses
3. The difference in diameters between a shaft journal and its sup-
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Porting sleeve bearing is called bearing slack oil clearance distributing groove.

4. A typical oil clearance would be 0.00015 inch 0.0015 inch 0.15 inch.

5. The bearing that prevents excessive endwise movement of the crankshaft is called the push bearing thrust bearing face bearing.

6. The characteristic of the bearing that allows foreign particles to embed in it is called absorption embeddability conformability fatigability.

7. The rotating effect of the connecting rod on the connecting-rod bearing produces the inertia load pressure load centrifugal load.

8. When several different forces act at angles on an object, the combining of these forces produces a resultant force remaining force canceling force.

Chapter Checkup

Note: Since the following is a chapter review test, you should review the chapter before taking the test.

You have made real progress in your studies of the automotive engine and are rapidly approaching the point where you will be able to take the information you are learning into the automotive shop and begin to do actual repair work on engines. The following checkup will help you check yourself on how well you are retaining the essential information that you will need in your shopwork. Turn back into the chapter and do some rereading if you have any doubts about the answers to any of the questions below.

Where you are asked to write something down, write it in your notebook. By now your notebook should have a good deal of valuable information in it. If you have not been keeping a notebook, now is a good time to start one.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. The crankshaft is suspended from the lower part of the crankcase cylinder block cylinder head oil pan.
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2. The ignition distributor and fuel pump are driven from the flywheel crankshaft camshaft fan belt.

3. The sealing devices placed between the cylinder block and the parts attached to it are called gaskets studs bolts cylinder heads.

4. The manifold heat-control valve is assembled into the intake manifold exhaust manifold crankcase cylinder head tail pipe.

5. The muffler is located in the exhaust manifold intake manifold exhaust line tail pipe.

6. Attached to the rear end of the crankshaft is the vibration damper flywheel drive pulley timing gear.

7. If oil clearance in a bearing is excessive, then there will probably be excessive oil pressure oil throwoff oil compression.

8. Important bearing characteristics include embeddability, compression, and fatigue embeddability, conformability, and fatigue resistance.

9. Three loads imposed on the connecting-rod bearing are due to centrifugal force, inertia, and combustion pressure atmospheric pressure, inertia, and torsional vibration inertia, engine speed, and centrifugal force.

10. Two of the three connecting-rod-bearing loads that increase as engine speeds increase are pressure and inertia loads pressure and centrifugal loads centrifugal and inertia loads torsional and pressure loads.

Definitions and Lists

In the following you are asked to write down the function or define the purpose of different engine parts, or to make lists. Write these down in your notebook. The act of writing down these items does two things; it tests your knowledge, and it also helps fix the information more firmly in your mind. Turn back into the chapter if you are not sure of an answer and reread the pages that will give you the information.

1. What are the three functions of the flywheel?
2. List 10 parts attached to or installed in the cylinder block.
3. List five parts attached to an I head.
4. What is the purpose of the manifold heat-control valve?
5. What is the purpose of the intake manifold?
6. List five desirable characteristics of a sleeve bearing.
7. What is the purpose of the vibration damper?
8. What are the three types of load imposed on the connecting-rod bearing?
To study engine construction further, go to a friendly service shop where engine repair work is done and watch different engines being torn down and serviced. If possible, handle various engine parts and examine them closely. Note how pistons, connecting rods, crankshafts, and other parts are made and how they are assembled into the engine. Examine as many cylinder blocks as you can and notice the many machined surfaces on the top, sides, ends, and bottom for attachment of different parts.

You will also be able to handle and study various engine parts in your own school automotive shop. Your school shops may also have cutaway and working models on display, and a study of these will help you understand engine construction.
7: Pistons and valves

THIS CHAPTER continues the descriptions of engine construction, with emphasis on pistons and valves. The previous chapter discussed cylinder blocks and heads; here we consider the moving parts that go into the block and head to make a complete engine. The information in these two chapters will enable you to move

![Connecting rod with bearings and bearing cap in disassembled view (top) and assembled view (bottom). (Plymouth Division of Chrysler Corporation)](image)

- Cap-bolt-nut lock washer
- Cap-bolt nut
- Cap
- Tongue and groove
- Rod bearings
- Cap bolt
- Piston-pin bearing
- Oil holes
ahead with confidence into the trouble-shooting and servicing sections in the latter part of the book.

§110. Connecting rod. The connecting rod (Fig. 7-1) is attached at one end to a crankpin on the crankshaft and at the other end to a piston, through a piston pin or wrist pin. The connecting rod must combine great strength and rigidity with light weight. It must be strong enough to maintain rigidity when carrying the thrust of the piston during the power stroke. At the same time it must be as light as possible so that the centrifugal and inertia loads on the bearings will be no greater than is necessary (§107).

The crankpin end of the connecting rod is provided with a split-type sleeve bearing, as shown in Fig. 7-1. It is attached to the crankpin by means of the bearing cap, rod bolts, and nuts.

The piston end of the connecting rod is attached to the piston by means of a piston pin (also called a wrist pin). Bosses are provided in the piston (Fig. 7-5), with holes into which the piston pin is assembled. The pin also goes through the bearing provided for it.
in the connecting rod. Three methods of attaching the piston and the connecting rod with the piston pin are used. One method locks the piston pin in the piston by a lock bolt (Fig. 7-2). On this type of installation the connecting rod has a sleeve bearing that provides a bearing surface between the rod and the pin so that the rod can rock back and forth on the pin. A second design locks the pin to the connecting rod with sleeve bearings in the two piston bosses in which the pin can turn back and forth (Fig. 7-3). A third design has sleeve bearings in both the piston bosses and the connecting rod, the pin not being locked to either. In this latter design the pin

Fig. 7-3. Piston and connecting-rod assembly with piston cut away to show arrangement for locking piston pin to connecting rod. 1, piston; 2, lock nut; 3, clamp screw. (Studebaker-Packard Corporation)

Fig. 7-4. Piston and connecting-rod assembly of type with lock rings to hold piston pin in position in piston and connecting rod. (De Soto Division of Chrysler Corporation)
is prevented from moving out and scoring the cylinder walls by means of snap rings (also called lock rings) in the piston bosses (Figs. 7-4 and 7-6).

To provide lubrication of the piston pin, an oil-passage hole is often drilled the entire length of the connecting rod from the crankpin-journal bearing to the piston-pin bearing. A hole in the rod bearing (not the cap bearing) feeds oil to the connecting-rod oil passage from oil lines drilled in the crankshaft. Oil circulates through the connecting-rod oil passage to the piston-pin bearing. On some applications a second hole is drilled on one side of the connecting rod, as shown in Fig. 7-2. This hole is called the oil-spit hole because, as the crankshaft rotates within the bearing, an oil-passage hole in the crankshaft indexes with this hole. Oil feeds
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through so that for a moment oil spits, or streams, from the hole in the connecting rod. This oil is thrown against the cylinder wall to provide additional cylinder-wall lubrication. The holes are arranged to index just as the piston approaches TDC (top dead center); thus a large area of the cylinder wall is covered with oil.

In order to maintain good engine balance, connecting rods are carefully matched in sets for engines. All rods in an engine must have the same weight and balance; if they are not in balance, a noticeable vibration may result.

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Essentially, the piston is a long cylinder open at the bottom, closed at the top, and attached to the connecting rod at an intermediate point (Figs. 7-2 to 7-6). The piston moves up and down in the engine cylinder, compressing the air-fuel mixture, transmitting the combustion pressure to the crankpin through the connecting rod, forcing out the burned gases on the exhaust stroke, and producing a vacuum in the cylinder that "draws in" the air-fuel mixture on the intake stroke. The piston may seem to be a fairly simple part, but actually it has been the subject of possibly more study and design than any other engine part. It must be light so as to keep inertia loads to a minimum. But it must also be rigid and strong enough to take the punishing heat and pressure developing in the combustion chambers.

However, before we discuss pistons further, let us consider the piston rings. After a discussion of rings, we shall come back to pistons again (in §117).

§112. Piston rings

A good seal must be maintained between the piston and the cylinder walls so that blow-by is prevented. "Blow-by" is an expression used to describe the escape of burned gases from the combustion chamber, past the piston, and into the crankcase. In other words, these gases "blow by" the piston. It would be difficult to machine a piston to fit the cylinder accurately enough to prevent excessive blow-by. Even if this were possible, the differences in expansion between the cylinder and the piston during engine operation, caused by variations in temperature, would change the fit so that it would be either too loose or too tight.

Piston rings, assembled into grooves in the piston as shown in Figs. 7-4, 7-6, and 7-20, are used to provide a good seal so that blow-by is kept at a minimum. Also, they seal in the compressed
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Air-fuel mixture; they maintain good compression. Piston rings also perform a second function; they scrape oil off the cylinder walls on the piston downstrokes (power and intake). This prevents excessive amounts of oil from working up past the piston and getting into the combustion chamber. Oil in the combustion chamber burns, leaving a residue of carbon that fouls spark plugs, valves, and piston rings.

Piston rings perform a third function; they help cool the piston by transmitting a considerable amount of heat from the pistons to the cylinder walls. Since the cylinder walls are cooled by the water circulating in the water jackets, the cooling effect is thus carried through the rings to the piston. This helps guard against excessive and possibly damaging piston temperatures.

Piston rings on modern engines are of two types, according to their purpose: compression rings and oil-control rings. There are usually three or more rings on a piston. The upper rings are of the compression type and have the job of sealing in compression and preventing blow-by. The lower rings are of the oil-control type and have the job of controlling the oil on the cylinder walls. That is, these rings scrape off excessive amounts of oil and return it to the crankcase, leaving only enough oil on the cylinder walls to provide piston and ring lubrication.

Figure 7-7 illustrates a compression ring (top) and an oil-control ring (bottom) with the various parts named. Figure 7-8 shows a piston with two compression and two oil-control rings installed on it. Note that the rings have a joint (they are split) so that they can be expanded and slipped over the piston head and into the recessed grooves cut in the piston. The joint may be straight-edged (butt), angled, or of the lap or sealed type (Fig. 7-9), among others.

The reason that two compression rings and two oil-control rings may be used on a piston (instead of only one of each) is that more than one ring of each type is usually required to do the job. For example, the top compression ring may seal in most of the combustion pressure, but the second ring is required to complete the job. Even with two rings, some slight amount of blow-by may be experienced. However, two rings keep it down to an unimportant minimum (when ring, cylinder wall, and other engine parts are in good condition). Most automobile engines have two compression rings, but some heavy-duty engines have more.

Two oil-control rings are used on many engines (some use only
one) to provide adequate oil control. The lower ring removes most of the oil from the cylinder wall, and then the upper oil-control ring removes the remainder of the excess oil. Actually, a thin film of oil is left on the cylinder wall. If all the oil were removed, actual metal-to-metal contact between rings and wall would result, and this would cause very rapid ring and wall failure. As a matter of fact, the two oil-control rings leave a little more oil on the cylinder walls than is absolutely necessary. The two compression rings take care of this (see §113). Some engines use only one oil-control ring.
Fig. 7-9. Various types of ring joints. (Sealed Power Corporation)

Fig. 7-10. Piston rings pinned in place in ring grooves. When they are installed in the cylinder, the clearance, as shown at upper right, is small and allows no rotary ring travel. (American Motors Corporation)

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ring. On these, the two compression rings are relied upon to complete the oil-control job. A ring expander (§116) may be used under the oil-control ring as shown in Figs. 7-20 and 7-25.

The ring is of a somewhat larger diameter than it will be in the cylinder. When it is placed in the cylinder, the ring is compressed so that the joint is nearly closed. Compressing the ring into the cylinder in this way places an initial tension on it; it presses tightly against the cylinder wall.

On one type of application the piston rings are pinned into place by means of a pin inserted into holes through the ring lands (Fig. 7-10). This prevents the rings from moving around in the ring grooves. On other applications the rings are free and they turn, or "walk around," in the grooves. The ring gap on the free-ring applications usually does not stay in any one place but moves around.

§113. Compression rings Compression rings are made of cast iron. This material has excellent wearing qualities and at the same time provides adequate initial ring tension, or pressure, on the cylinder walls. The shape of the ring has undergone many changes in the past 30 years. Some of the different shapes used are shown in Fig. 7-11. The counterbored and scraper types are of special interest since they are widely used for top and second compression rings in automotive engines today. Figure 7-12 shows a counterbored, or grooved, compression ring. Cutting out the groove unbalances the internal tension forces in the ring. When the ring is compressed (joint is closed) as it is installed in the cylinder, these unbalanced tensions in the ring cause it to twist slightly. A similar twisting takes place with the scraper type of compression ring. These rings are effective in controlling the oil that gets past the oil-control rings; on the intake stroke, they scrape all but a very small amount of the remaining oil from the cylinder wall (Fig. 7-13). Then, on the exhaust and compression strokes, when the rings are moving upward, they tend to "skate" over the film of oil on the cylinder wall so that they have less tendency to carry oil up into the combustion-chamber area. At the same time, this minimizes wear on the up-strokes.

On the power stroke combustion pressures press down on the top and on the back of the rings. This overcomes the internal tensions [202]
in the rings, causing them to untwist and straighten and thus present full-face contact with the cylinder walls for effective sealing (Fig. 7-14).

Various coatings have been used on compression rings as an aid to effective wear-in and also to prevent rapid wear (thus prolonging ring and cylinder-wall life). These coatings include phosphate, graphite, iron oxide, tin, and chromium. By "wear-in" we mean this: when new, the rings and cylinder wall have certain irregularities and do not mate, or fit, adequately. However, after a time, these irregularities are worn away so that a much better fit, or mating, between the rings and wall comes about. Relatively soft substances such as phosphate, graphite, and iron oxide, which wear rapidly, help this wear-in. In addition, they have oil-absorbing properties
which permit them to "soak up" a certain amount of oil for improved lubrication. Also, these substances (particularly iron oxide) tend to prevent ring scuffing; scuffing results from metal-to-metal contact, high local temperatures, and actual small-area welding of the ring and cylinder-wall metal. The welds, of course, are broken by further ring movement, but scuffed places, or depressions, are left in the rings. Such substances as iron oxide prevent scuffing because a weld cannot take place unless the pure metal is exposed and in contact. The protective coating tends to prevent this even if
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the oil film should fail. Tin is another relatively soft protective coating that wears during initial operation to provide good wear-in. Chromium, on the other hand, is a very hard metal and thus wears slowly (as much as 80 percent slower than cast iron). This fact might lead you to believe that a chromium-plated ring would cause very rapid cylinder-wall wear. However, in the manufacture of these rings, the chromium plate is lapped to a very smooth finish. One manufacturer specifies that surface irregularities must be no greater than 0.0001 inch in the finished ring. With this extreme smoothness, wear-producing "high spots" are at a minimum: cylinder-wall wear is therefore low. Further, since chromium will not normally weld to cast iron, welding and scuffing of the chromium-plated rings are not apt to occur. The use of chromium-plated rings has increased in recent years.

§114. Oil-control rings The oil-control rings have the job of preventing excessive amounts of oil from working up into the combustion chamber. As we mentioned in our discussion of engine bearings, the oil throwoff from the bearings lubricates the cylinder walls, rings, and pistons. In addition, some connecting rods have an oil-spit hole which spits oil on the cylinder wall to provide additional lubrication. Actually, under most circumstances, there is far more oil thrown on the cylinder walls than is needed for lubrication. Most of it must be scraped off and returned to the crankcase. However, this scraped-off oil does serve a purpose. It carries away with it particles of carbon that have formed as well as dust or dirt particles that have come into the engine with the air-fuel mixture. These particles are then removed from the oil by the oil filter or screen. Thus, the oil circulates as well as lubricates and this circulation of the oil helps keep the cylinder walls, pistons, and rings clean.

The oil circulation also has some cooling effect. The oil picks up heat from the cylinder walls and also from the piston and rings as it passes around and through the rings after being scraped from the walls. The oil then drops back into the oil pan where it is cooled and then recirculated in the engine by the oil pump.

Note: The oil does a fourth job, in addition to lubricating, cleaning, and cooling. It also helps to seal between the rings and the cylinder wall, and between the rings and the piston. The oil, because of its ability to cling to metal surfaces, improves the sealing
effect of the rings. You can test this effect yourself on an old engine with tapered walls and worn rings. Such an engine will not hold compression and is subject to excessive blow-by. If you remove the spark plugs, pour in a little heavy oil, and then test the compression with a gauge, you will find the compression has improved. The heavy oil temporarily improves the seal between the rings, wall, and piston. This is a test that is actually performed on engines that have lost compression to determine whether or not cylinder and ring wear is the cause. More on this in Chap. 11, "Engine-testing Procedures and Tools."

Figure 7-15 shows various types of integral, or one-piece, oil-control rings. Note that all these rings have holes or slots between upper and lower bearing surfaces. These openings give the oil scraped from the cylinder walls somewhere to go. The oil passes...
through these openings and through holes drilled in the back of the oil-ring grooves in the piston. From there, it returns to the crankcase. Most rings of this type now are slotted (or channeled) since this provides the most room for the oil and thus permits maximum oil circulation.

Another type of oil-control ring that has recently come into use is shown in Fig. 7-16 (bottom ring). This ring is made of flexible strip steel. The extremely open construction of this ring makes it especially effective in handling large quantities of oil. Since it scrapes most of the oil from the cylinder walls, the second oil-control ring can do a more effective job on the oil that remains. At the same time, the flexible steel ring provides very uniform cylinder-wall pressure around its entire circumference; an unusually good fit is maintained.

§115. Effect of speed on oil control. As engine speed increases, the oil-control rings have a harder time controlling the oil and preventing excessive amounts of oil from passing them. There are several reasons for this. For one thing, the engine parts and engine oil become hotter at high speed. This means the oil becomes thinner so that it can pass the rings more easily. In addition, more
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Oil is pumped at high speed, more oil is thrown off the bearings, more oil gets on the cylinder walls. All this means that the oil-control rings have a harder job to do. And they have less time to do it. As a consequence, the oil control rings are less effective at high speed; more oil works past them and gets into the combustion chamber where it is burned. This increases oil consumption considerably. An engine uses two or three times as much oil at high as at low speeds. Much, but not all, of this is due to the reduced effectiveness of the oil-control rings at high speed (see §194 for further discussion of effect of speed on oil consumption).

§116. Replacement rings As engine mileage piles up, the rings and cylinders (among other parts) wear. Cylinders wear tapered and out of round. Figure 15-14 illustrates the manner in which a cylinder wears tapered. Most wear naturally takes place at the top, where maximum combustion pressures and ring pressure on the cylinder walls occur. When an engine is torn down for repair, the cylinder bores must be checked to determine the amount of this taper wear. If the taper wear is not too great, satisfactory repair can often be made by installing a set of special rings. Figure 7-17 illustrates such a set of rings, installed on a piston. This same set of rings is shown in disassembled view in Fig. 14-34.

The lower of the two compression rings (2 in Fig. 7-17) has a ring expander back of it. The ring expander is a steel spring in the [208]
shape of a wavy or humped ring (Fig. 7-25) that adds tension, or cylinder-wall pressure, to the compression ring. With the ring expander, the ring can be made somewhat thinner (from back to front); the ring expander more than makes up for any loss of tension from the reduced thickness. Figure 7-18 shows the shape and location of a ring expander in place under a compression ring. This combination offers the advantage of high flexibility with high tension (which gives high wall pressure). In a tapered or out-of-round bore, the ring must expand and contract—it must change shape—as it moves up and down in the cylinder. This means that the ring must have good flexibility as well as relatively high tension. The combination of ring and ring expander gives the ring a better chance to conform to the changing shape of the bore as the ring moves up and down in the cylinder.

NOTE: Some of the late-model engines include expanders under the bottom (oil-control) ring. These engines use only one oil-control ring; this additional assistance (from the expander) is desirable since one ring has the entire major oil-control job to do (see Figs. 7-20 and 7-25).

Still speaking of replacement rings for tapered cylinders, note that the upper oil-control ring (3 in Fig. 7-17) is of the slotted, or channel, type. A ring expander is used in back of it. The bottom oil-control ring (4 in Fig. 7-17) is made up of three parts, upper and lower rails with an expanding spring between them.
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§117. Pistons Just as piston rings have become more complex in design to meet today's operating requirements, so also have pistons been adapted for satisfactory operation in modern automotive engines. As we have already mentioned, the piston must be strong and rigid so that it can withstand the hammering effect of the combustion pressure. It must also be kept as light as possible so as to reduce inertia loads on the bearings as well as inertia losses. The power that is used up in stopping and starting the piston at the ends of the piston strokes increases with piston weight.

Pistons have been made of various materials, including cast iron, semisteel, and aluminum. Aluminum is less than half as heavy as cast iron, and thus most automobile engines are now equipped with aluminum alloy pistons. Since aluminum expands more rapidly than cast iron, aluminum pistons must be fitted somewhat more loosely in the cylinder when cold. This provides ample clearance between the cylinder wall and piston after the piston has expanded due to temperature increase.

§118. Piston clearance Proper clearance between piston and cylinder wall is important. Excessive clearance causes piston slap. Piston slap results from the sudden tilting of the piston in the cylinder as the piston starts down on the power stroke. The piston moves from one side of the cylinder to the other with sufficient force to produce a distinct noise. Usually, piston slap is a problem only in older engines with worn cylinder walls and worn or collapsed piston skirts, any of which produce excessive clearance. On the other hand, the clearance must be large enough. If it is too small, then oil will not be able to get to the rings and upper part of the bore. Further, piston expansion, with increasing temperature, may cause the piston to seize. In either event, engine failure will result.

There are several methods of keeping pistons from excessively changing dimensions with temperature. One method, used on aluminum pistons, is to cast into the piston special alloy-steel struts or rings. Since the alloy steel does not expand with temperature as much as aluminum, the struts or rings reduce piston expansion. Thus, a more constant clearance between the piston and cylinder wall is maintained.

Another method of reducing dimensional changes is to keep heat away from the lower part of the piston, so far as possible. One
way of doing this is to cut horizontal slots in the piston just below the lower oil-control ring (Fig. 7-19). These slots reduce the path for the heat traveling through the piston from the piston head to the piston skirt. Thus, the skirt does not become quite so hot and does not expand quite so much. On many pistons a vertical slot is cut in the skirt about ninety degrees from the piston-pin holes (Fig. 7-19). This slot permits the piston to expand without increasing its diameter. Usually the bottom of the piston skirt in a slotted piston is left solid, as shown, so that the piston will retain its shape without collapsing.

Another method of reducing heat travel to the piston skirt makes use of a heat dam (Figs. 7-20 and 7-24, left). The dam consists of a groove cut near the top of the piston, which reduces the size of the path the heat can travel from the piston head to the skirt. The skirt therefore runs cooler and does not expand so much.

Typical operating temperatures of a piston are shown in Fig. 7-21. Note that, in the example shown, there is a 220° difference between the top and skirt of the piston. The piston rings help the heat accumulating in the piston head to escape; they transmit the heat from the piston to the cylinder walls.
§119. Cam-ground pistons In many engines pistons are slightly oval or elliptical in shape when cold, with the long axis (B in Fig. 7-22) perpendicular to the piston-pin holes. Such pistons are called cam-ground pistons because they are ground to size on a machine that uses a cam to move the piston toward and away from the grinding wheel as the piston is revolved. When cam-ground pistons begin to warm up in operation, they gradually assume a round shape, so that their area of contact with the cylinder wall increases with temperature. At operating temperature, full contact area has
FIG. 7-23. As the cam-ground piston warms up, the expansion of the skirt distorts the piston from an elliptical to a round shape, so that the area of contact between the piston and cylinder wall is increased.

been established (Fig. 7-23). “Contact” here must not be construed as meaning actually touching or being in direct contact. There is some clearance between the piston and the cylinder wall (in the neighborhood of 0.001 inch) and this is filled with oil, so that actual contact is not established. Actual contact would, of course, cause rapid wear and possible piston seizure.

§120. Piston heads and skirts Some pistons have a rather complex head formation. The one shown to the left in Fig. 7-24 is designed to improve turbulence of the air-fuel mixture in the combustion chamber and thus to improve combustion of the mixture. The one shown to the right in Fig. 7-24, which is used in the Buick V-8 engine.
engine, has two depressions on one side to provide adequate clearance between the piston and the valves when they are open. By using a piston with such depressions and a dome-shaped head, a smaller TDC or clearance volume can be achieved and thus a higher compression ratio can be attained. Refer to Fig. 5-8 to see how this piston fits in the engine and the manner in which the piston head fits the dome-shaped combustion chamber. The piston shown in Fig. 7-4 also has depressions in the head to provide clearance between the piston and valves. The engine in which this piston is used is shown in Fig. 5-6.

On some engines, particularly the V-8, the trend is toward the cutaway or “slipper” piston (Fig. 7-25). This type of piston permits a more compact engine since relieving the piston skirt as shown allows sufficient clearance between the piston and the counterweights on the crankshaft as the piston passes through BDC (bottom dead center). With a conventional piston, the connecting rod and cylinder would have to be longer to avoid interference between the piston and counterweights. Special internal struts and cast-in steel belt or other reinforcing keep the skirt expanded and in shape so that a good fit between the piston and
cylinder is maintained throughout the full range of engine operating temperatures.

Instead of cutting away the skirt of the piston to avoid interference with the crankshaft counterweights, the Buick V-8 engine has the counterweights machined to a contour that permits clearance between the piston skirt and counterweights. The counterweight contour can be seen in Fig. 5-8. In this engine full-skirted pistons are used. One of these pistons is shown to the right in Fig. 7-24.

CHECK YOUR PROGRESS

Progress Quiz 13

Here is your chance to check up on yourself once more and find out how well you have been absorbing the material you have been reading. If any of the questions seem hard, just review the past few pages.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. In the piston and connecting-rod assembly the piston pin may be free or locked to piston or rod free or locked to crankpin or rod free or locked to head or camshaft
2. The escape of burned gases from the combustion chamber past the pistons and into the crankcase is called gas loss blow-by by-pass passed gas
3. Piston rings do three jobs: they cool, seal, and control oil seal, prevent piston slap, and hold compression seal, compress, and control
4. Three types of ring joint are split, butt, and flat butt, straight, and angle butt, angle, and lap
5. The counterbored, or grooved, compression ring holds its twisted position on all piston strokes except the intake stroke compression stroke power stroke exhaust stroke
6. The ring expander combined with the ring offers the advantage of high flexibility with high tension high rigidity with high tension high oil control with high compression
7. Piston slap results from excessive clearance between the piston and piston pin piston and piston rod piston and rings piston and cylinder wall
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8. The groove cut near the top of the piston to reduce the size of the heat-travel path is called the heat groove, heat dam, skirt groove, heat path.

9. Pistons which are slightly elliptical when cold, but round when warm, are termed slipper pistons, round-ground pistons, cam-ground pistons.

10. The type of piston in which the piston skirt has been cut away below the piston-pin bosses is called a full-skirt piston, slipper piston, short-skirt piston.

§121. Cams and camshafts  
A cam is a device that can change rotary motion into linear, or straight-line, motion. The cam has one or more high spots, or lobes; a follower riding on the cam will move away from or toward the camshaft as the cam rotates (Fig. 7-26).

In the engine, cams are used to control the opening and closing of the intake and exhaust valves. Figures 7-36 and 7-38 show the valve mechanisms (also called valve trains) on L-head and I-head engines. The cams are formed as integral sections of the camshaft; each cam has one lobe, or high spot. There are two cams for each engine cylinder, one each for the intake valve and the exhaust valve.

In addition, the camshaft has another cam (or an eccentric) to operate the fuel pump and also a gear to drive the ignition distributor and the oil pump. The camshaft is driven from the crankshaft by sprockets and chain (Figs. 7-27 and 7-42) or by two gears (Fig. 7-28). The camshaft sprocket or gear is twice as large as the crankshaft sprocket or gear. This gives a 1:2 gear ratio; the camshaft turns at half the speed of the crankshaft. Thus, every two crankshaft revolutions gives one camshaft revolution and one cycle of valve action; that is, the intake valve and the exhaust valve open and close once every two crankshaft revolutions. In in-line engines the camshaft is mounted in bearings in the lower part of the [216]
FIG. 7-27. Crankshaft and camshaft sprockets with chain drive showing timing marks on sprockets. 1, camshaft-sprocket mark; 2, crankshaft-sprocket mark; 3, center line of shafts. Note that the larger of the two sprockets is on the camshaft so that it turns at one-half crankshaft speed. (Plymouth Division of Chrysler Corporation)

FIG. 7-28. Camshaft and crankshaft gears to drive camshaft. Note timing marks on gears. (Studebaker-Packard Corporation)
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cylinder block (Figs. 3-2 and 6-3). In V-type engines the camshaft is located directly above the crankshaft and between the two banks of cylinders (Figs. 5-6 and 5-7).

§122. Valves There are two valves from each cylinder in most engines, an intake valve and an exhaust valve (two-cycle engines may have less or none while certain heavy-duty engines may have more). The intake valve opens during the intake stroke to admit air-fuel mixture into the cylinder. The exhaust valve opens during the exhaust stroke to permit the burned gases to be exhausted from the cylinder. The cam lobes on the camshaft are so related to the crankshaft crankpins (through the gears or sprockets and chain) as to cause the valves to open and close with the proper relationship to the piston strokes (see §§132 and 133).

Various types of valves have been used in the past for internal-combustion engines, among them sliding-sleeve and rotary valves. However, almost all internal-combustion engines now use the mushroom, or poppet, valve (Figs. 7-29 and 7-30).

The valve is normally held closed and firmly seated by one or
more heavy springs and by the pressures in the combustion chamber. The manner in which the spring is fastened to the valve stem is described in §126. As the camshaft rotates, the cam lobe raises the valve lifter, causing the spring to compress and the valve to be lifted off its seat. When closed, the valve face makes uniform contact with the valve seat around the entire circumference of the valve. The seat and valve face are ground at the same angle and both are circular, so that a good seal is formed.

Fig. 7-30. Valve with parts named.

![Diagram of a valve with parts labeled.](image)

Fig. 7-31. Temperatures in an exhaust valve. Valve is shown in sectional view. (Eaton Manufacturing Company)

§123. Valve cooling The intake and exhaust valves are essentially similar. However, the intake valve is required to pass only the relatively cool air-fuel mixture, while the exhaust valve must pass the very hot burned gases. The exhaust valve may actually get red hot. Temperatures above a thousand degrees are common. Figure 7-31 shows a typical temperature pattern of an exhaust valve. Note that the area near the valve face is somewhat cooler than the part closer to the center. The valve stem is also relatively cool. The reason that the valve face is not as hot as the inner part of the valve head is that when the valve is closed, it is cooled to some extent by the valve seat; that is, heat passes from the valve to the seat. The valve stem is also cooled since it passes heat to the valve guide. It is obvious that in order to avoid excessive valve temperatures (which cause rapid valve failure) the valve seat and guide must
Automotive Engines

be adequately cooled. To accomplish this, water-distributing tubes are often placed in the cylinder-block water jacket in L-head engines (Fig. 7-32), and water nozzles are used in the cylinder head in I-head engines (Fig. 7-33). These provide for additional water circulation and cooling around the critical areas.

Figure 7-31 also emphasizes the importance of proper valve seating. If the valve face and valve seat do not mate properly, or are rough or worn, then full-face contact will not be attained. This means that there is a smaller area of contact through which heat transfer (and valve cooling) can take place. At the same time, uneven contact may mean that hot exhaust gases will leak between the valve face and seat in some spots. These spots will naturally run hotter. Actually, a poor seat may cause the valve to run several hundred degrees hotter than normal with local hot spots running at even higher temperatures. Naturally, these higher temperatures greatly shorten valve life.

[220]
§124. Sodium-cooled valve  To assist in valve cooling, many of the higher-output heavy-duty engines use sodium-cooled exhaust valves. This type of valve (Fig. 7-34) has a hollow stem which is partly filled with metallic sodium. Sodium melts at 208°F. Thus at operating temperatures the sodium is liquid. As the valve moves up and down, opening and closing, the sodium is thrown upward into the hotter part of the valve. There it absorbs heat which it gives up to the cooler stem as it drops down into the stem again. This circulation of liquid sodium in the valve stem cools the valve head. The valve therefore runs cooler. Actually, a sodium-cooled valve will run as much as 200° cooler than a solid-stem valve of similar design. Other factors being equal, this means considerably longer valve life.

§125. Valve seat  The exhaust-valve seat, as well as the exhaust valve, is subjected to the high temperatures of the burned gases passing from the engine cylinder through the exhaust port. For this reason, the exhaust-valve seat is often made of a special heat-resistant steel-alloy insert in the form of a ring. This ring is set into a counterbore in the cylinder block or head (Fig. 7-35). The ring, which is made of a very hard, heat-resistant metal, is better...
able to withstand the high exhaust-gas temperatures than are the block or head materials. Consequently, it holds up better and gives longer service life. It can be serviced after it has become worn or rough by a valve-seat grinding machine. A seat reamer, or cutter, cannot be used on this type of valve seat. If the seat has become badly worn or damaged, the seat insert can be removed and a new one installed. Chapter 13, "Valve and Valve-mechanism Service," discusses valve and valve-seat service in detail.

§126. L-head valve train The L-head engine uses a relatively simple valve train, or valve mechanism; the valves are located near and in a straight line with the camshaft. Figure 3-10 shows this valve mechanism with the various parts named, while Fig. 7-36 shows the valve mechanisms for two cylinders in a cutaway cylinder block. The valve spring is compressed between the cylinder block...
at one end and a spring retainer at the other. The spring retainer is attached to the end of the valve stem with a retainer lock (Fig. 7-37). The conical type is the most commonly used lock. It consists of two halves that fit into a conical recess in the retainer and into an undercut, or groove, in the valve stem. To remove the lock, the valve spring must be compressed by moving the retainer up out of the way. The lock is then free and can be removed. With the lock out, the valve can be pulled (from the top of the block) and the spring and retainer removed.

The valve rides in a valve guide assembled into the cylinder block (Fig. 3-10). Essentially, the valve guide consists of nothing more than a hollow steel tube, carefully dimensioned to be a tight fit in a drilled hole in the block, and having a close clearance fit with the valve stem. While the valve could be installed directly in a hole drilled in the block, this method of installation would make it...
difficult to correct for wear. But with the guide, excessive wear can be corrected by installation of a new guide.

The valve lifter (or tappet, as it is sometimes called) rides on the cam and moves up and down as the cam lobe passes under it. This motion is carried to the valve, causing it to open. Valve-spring pressure then recloses the valve as the cam lobe moves out from under the valve lifter. The lifter is essentially nothing more than a cylinder with a flat face on the lower end, which rides on the cam. On the other end there is an adjusting screw which can be turned into or out of the lifter to adjust the clearance in the valve train. It is this adjusting screw that makes contact with the end of the valve stem. Some clearance must be maintained in the system to allow for dimensional changes resulting from temperature variations. If the screw were adjusted to give zero clearance with the engine cold, then, as the engine warmed up, the valve stem would lengthen so that the valve would not seat. This would cause valve [224]
leakage and such troubles as burned exhaust valves. Either the adjusting screw is self-locking or there is a lock nut which is tightened after adjustment is made, to keep the screw from turning and thereby changing the adjustment.

The valve lifter is free in its mounting and normally revolves as the cam rotates against its face. This distributes the wear over a larger area of the lifter face.

Fig. 7-38. Valve-operating mechanism for I-head, or overhead-valve, engine. Sectional view of an actual engine is shown in (a). In (b) only the essential moving parts are shown, including the gears to drive the camshaft, the valve lifters, push rods, rocker arms, and valves for one cylinder. (Buick Motor Division of General Motors Corporation)

§127. I-head valve train In the I-head, or overhead, valve design (Figs. 7-38 and 7-39) two parts are installed in the valve train in addition to those the L-head train requires. These parts are the push rod and the rocker arm (Fig. 7-40). As the push rod is moved
upward by the lifter, it causes the rocker arm to pivot, or rock, on its mounting shaft. The valve end of the rocker arm then bears down on the valve stem, pushing it down, so that the valve opens. Figure 7-41 shows how the rocker arms are assembled to a shaft mounted on the cylinder head.

In this design proper clearance between the valve stem and the rocker arm is maintained by an adjusting screw and lock nut as-
sembled into the rocker arm. The lower end of the adjusting screw is ball-shaped, and it rests in a socket in the upper end of the push rod. Measurement of the clearance is made between the valve stem and rocker arm, but adjustment is made in the push-rod side of the rocker arm.

Spring tension on the valve may be provided by one spring, as shown in Fig. 7-39, or by an inner and an outer spring, as shown in Fig. 7-38.

Figure 7-42 shows the valve mechanism in an overhead-valve V-8 engine. You will note that the rocker arms in this engine have no adjusting screws. There is no means of adjusting valve clearance in this engine; a special self-adjusting valve lifter is used in this engine. This valve lifter is hydraulic and makes use of oil pressure to maintain zero valve clearance. In addition to compensating automatically for dimensional changes produced by temperature variations, this valve lifter is very quiet in operation. Section 131 describes the hydraulic valve lifter in detail.
§128. F-head valve trains. The F-head design combines both the L-head and the I-head design in one engine (Fig. 7-43). In the engine shown the intake valves are in the head, and the exhaust valves are in the block. The intake valves are operated from the camshaft through lifters, push rods, and rocker arms, exactly as in a conventional I-head engine. The exhaust valves are operated through valve lifters as in an L-head engine. Both sets of valves are operated from the same camshaft. The manufacturer of this engine believes that the F-head arrangement permits the use of larger intake valves and shorter, more direct air-fuel mixture passages (thus improving volumetric efficiency). At the same time, the exhaust valves, being located in the block, incorporate the simplicity of the L-head design.

§129. Valve rotation. In all the valve mechanisms thus far discussed, the valve simply moves up and down; it has little tendency to rotate. The valve-spring pressure, carried through the valve retainer and lock to the valve stem, tends to prevent any valve rotation in the valve guide. However, tests have shown that if the valve could be allowed to rotate a small amount each time it opened and closed, many valve troubles would be minimized. For example, one common cause of valve burning is the depositing of combustion products on the valve faces. Such deposits prevent normal valve seating, face-to-seat contact, and heat transfer. Soon, as the deposits collect, valves begin to overheat and burn. The poor seating also permits exhaust-gas leakage, which accelerates the burning process. Another cause of valve trouble is valve sticking. This condition usually results from accumulations of decomposed, or carbonized, oil (brought about by the high temperatures) on the valve stem. Ultimately, these deposits work into the clearance between the valve stem and valve guide; the valve sticks, or "hangs up" in the guide and does not close. Then, with poor or no seating, the valve soon overheats and burns.

Whenever a valve burns or does not seat properly, loss of compression and loss of combustion pressure will result. This means that the engine cylinder where the offending valve is located will be "weak"; it will not deliver its share of the power.

If the valve is rotated as it opens and closes, there will be less chance of valve-stem accumulations causing the valve to stick.
### Fig. 7-43. End sectional view of an F-head engine with inlet valves in head and exhaust valves in block.

<table>
<thead>
<tr>
<th>Number</th>
<th>Part Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inlet valve-spring retainer</td>
</tr>
<tr>
<td>2</td>
<td>Breather cap</td>
</tr>
<tr>
<td>3</td>
<td>Adjusting screw</td>
</tr>
<tr>
<td>4</td>
<td>Adjusting-screw nut</td>
</tr>
<tr>
<td>5</td>
<td>Rocker arm</td>
</tr>
<tr>
<td>6</td>
<td>Push rod</td>
</tr>
<tr>
<td>7</td>
<td>Intake-valve guide</td>
</tr>
<tr>
<td>8</td>
<td>Intake valve</td>
</tr>
<tr>
<td>9</td>
<td>Exhaust valve</td>
</tr>
<tr>
<td>10</td>
<td>Cylinder-head gasket retainer</td>
</tr>
<tr>
<td>11</td>
<td>Exhaust-valve guide</td>
</tr>
<tr>
<td>12</td>
<td>Exhaust manifold</td>
</tr>
<tr>
<td>13</td>
<td>Exhaust-valve spring</td>
</tr>
<tr>
<td>14</td>
<td>Ventilator baffle</td>
</tr>
<tr>
<td>15</td>
<td>Crankcase ventilator</td>
</tr>
<tr>
<td>16</td>
<td>Oil pump driven</td>
</tr>
<tr>
<td>17</td>
<td>Camshaft</td>
</tr>
<tr>
<td>18</td>
<td>Oil pump</td>
</tr>
<tr>
<td>19</td>
<td>Relief plunger</td>
</tr>
<tr>
<td>20</td>
<td>Relief-plunger spring</td>
</tr>
<tr>
<td>21</td>
<td>Relief-spring</td>
</tr>
<tr>
<td>22</td>
<td>Oil pan</td>
</tr>
<tr>
<td>23</td>
<td>Oil-pan drain plug</td>
</tr>
<tr>
<td>24</td>
<td>Oil-float support</td>
</tr>
<tr>
<td>25</td>
<td>Oil float</td>
</tr>
<tr>
<td>26</td>
<td>Crankshaft</td>
</tr>
<tr>
<td>27</td>
<td>Timing-hole cover</td>
</tr>
<tr>
<td>28</td>
<td>Rear engine plate</td>
</tr>
<tr>
<td>29</td>
<td>Cylinder block</td>
</tr>
<tr>
<td>30</td>
<td>Connecting rod</td>
</tr>
<tr>
<td>31</td>
<td>Oil-filler tube</td>
</tr>
<tr>
<td>32</td>
<td>Piston</td>
</tr>
<tr>
<td>33</td>
<td>Vacuum-tube connection</td>
</tr>
<tr>
<td>34</td>
<td>Cylinder head</td>
</tr>
<tr>
<td>35</td>
<td>Inlet valve spring</td>
</tr>
</tbody>
</table>
Also, there will be a wiping action between the valve face and the valve seat; this tends to prevent any build-up of face deposits. In addition, valve rotation results in more uniform valve-head temperatures. Some parts of the valve seat may be hotter than others; actual hot spots may develop. If the same part of the valve face continued to seat on a hot spot, that part of the valve face would reach a higher temperature and would tend to wear, or burn, faster. But if the valve rotates, no one part of the valve face is subjected to this higher temperature. Valve-head temperature is more uniform.

§130. Valve rotators  The engine shown in Fig. 7-43 uses a "free-valve" type of rotator on the exhaust valve. Details of this type of [230]
rotators are shown in Figs. 7-44 and 7-45. In this design the spring-retainer lock has been replaced by two parts, a washer-type lock (split) and a tip cup. As the valve lifter moves up, the adjusting screw presses against the tip cup, and the tip cup then carries the motion to the lock and valve retainer. The valve retainer is lifted, thereby taking up the valve-spring pressure. Then the bottom of the tip cup moves up against the end of the valve stem, so that the valve is lifted. Note that the spring pressure is taken off the valve stem; the valve is free. Since it is free, it can rotate. Engine vibration causes the valve to rotate.

The free-valve type of rotator can be used on either an L-head or an overhead-valve engine. Figure 7-44 shows it installed on an L-head type exhaust valve.

A positive-rotation type of valve rotator is shown in Figs. 7-46 and 7-47. This design contains a device that applies a rotating force on the valve each time it is opened, thereby assuring positive rotation. Figure 7-46 shows the details of the rotator, while Fig. 7-47 shows it installed on a valve in an I-head engine. A seating collar (A in Fig. 7-46) is spun over the outer lip of the spring retainer (B). The valve spring rests on the seating collar. The collar encloses a flexible washer (C) placed above a series of spring-loaded balls (D). The middle view shows how the balls and springs are positioned in grooves in the spring retainer. The bottoms of the grooves (or races) are inclined as shown in the bottom view (E), which is a section (X-X) cut from the middle view. When the lifter is raised, the adjusting screw (G) lifts the valve and applies an increased pressure.
(as the valve spring is compressed) on the seating collar. This flattens the flexible washer (C) so that the washer applies the spring load on the balls (D). As the balls receive this load, they roll down the inclined races. This causes the retainer to turn a few degrees; this turning motion is applied through the retainer lock to the valve stem; the valve therefore turns. When the valve closes, the spring pressure is reduced so that the balls return to their original positions, ready for the next valve motion.

Fig. 7-47. Installation of positive-rotation type of valve rotator on the valve in an I-head, or overhead valve, engine. (Thompson Products, Inc.)

The positive-rotation type of valve rotator can be installed on the valves in either the L-head or I-head engine. It can be installed at the tip end of the valve, as shown in Fig. 7-47, or at the valve-guide end, between the valve spring and the cylinder block, or head. In the latter installation, the turning motion would be carried from the rotator through the spring, spring retainer, and lock to the valve stem.

§131. Hydraulic valve lifter Many engines now use a hydraulic valve lifter. This type of lifter, which provides zero valve clearance,
is very quiet in operation. There is no "click" (or tappet noise, as it is called) as the adjusting screw on the valve lifter meets the valve stem (or push rod), as there may be with other lifters, particularly when clearances are high. On the hydraulic valve lifter there is no adjusting screw and there is no clearance.

Figure 7-48 is a cutaway view of one bank of a V-8 L-head engine using hydraulic valve lifters. Figure 7-49 shows a somewhat different type of hydraulic valve lifter installed on a V-8 overhead-valve engine. Figure 7-50 shows the operation of this type of valve lifter, while Figs. 7-51 and 7-52 show details of construction of the lifter. Figure 7-53 illustrates a hydraulic valve lifter of another type. Regardless of type, oil is fed into the valve lifter under engine-oil-pump pressure, from an oil gallery that runs the length of the engine (a V-8 would have two oil galleries, one for each bank).

When the valve is closed, oil (from engine oil-pump) is forced
into the hydraulic valve lifter through the oil holes in the lifter body and plunger (see Fig. 7-50 for an illustration of the following action story). As the oil enters the plunger, it acts on the ball-check valve in the bottom of the plunger, forcing it open. Oil now passes the ball-check valve and enters the space under the plunger. The plunger is therefore forced upward until it comes into contact with the valve push rod (or valve stem on L-head engine). This takes up any clearance in the system.

Now, when the cam lobe moves around under the lifter body,
Pistons and Valves

§131

**Fig. 7-50.** Two positions of the hydraulic valve lifter: with valve open and valve closed. *(Mercury Division of Ford Motor Company)*

**Fig. 7-51.** Cutaway view of a hydraulic valve lifter. *(Chevrolet Motor Division of General Motors Corporation)*
the lifter is raised. Since there is no clearance there is no tappet noise. As the lifter is raised, the sudden increase in oil pressure in the body chamber under the lifter causes the ball-check valve to close. The oil is therefore trapped in the chamber and the lifter acts

![Disassembled view of hydraulic valve lifter](image1)

![Sectional view of a hydraulic valve lifter](image2)

as a simple, one-piece lifter. It moves up as an assembly and causes the valve to open. Then, when the lobe moves out from under the lifter, the valve spring forces the valve to close and the lifter to move down. The pressure on the oil in the chamber under the
plunger is reduced and the ball-check valve opens. Oil from the engine oiling system is again forced past the ball-check valve to replace whatever oil may have leaked from the chamber. Slight amounts of oil may leak past the ball-check valve and between the plunger and lifter body. As this oil is replaced, the plunger moves up as much as is necessary to bring the push-rod seat into contact with the push rod. This eliminates any clearance in the valve train.

§132. Valve timing In previous discussions of engine and valve action it was assumed that the intake and exhaust valves opened and closed at TDC and BDC. Actually, as can be seen from Fig. 7-54, the valves are not timed to open or close at these points in the engine cycle of operation. For example, in the valve-timing diagram illustrated the exhaust valve starts to open at 45 degrees before BDC on the power stroke. It remains open through the remainder of the power stroke and through the entire exhaust stroke. It does not close until 5 degrees after TDC on the intake stroke. This additional exhaust-valve opening gives more time for the exhaust
gases to leave the cylinder. When the exhaust valve starts to open
(45 degrees before BDC), the combustion pressures have dropped
considerably; most of the available power of the burning charge has
already been transmitted to the downward-moving piston. Opening
of the exhaust valve this early gives the exhaust gases additional
time to exhaust from the cylinder.

Note: To get an idea how much the combustion pressure has
dropped at 45 degrees before BDC on the power stroke, refer to
Fig. 4-5 which shows the pressures in an engine cylinder during
the four piston strokes. In the curve shown, the pressure has
dropped from a peak combustion pressure of almost 700 psi
(pounds per square inch) to about 100 psi at 45 degrees before
BDC on the power stroke.

The intake valve starts to open at 5 degrees before TDC on the
exhaust stroke, thus giving a 10-degree overlap during which both
valves are at least partly open. The intake valve then stays open
until 45 degrees past BDC on the compression stroke. This gives
the air-fuel mixture additional time to enter the cylinder. As you
will recall from our discussion of volumetric efficiency (§69),
delivery of adequate amounts of air-fuel mixture to the cylinders
is a critical item in engine operation. Actually, the cylinder is never
quite "filled up" when the intake valve closes. Thus there is no
loss of compression resulting from the intake valve staying open
well past BDC on the compression stroke. At BDC as the com­
pression stroke starts, pressure in the cylinder is below atmospheric
(see Fig. 4-5). Pressure does not reach atmospheric until the
piston is well past BDC.

The illustration of valve timing (Fig. 7-54) is for one engine.
Different engines have different degrees of valve timing. In some,
valves open and close earlier or later than shown in Fig. 7-54, re­
main­ing open for different degrees of cam rotation.

Timing of the valves is obtained by the relationship between the
gears or sprockets on the camshaft and crankshaft, as well as by
the contours of the cam lobes. Changing the relationship between
the driving gear or sprocket and the driven gear or sprocket changes
the timing at which the valves open and close. For instance, if the
camshaft gear were de-meshed and then moved ahead one tooth
and remeshed, the valves would open and close that much earlier
(in relation to crankshaft and piston position). If this moved the
[238]
valve action ahead 15 degrees, the exhaust valve would open at 60 degrees before BDC on the power stroke and close at 10 degrees before TDC on the exhaust stroke (in the example shown in Fig. 7-54). The intake-valve actions would be moved ahead a like amount. This would seriously reduce engine performance. In addition, in the newer engines with very small clearances between piston and valves, there would be danger of the piston striking the valve heads. To prevent these troubles, the gears or sprockets are marked so that they can be properly aligned (see Figs. 7-27 and 7-28).

§133. Cam contours Figure 7-55 shows the details of a cam-lobe contour. The width of the lobe determines the number of degrees of cam rotation that the valve will be open. If the lobe were wider (nose broader or less pointed), then the valve would remain open longer, or for a greater number of degrees of cam rotation. The lift is the distance between the base circle and the nose; this distance determines the distance that the valve will move as it opens. If the lift is increased, then the valve will move further and thus open wider. The flank is the curved area from the base circle (closed-valve section) to the nose (wide-open-valve section).

The cam contours must be designed for each engine so as to give the valve movements that will produce best engine performance. The valve must open and close at the proper times, and stay open for the correct number of degrees of cam rotation. In addition, it must open the correct amount (have the proper lift). Furthermore, the acceleration of the valve (as it starts to open, speeds up, reaches...
wide-open position, then closes again) must be correct. This is a function of the flank contour. If acceleration is excessive, the valve-train parts will be "pounded" or subjected to excessively rapid speed changes which will wear them rapidly. For instance, if the flank permitted excessively rapid valve closing, the valve face and valve seat would be brought together too rapidly. This would mean short valve and seat life.

CHECK YOUR PROGRESS

Progress Quiz 14

Once more you can pause and check up on the progress you are making in remembering the facts you are reading in the book. If any of the questions seem hard or stump you, just review the past few pages.

Correcting Parts Lists

The purpose of this exercise is to help you spot unrelated parts in a list. For example, in the list, valve, spring, lifter, retainer, spark plug, the only part that is not part of the valve mechanism is the spark plug. This part, therefore, does not belong in the list.

In each of the lists, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. Parts that operate off the camshaft include the valves, fuel pump, water pump, oil pump, distributor.
2. Parts of the poppet valve include the head, margin, skirt, face, stem.
3. Parts in the L-head valve train include the valve, spring, retainer, crankshaft, lifter, lock, adjusting screw.
4. Parts in the I-head valve train include the lifter, push rod, rocker arm, connecting rod, valve, spring, adjusting screw.
5. Parts in the hydraulic valve lifter include the push-rod seat, plunger, ball, ball retainer, piston ring, body, spring.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. In operation it is not uncommon for the exhaust-valve-head temperatures to reach 1000°F, 1500°F, 2000°F, 2500°F.
Pistons and Valves

2. In normal operation the part of the exhaust valve that gets the hottest is the face middle of stem edge of margin center of head.

3. Cooling of the exhaust valve is assisted by two parts, the guide and lifter guide and spring guide and seat guide and cam.

4. The sodium-cooled valve, in comparison with solid-stem valves operating under similar conditions, will run as much as 200 ° cooler 400 ° cooler 100 ° hotter 200 ° hotter.

5. The conical type of valve-spring-retainer lock fits between the valve stem and spring valve stem and spring retainer valve lifter and stem.

6. The I-head valve train includes two items not found in the L-head valve train. These are the push rod and lifter spring retainer and lock push rod and rocker arm rocker arm and valve lifter.

7. In the I-head valve train the adjusting screw is located in the rocker arm push rod valve lifter.

8. Valve rotation improves valve life since it tends to prevent the accumulation of deposits on the valve stem and head valve margin and face valve stem and face.

9. In the free-valve type of valve rotator, valve-spring pressure on the valve stem is relieved as the tip cup moves up against the valve head spring-retainer lock valve spring roller balls.

10. As the hydraulic valve lifter moves up, opening the valve, the ball-check valve in the plunger is opening closing open closed.

CHAPTER CHECKUP

NOTE: Since the following is a chapter review test, you should review the chapter before taking the test.

You have now completed the first half of the book, or the part that is designed to give you the theoretical background on engines that you need for automotive-engine maintenance and repair work. You have been making excellent progress and by now should have a good practical knowledge of engine components, their construction and operation. Once again, a checkup has been included to permit you to check yourself on how well you have been absorbing the material you have been reading. If you are not sure of the answers for any of the questions, turn back into the chapter and reread the pages that will give you the answer. Also, when you are asked to make a list of parts, as for instance
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those in the hydraulic valve lifter, you may wish to refer to the text and illustrations pertaining to the lifter. The act of writing down the names of the parts will help you to remember them. Write down your answers in your notebook.

Note: It is still not too late to start a notebook in case you have not been keeping one. A notebook becomes increasingly important as you move into the shopwork part of the Automotive Engines book, since you will want to write down and keep important details of making engine repairs and operating repair machinery.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. The three methods of installing the piston pin are ___________.
   - pin locked to rod, locked to crankpin, or free
   - pin locked to rod, locked to piston, or free
   - pin locked to piston boss, locked to piston, locked to rod

2. Three jobs that piston rings do are ___________.
   - seal, attach piston pin, control oil
   - hold intake, hold compression, seal
   - control oil, cool

3. With reference to the number of piston rings, automotive engines usually use ___________.
   - two or three rings
   - three or four rings
   - four or five rings

4. The oil that circulates on the cylinder walls and piston and through the oil-control rings can be said to do four jobs; it ___________.
   - lubricates, seals, cleans, and cools
   - lubricates, cools, oils, and cleans
   - circulates, lubricates, cleans, and oils

5. Under normal operating conditions the difference in temperature between the piston head and the lower part of the piston skirt may be between ___________.
   - 20 and 30°
   - 200 and 300°
   - 2000 and 3000°

6. Clearance between the cylinder wall and piston of a new engine is somewhere around ___________.
   - 0.0001 inch
   - 0.001 inch
   - 0.01 inch
   - 0.1 inch

7. When the valve is seated, it is in contact with two stationary parts, the ___________.
   - seat and guide
   - seat and retainer
   - seat and retainer lock

8. One advantage of using an exhaust-valve-seat insert is that the ring ___________.
   - is more easily machined
   - wears in more quickly
   - withstands high exhaust-gas temperatures better
Pistons and Valves

9. One of the important reasons for the use of a valve guide, rather than a hole drilled in the block (or head), is that the guide wears in more quickly and can be replaced when it wears is more easily machined.

10. In the cam, the distance between the base circle and the nose is called the flank lobe nose lift.

Definitions and Lists

In the following you are asked to write down the function or define the purpose of different engine parts, or to make lists. Write these down in your notebook. The act of writing down these items does two things; it tests your knowledge, and it also helps fix the information more firmly in your mind. Turn back into the chapter if you are not sure of an answer, and reread the pages that will give you the information you need.

1. List the various parts that make up the connecting-rod assembly.
2. List four types of piston-ring joints.
3. What are the three functions of piston rings?
4. What four jobs does the lubricating oil do on the cylinder walls, rings, and piston?
5. What is the function of the piston-ring expander?
6. What happens when a cam-ground piston warms up?
7. List the parts in the L-head valve train.
8. List the parts in the I-head valve train.
9. What are three advantages of rotating the valves?
10. List the parts in a hydraulic valve lifter.
11. What determines the amount that the valve will move as it opens?
12. What determines the number of degrees of cam rotation that the valve will stay open?

Suggestions for Further Study

To study pistons and valves further, go to a friendly service shop where engine repair work is done, so that you can see various types of pistons and valve mechanisms. Handle these parts if you can and notice how they are constructed and put together. You will be able to handle and inspect these parts in your own school automotive shop, of course. Your school shop may have cutaway and working models that will help you understand better how valve mechanisms operate. You will also find factory shop manuals of interest. These manuals are published by engine and accessory manufacturers for the benefit of automotive mechanics. They contain much valuable information on the construction and servicing of automotive engines. A careful study of such manuals will be of value to you.

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8: Automotive engine fuels and fuel systems

This chapter describes in further detail automotive fuel systems and also supplies information on fuels used in automotive engines. In Chap. 3 (§56) we described the manner in which the fuel pump delivers gasoline from the fuel tank to the carburetor and gave a brief description of how the carburetor operates. In the pages that follow we describe carburetor action in more detail and then discuss the relationships between engine performance and fuel characteristics. We suggest that you review §56 before starting this chapter. Some engines use as many as three carburetors that work together to provide better acceleration and high-speed performance. Some engines do not have carburetors. Instead, they use a fuel-injection system that sprays the fuel into the intake manifold (§143).

§134. Carburetor circuits The carburetor (Fig. 8-1) has several fuel passages, or circuits, that work together or separately to provide balanced performance under varying operating conditions. These circuits include: (1) float circuit; (2) idle and low-speed circuit; (3) high-speed part-load circuit; (4) high-speed full-power circuit; (5) accelerating-pump circuit; and (6) choke circuit. Let us discuss each of these in detail.

§135. Air cleaner Before we start discussing the carburetor circuits, we should describe the air cleaner, the device mounted on the carburetor that removes dust from the air entering the carburetor. Figures 5-2 and 5-8 illustrate engines with the carburetors and air cleaners in place.

The air drawn into the engine through the carburetor contains dirt and dust particles. If these particles got into the engine,
they could cause rapid wear of all moving engine parts, including bearings, piston rings, pistons, and valves. This will give you some idea of the amount of air the engine requires: The engine may use as much as 100,000 cubic feet of air every 1,000 miles. And 100,000 cubic feet of air can hold a considerable amount of dust.

An oil-bath type of air cleaner is shown in Fig. 8-2, partly cut away so that the air path through it can be seen. As the air enters, it first moves past the oil reservoir, picking up particles of oil as it does. The air then moves up through the cleaning unit, which is composed of fine-mesh metal threads, or strands. Here dust particles, as well as the oil particles, are trapped. The cleaned air moves on into the carburetor. The oil drops back down into the oil reservoir, washing out many of the dust particles as it does so. The air
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§136. **Float circuit** The float circuit has already been described in some detail (§56, 3). A simplified drawing of a float bowl is shown in Fig. 3-19. Figure 8-3 is a drawing of an actual float-bowl system. Gasoline enters as shown by the large arrow, passing the float needle valve to fill the float bowl. As the bowl fills, the float rises, pivoting on the lever that attaches it to the bowl. As the float rises, the float-lever lip moves up, thereby lifting the needle valve and forcing it into the needle-valve seat. This shuts off the delivery of gasoline to the float bowl. When gasoline is withdrawn from the float bowl by the carburetor, the float drops, opening the needle valve, so that the fuel pump can deliver additional fuel to the float bowl.

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Idle and low-speed circuit

When the engine is idling or running at low speed, the throttle is closed or nearly so. This means that only a small amount of air can flow through the carburetor air horn. The air flow is so small, in fact, that no appreciable amount of vacuum develops in the carburetor venturi. This means that the main fuel nozzle centered in the venturi (Figs. 3-20 and 3-23) will not deliver any gasoline. Another fuel circuit must deliver gasoline under these conditions.

The idle and low-speed circuit takes over when the throttle is closed or nearly closed, and supplies the engine with the air-fuel mixture it needs to operate. This circuit consists of a series of openings and holes drilled in the carburetor body which connect between the upper part of the carburetor air horn and a port (the idle port) below the throttle valve (Fig. 8-4). With the throttle closed there is a high vacuum in the intake manifold (or under the throttle valve) while the engine is running. Atmospheric pressure therefore pushes air and gasoline through the idle and low-speed circuit and out around the idle adjustment screw. There it mixes...

Fig. 8-3. Sectional view of a carburetor, showing float system. Fuel enters as shown by large arrow. (Studebaker-Packard Corporation)
with the air leaking past the throttle valve to form a mixture of satisfactory richness for idle operation. To change the mixture richness, the idle adjustment screw can be turned in or out. When it is turned out, the size of the opening around the needle tip of the screw is increased, thereby allowing more air-fuel mixture to pass. This enriches the mixture. Turning the adjustment screw in reduces the amount of air-fuel mixture that can pass through the idle port. This leans out the mixture.

§138. Low-speed circuit When the throttle is opened slightly, the edge of the valve moves past a low-speed port in the side of the carburetor horn (located just above the idle port). This port is usually a vertical slot or a series of holes with one drilled just above the next. As the throttle valve moves past the low-speed port, the intake-manifold vacuum (below the valve) causes the low-speed port to start discharging air-fuel mixture (Fig. 8-5). This supplies the engine with the additional fuel it needs for operating at a speed [248]
a little above idle. Note that some air is now moving past the throttle valve; it mixes with the air-fuel mixture discharging from the idle and low-speed ports to produce a mixture of the proper richness for the operating conditions.

Fig. 8-5. Idle and low-speed circuit in carburetor. Throttle valve has been opened slightly and air-fuel mixture is being fed through the low-speed port. Lines indicate air; arrows indicate gasoline. (Chevrolet Motor Division of General Motors Corporation)

§139. High-speed, part-load circuit As the throttle is opened further for high speed operation, its edge moves well past the low-speed port. In this position the vacuum at the port is insufficient to produce any appreciable air-fuel discharge. However, under these conditions the air moving down through the air horn is sufficient to produce an operating vacuum in the carburetor venturi. The high-speed circuit now goes to work and supplies the fuel that the engine needs to operate. The high-speed circuit consists of the venturi, the high-speed nozzle (or main nozzle), and the gasoline passages from the float bowl to the nozzle (Fig. 8-6). The gasoline discharged from the main nozzle mixes with the passing air so that a mixture of the proper richness for the operating conditions is produced.
The low-speed circuit does not suddenly stop supplying air-fuel mixture and the high-speed circuit suddenly take over. Actually, one leaves off more or less gradually (as the throttle is slowly opened) as the other takes over. They overlap to some extent.

**Fig. 8-6.** High-speed circuit in carburetor. Throttle valve is partly open and gasoline is discharging from the high-speed or main nozzle. Lines indicate air; arrows indicate gasoline. (Chevrolet Motor Division of General Motors Corporation)

§140. **High-speed, full-power circuit** The air-fuel ratio of the mixture supplied by the high-speed circuit is satisfactory for all engine operation from partly open to nearly wide-open throttle. But at wide-open throttle, when full power is demanded from the engine, a somewhat richer mixture is required. To achieve this a special device is incorporated in the carburetor, which supplies additional gasoline under full-power, wide-open-throttle operation.

Figure 8-7 shows the details of this special device. Essentially, it is nothing more than a rod and a jet, or fuel opening. The rod has a smaller diameter section at its lower end. The metering-rod jet is the fuel opening through which all gasoline passes from the float bowl to the main nozzle. You can see the location of the metering rod and jet in Fig. 3-23 (lower right). The rod is attached to the throttle linkage so that it is lifted as the throttle is opened. By [250]
the time the throttle is wide open the smaller diameter section of the rod has lifted into the rod jet. This, in effect, opens up the jet more and allows more gasoline to flow through. This enriches the mixture so that the engine develops full power.

The job may be done by intake-manifold vacuum, instead of by mechanical linkage. Figure 8-8 shows a carburetor with a vacuum-operated valve that stays closed during part-throttle operation when there is vacuum in the intake manifold. (The valve is called an economizer valve in the design shown.) During this type of operation the vacuum holds the vacuum piston up so that the economizer valve remains closed. When the throttle is opened wide, the manifold vacuum drops. When this happens, the vacuum is no longer sufficient to
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hold the vacuum piston up. Spring pressure pulls the vacuum piston down, and the end of the piston rod opens the economizer valve. This opens a second jet through which fuel can be fed to the main nozzle; the mixture is enriched.

In some carburetors a metering rod is used which is operated by both throttle linkage and intake-manifold vacuum. In these units either mechanical linkage from the throttle linkage or vacuum in the intake manifold can control the full-power device. This arrangement permits mixture richness at part throttle with a low manifold vacuum (as for instance during low-speed, part throttle, heavy-pull conditions).

§141. Accelerating-pump circuit When the throttle is moved from the closed position, the low-speed circuit stops supplying gasoline. At the same time, as the throttle opens, it takes a moment for the high-speed nozzle to start supplying gasoline. Thus there may be a moment when neither circuit is supplying enough gasoline; this

Fig. 8-9. Accelerator-pump system in carburetor. Lines indicate air; arrows indicate gasoline. (Chevrolet Motor Division of General Motors Corporation)
could cause a momentary "flat spot" in engine performance during which the engine hesitates or does not pick up speed. To get the engine over this flat spot, the carburetor incorporates an accelerating-pump circuit. The accelerating-pump circuit operates as the throttle is opened to supply additional gasoline to the air passing through the carburetor. This momentarily enriches the mixture and carries the engine through the closed-throttle to open-throttle transition period.

The accelerating-pump system consists of a pump piston linked to the throttle and a fuel passage from the piston chamber to the carburetor air horn (Fig. 8-9). When the throttle is opened, the piston is forced downward, and this forces gasoline through the passage; it then sprays out the accelerating-pump jet into the passing air stream. Figure 3-23 shows a complete carburetor in sectional view; you can see in this illustration how the accelerating-pump system is related to other carburetor parts.

§142. Choke

When the engine is being cranked for starting, the air speed through the carburetor air horn is very low. This means that carburetor-venturi and intake-manifold vacuum will be low so that only small amounts of gasoline are delivered from the fuel nozzles. In addition to this, if the engine is cold, then the gasoline that is delivered will not evaporate and mix readily with the passing air. Under these conditions it would be very difficult to start the engine and keep it running when it is cold, if it were not for the carburetor choke.

The carburetor choke is designed to cause the carburetor to deliver additional amounts of gasoline for starting and when the engine is cold. The choke consists of a round, or butterfly, valve (much like the throttle valve in shape) assembled into the top part of the carburetor air horn. The choke valve is attached to a shaft. When the shaft is rotated, the choke valve is tilted more or less in the air horn. In the "dechoked" position the choke valve is vertical as shown in Fig. 8-9. But in the choking position the choke valve is tilted until it is almost horizontal as shown in Fig. 8-10, and it "choke off" most of the air. This means that there is a vacuum under the choke valve when the engine is being cranked or is running. The vacuum then causes the main nozzle to deliver...
gasoline as shown in Fig. 8-10. A very rich mixture is therefore delivered to the engine. This aids starting and initial running when the engine is cold.

Most automobiles now have automatic devices that operate the choke valve in accordance with engine demands: very rich for starting, rich for initial running when the engine is cold, and leaning out as the engine warms to normal hot-engine mixture ratios.

The choke valve may be controlled electrically, thermostatically, or manually. The thermostatic control is the most commonly used choke control (Fig. 8-11). The thermostat is a bimetal spring that winds up and unwinds with changing temperatures (see §18). When the engine is cold, the thermostat has unwound enough to cause the choke valve to assume the closed position. When the engine is cranked for starting, the choke valve causes the carburetor to deliver a very rich mixture. As soon as the engine starts, this initial mixture will be too rich. To provide for some leaning out, the choke...
valve is unbalanced (with attaching shaft toward one side) so that the air passing through the air horn tends to open it (working against the thermostatic-spring tension that tries to keep it closed). At the same time the vacuum under the throttle valve (as the engine runs) works a vacuum piston in the choke control. The vacuum piston moves down in its cylinder against the thermostatic-spring tension to produce further choke-valve opening.

This process opens the choke valve the correct amount for proper mixture richness during initial, cold-engine running. When the throttle is opened, the vacuum in the intake manifold is reduced, and this releases the vacuum piston. The thermostatic spring (against which the vacuum piston has been working) now causes choke-valve movement toward the closed position. This enriches the mixture, adding to the accelerating-pump action, for good cold-engine acceleration.

As the engine warms up, the thermostatic spring begins to wind up. This winding up gradually relieves the spring tension tending to hold the choke valve closed. The choke valve moves toward the open position, thereby causing a leaning out of the mixture. By the time the engine has reached operating temperature, the choke valve
§143. Gasoline fuel-injection systems The gasoline fuel-injection system that is used on a number of engines eliminates the carburetor. In place of the carburetor, a fuel-injection pump and an injector are used (Fig. 8-12). The fuel-injection pump delivers liquid gasoline to the injectors. The injectors then spray the liquid gasoline into the air streams entering the cylinders when the intake valves are open. The gasoline is rapidly vaporized in this process so that the air-fuel mixture can burn efficiently.

The system is controlled by an air-throttle valve that is similar to the throttle valve in carburetors. When the air-throttle valve is opened, more air enters. At the same time, the fuel-injection pump and injectors provide more fuel. Thus the engine develops more power and increases in speed. In some systems, the air-throttle valve is linked mechanically to a metering valve in the fuel-injection system. This mechanical linkage varies the amount of fuel delivered as the throttle position and amount of air delivered are varied. In other systems, the variation of the amount of fuel delivered is determined on a speed basis through mechanical or electric controls.

§144. Other carburetor controls In addition to the circuits and controls discussed above, the carburetor may contain other controls that influence carburetor and engine operation under certain conditions. These are discussed below.

1. Throttle cracker. During cranking for starting, the throttle must be opened a small amount, or cracked, so that enough air can get to the engine. To accomplish this, there is a linkage between the cranking motor and the throttle valve. When the cranking motor is operated, the throttle valve is opened slightly.

2. Fast idle. When the engine is cold, it must be idled at a fairly high speed. Otherwise, it is apt to die for lack of gasoline. This high idling speed with the engine cold is obtained by a linkage between the carburetor choke valve and a fast-idle cam. When the choke valve is closed (by the thermostatic control), the linkage has rotated the fast-idle cam into a position so that the fast-idle adjusting screw now rests on the high point of the cam. This prevents the throttle valve from closing completely. The engine, therefore,
idles fast. As the engine warms up, the thermostat opens the choke valve. At the same time, the linkage to the fast-idle cam rotates the cam so that the fast-idle adjusting screw no longer rests on the high point of the cam. It therefore no longer tends to hold the throttle open. The throttle can close to give the normal warm-engine, slow idle.

3. Antipercolator. Since the carburetor is subjected to engine and exhaust-manifold heat, it sometimes develops a tendency to "percolate," that is, to boil over and feed extra gasoline. This happens particularly when the throttle is suddenly closed after a hard run. To prevent this the carburetor may include an antipercolator device that opens a vent when the throttle is cold, to permit gasoline vapor to escape instead of forcing the gasoline to boil over. Other types of antipercolator devices make use of a small tube or opening in the high-speed circuit, which vents gasoline vapor into the air horn.

4. Starting control switches. Some carburetors have built-in starting control switches which close the control circuit to the starting motor when the accelerator pedal is depressed. After the engine starts, the intake-manifold vacuum opens the starting control switch; the throttle movement then has no effect on the switch. The switch works only when the engine is not running.

5. Automatic transmission controls. Some cars equipped with automatic transmissions have special devices on the carburetor that enable the engine and transmission to cooperate more closely. One such device is a throttle-return check which prevents sudden closing of the throttle. This is important with certain automatic transmissions since the fluid coupling or torque converter in the transmission inserts considerable flexibility between rear wheels and engine. Sudden closing of the throttle could therefore permit rapid slowing of the engine even though the car keeps on moving (the coupling or converter meanwhile slipping). This could cause momentary hesitation of the engine. But the throttle-return check prevents this since it slows down throttle closing. Kick-down switches and other devices related to automatic-transmission operation are also incorporated in some carburetors. See Automotive Fuel, Lubricating, and Cooling Systems (another book in the McGraw-Hill Automotive Mechanics Series) for further details.
CHECK YOUR PROGRESS

Progress Quiz 15

Here is your periodic checkup again. Read the instructions, and go to it. Write in your notebook so that you will have a permanent record of your achievements.

Unscrambling the Circuits

When the two lists below are unscrambled, they will form a list of the various circuits in a carburetor. To unscramble the lists, take one item at a time from the list to the left, and then find the item from the list to the right that goes with it. Write the result down in your notebook. For example, the first item in the list to the left is "idle." When you look down the list to the right, you can see that the only item that goes with "idle" is "and low-speed circuit." So you put the two together to form "idle and low-speed circuit" which is one of the circuits in the carburetor.

<table>
<thead>
<tr>
<th>idle</th>
<th>circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>high-speed</td>
<td>and low-speed circuit</td>
</tr>
<tr>
<td>accelerating-pump</td>
<td>part-load circuit</td>
</tr>
<tr>
<td>float</td>
<td>circuit</td>
</tr>
<tr>
<td>high-speed</td>
<td>circuit</td>
</tr>
<tr>
<td>choke</td>
<td>full-power circuit</td>
</tr>
</tbody>
</table>

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. The device on the carburetor that removes dust from the entering air is called the
   - air cleaner
   - air circuit
   - oil-bath duster

2. The circuit in the carburetor that maintains a constant level of gasoline in the gasoline reservoir, or bowl, is called the
   - idle circuit
   - reserve circuit

3. The reason that the main nozzle cannot deliver gasoline when the engine is idling is that the air speed through the carburetor is too low to develop sufficient
   - fuel velocity
   - venturi vacuum
   - fuel pressure
   - mixture leanness

4. When the engine is idling, all gasoline being burned is discharged around the idle adjustment screw around the idle-speed

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5. As the metering rod is lifted by movement of the throttle to the wide-open position, more fuel is permitted to pass through the needle valve metering-rod jet idle circuit low-speed circuit.

6. When the accelerating-pump piston is forced down by opening the throttle, a spray of gasoline is delivered through the throttle circuit to the intake manifold to the passing air stream to the low-speed circuit.

7. When the choke valve is closed and the engine is cranked for starting, the high vacuum in the intake manifold causes gasoline to flow from the starting circuit choke circuit main nozzle idle circuit.

8. In the automatic choke the position of the choke valve is determined by the thermostatic spring and vacuum piston magnetic spring and pump piston choke button choke knob choke lever.

9. The device that opens the throttle slightly during cranking is called the throttle choke throttle linkage throttle cracker throttle valve.

10. The fast-idle cam, which causes the engine to idle fast when cold, is connected by linkage to the idle circuit low-speed circuit choke valve.

§145. Automotive-engine fuels

The American passenger-car engine uses gasoline as a fuel. Other types of engines, such as those used in tractors, trucks, buses, and road machinery, may use fuel oil (diesel-engine type) or liquefied petroleum gas (abbreviated LPG). Since the great majority of automotive engines use gasoline as fuel, most of the discussion of fuels that follows deals with gasoline. However, brief discussions of other types of fuel also are included; the automotive man should know something of the characteristics of these other fuels.

§146. Diesel-engine fuel

As you will recall, the diesel engine compresses only air on the compression stroke, and then injects fuel oil at the start of the power stroke (§87). The oil is ignited by the heat of the compressed air so that combustion and the power stroke follow. Diesel fuel oil essentially is a light oil produced by a refining process from crude petroleum. Section 148 supplies further information on the source of crude oil, or petroleum. A good diesel-

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engine fuel oil must have certain characteristics, such as proper viscosity, cetane number, and specific gravity (or heaviness) as well as cleanliness. Several of these are discussed below.

1. **Viscosity.** "Viscosity" is a term that refers to the tendency of a liquid to resist flowing. A heavy oil has a higher viscosity than a light oil and flows more slowly. "Molasses in January" flows very slowly; it has a very high viscosity. Water has a very low viscosity; it flows very easily. The fuel oil for a diesel engine should have a relatively low viscosity so that it can flow with relative ease through the pumping and injection system that supplies the engine with fuel. On the other hand, it must be viscous enough to lubricate the moving parts in the fuel system and also to help seal the parts so as to prevent leakage. In addition, the fuel must have a sufficiently low viscosity to spray, or atomize, easily as it is injected into the cylinder. If the oil is not broken up into fine enough droplets because it is too viscous, then combustion and engine performance will be poor.

2. **Cetane number.** The cetane number refers to the ignition quality of the fuel. The lower the cetane number, the higher the temperature required to ignite the fuel. To say it another way, the higher the cetane number, the lower the auto-ignition point of the fuel. Increasing the cetane number of the fuel used in an engine reduces the tendency for the engine to knock and smoke at light loads. In order to understand how these factors are related, let us review for a moment the operation of the diesel engine. The air is compressed in the cylinder. At the end of the compression stroke the fuel system injects a spray of oil into the compressed air. The oil is not delivered all at once; the spray starts, continues for an appreciable time, and then stops. If the cetane number of the oil is high, ignition will begin almost as soon as the spray starts. An even combustion-pressure rise and full combustion of the oil will result. But if the cetane number is low, there will be an ignition delay; it takes longer for low-cetane fuel to ignite. During this delay additional oil accumulates in the combustion chamber (in the form of spray). Then, when ignition does occur, a considerable quantity of oil will ignite at once. This causes a sudden rise in pressure and combustion knock. At the same time, ignition will not be complete and smoke will result.

*Note:* A fuel with an excessively high viscosity will also smoke.
Such a fuel does not spray, or atomize, adequately. The oil particles are too large and full combustion cannot take place.

3. Other characteristics. The oil must not have too much sulfur since excessive amounts of sulfur in the fuel cause acids to form; these acids will corrode engine and fuel-system parts. The oil must be clean, without dirt, sediment, water, and so forth. Any foreign material is apt to cause trouble, particularly in the fuel system where the oil is being pumped at high pressure and forced through small passages (such as the tiny spray-tip holes in the injector).

§147. Liquified petroleum gas Liquified petroleum gas, or LPG, is a mixture of various hydrocarbons (made up of hydrogen and carbon compounds) which are found in the earth with natural gases and crude oil (see §148). It is liquid at high pressure but as soon as the pressure is relieved it turns to gas, or evaporates. After it is extracted from natural gas or crude oil, LPG must be kept under pressure until it is used. LPG can be used as fuel in a standard gasoline, or Otto-cycle, engine, after some conversion of the fuel system. The fuel tank must be of heavy construction so that the LPG can be stored in it under pressures of 20 to 225 psi (pounds per square inch). There must be a pressure regulator in the line from the tank to the carburetor. The pressure on the fuel entering the carburetor must be reduced so that it is slightly below atmospheric. As the pressure on the LPG is reduced, it evaporates, or turns into a gas. There is, therefore, no vaporization problem with LPG. The carburetor essentially is nothing more than a mixing valve that mixes the LPG with air.

In addition to conversion of the fuel system, other changes may be made in the engine so as to utilize LPG to the full extent. With LPG the compression ratio can be stepped up to as high as 10:1 or even 12:1.

LPG supplied for automotive engines is either propane or butane (or a mixture of the two). Propane and butane are two "varieties" of LPG. They are both hydrocarbon compounds; the difference between them lies in the number of carbon and hydrogen atoms in each molecule. At atmospheric pressure and normal temperatures both are gases. But butane turns to gas at a much higher temperature than propane. Butane boils at 32°F (at atmospheric pressure). Propane boils at −44°F (at atmospheric pressure). Thus propane
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must be pressurized more than butane in order to hold it in liquid form. On the other hand, butane will not turn to gas at a temperature below 32°F (freezing temperature). Thus butane fuel could not be used whenever temperatures fall below freezing since it would not vaporize on its way to the carburetor nor would it have enough vapor pressure in the tank to force it out. In most places in the country (and of course in the North) propane alone, or propane with a small amount of butane mixed with it, is used for engine fuel. This fuel will vaporize at the temperatures experienced in cold weather.

Gasoline

Gasoline is also a hydrocarbon, since it is also made up of hydrogen and carbon compounds. However, the gasoline hydrocarbon compounds are somewhat different from the LPG hydrocarbon compounds. They remain liquid at normal temperatures and atmospheric pressure, since their molecules are more complex.

Gasoline, fuel oil, LPG, and many other compounds are obtained from crude oil, or petroleum. No one knows how petroleum was formed. It is found in "pools" under the ground and there is evidence that it was formed over a space of many millions of years from animal or vegetable sources. The petroleum usually is under considerable pressure; when a well is drilled down to a pool, or reservoir, of petroleum, the crude oil gushes up out of the earth.

Petroleum is a very intricate mixture of many compounds. The oil refinery separates the petroleum into various substances, altering many and forming new combinations as it does so. From the refinery comes lubricating oil of different grades and viscosities, fuel oil (one series for diesel engines, another series for heating, and so forth), gasoline of many grades and types, LPG, and so on.

Gasoline is actually a blend of a number of different basic fuels, each with its own set of characteristics. By the blending of various fuels, a gasoline is obtained that will provide satisfactory operation under the many conditions the engine meets. Among the factors to be considered in blending gasoline are volatility, antiknock value, and freedom from harmful chemicals and gum. These factors are considered in more detail in the following sections.

Volatility

Volatility refers to the ease with which gasoline and other liquids vaporize, or change from a liquid to a vapor. In
simple compounds such as water or alcohol the volatility is determined by increasing its temperature until it boils, or vaporizes. A liquid that vaporizes at a relatively low temperature has a high volatility, or is highly volatile. But if its boiling point is high, it has a low volatility. A certain heavy oil, for example, has a low volatility since it will not boil until it reaches a temperature of above 600°F. Water is relatively volatile (boils at 212°F at atmospheric pressure). Gasoline is still more volatile. Gasoline, however, is blended from different hydrocarbon compounds that have different volatilities or boiling points. This assures satisfactory operation under the various operating conditions that the engine meets, as follows.

1. **Easy starting.** For easy starting with a cold engine, gasoline must be highly volatile so that it will vaporize as it passes through the carburetor even though air and fuel temperatures are low. Thus a certain percentage of the gasoline must be volatile enough to permit easy starting. In winter the percentage of high-volatility gasoline is increased for good cold-weather starting.

2. **Freedom from vapor lock.** If the gasoline is too volatile, heat from the engine will cause it to vaporize in the fuel lines and fuel pump. This produces gas pockets or vapor locks, which prevent the fuel pump from operating normally; not enough gasoline gets to the carburetor and the engine loses power or fails from fuel starvation. Thus the percentage of highly volatile fuel must not be so high as to cause vapor lock.

3. **Smooth acceleration.** When the throttle is opened for acceleration, there is a sudden increase in the amount of air passing through the carburetor. If the fuel does not vaporize quickly during this interval, there will be a flat spot in engine operation. Thus a percentage of the gasoline must be volatile enough to carry the engine over during this period.

4. **Good economy.** For economy the fuel must have relatively low volatility, or the mixture will become too rich. Thus a percentage of the fuel must be of relatively low volatility.

5. **Freedom from crankcase dilution.** If the gasoline is not sufficiently volatile, part of it will enter the cylinder in liquid form. This gasoline will wash down the cylinder walls, carrying with it part of the lubricating oil; loss of lubrication will increase cylinder-wall and piston-ring wear. Furthermore, the liquid gasoline passes on down into the crankcase where it dilutes the lubricating oil,
causing the oil to lose viscosity and lubricating properties. The gasoline must therefore be sufficiently volatile to prevent this from happening.

6. The volatility blend. It is obvious from the above discussion that no one volatility will satisfy all requirements. Thus some of the fuel must be of high volatility for easy starting and acceleration, while the rest must be of low volatility to give good economy and to combat vapor lock. Gasoline chemists must blend the gasoline from various amounts of different fuels of different volatilities. Such a gasoline then satisfies the various operating requirements. Another book in the McGraw-Hill Automotive Mechanics Series (Automotive Fuel, Lubricating, and Cooling Systems) contains additional information on gasoline.

§150. Antiknock value  During normal burning of fuel in the combustion chamber, the spark from the spark plug starts the burning process. A wall of flame then spreads out in all directions from the spark until all the fuel is burned. The speed with which the flame spreads is called the rate of flame propagation. Normal combustion of fuel in an engine combustion chamber is shown to the left in Fig. 8-13. While the pressure rise is rather steep and may reach 700 psi (see Fig. 4-5), there is no really sudden pressure increase.

If, however, the flame travels too rapidly through the mixture (rate of flame propagation is too high), the pressure increase will be too rapid. The effect will be as shown to the right in Fig. 8-13. The pressure increase is so fast, and it goes so high, that the last part of the air-fuel charge detonates, or explodes, with almost hammer-blow suddenness. The effect is almost as though you had suddenly struck the piston head with a heavy blow. In fact, it may sound as though this is what had happened, and this is the noise you identify as knocking. The sudden increase of pressure imposes heavy shock loads on the piston, connecting rod, crankshaft, and bearings. With very severe knocking, engine parts will actually fail.

Some fuels will knock very easily, while others will not. One fuel that knocks easily is heptane. A fuel that does not knock easily is iso-octane. The carbon and hydrogen atoms can be put together in gasoline molecules in various ways so that they resemble either heptane or iso-octane. Of course, if they are more like iso-octane, [264]
Fig. 8-13. Normal combustion without knocking is shown in the vertical row to the left. The fuel charge burns smoothly from beginning to end, providing an even, powerful thrust to the piston. Knocking is shown in the vertical row to the right. The last part of the fuel explodes to produce detonation, or knocking. (General Motors Corporation)
they are highly resistant to knock; such gasolines are high-octane fuels. A 70-octane gasoline is much less apt to knock than a 60-octane gasoline, for example. Fuels are thus rated by octane number, with the higher numbers indicating a higher resistance to knock.

Various chemicals have been blended with gasoline to see how they affected antiknock values. One chemical that was found to be highly effective in reducing the tendency to knock (or in raising the octane rating of the fuel) is tetraethyllead, or tel. A small amount of this substance added to gasoline reduces the rate of flame propagation so that detonation and knocking are much less likely to occur.

§151. Octane and engine compression ratio As previously mentioned, modern engines have higher compression ratios (§67). This increase of compression ratios brought with it the problem of an increased tendency to knock. Here's the reason for that. The higher the compression ratio, the more the air-fuel mixture is compressed at the end of the compression stroke. The more compression, the higher the compression temperature. Thus the temperature of the mixture just before ignition is higher in high-compression engines. Then, when ignition does occur, the charge burns and the temperature goes still higher. But with higher temperature and pressure to start with, detonating temperature and pressure are sooner reached. With low-compression engines the detonating temperatures and pressures are not attained, since pressure and temperature were lower to start with. But with the high-compression engine, they will be reached unless fuels of high antiknock value (or high-octane rating) are used. Thus high-compression engines must have high-octane gasoline.

§152. Harmful chemicals and gum The gasoline must be relatively free of harmful chemicals and substances that form gum. Such chemicals as sulfur must be kept to a minimum since they will form acids during the combustion process, and these acids may corrode and damage engine parts. Substances that form gum and varnish

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must also be at a minimum in the gasoline. Gum and varnish can coat engine parts (valves, rings, pistons) and cause them to work poorly so that the engine loses power or may actually fail.

Gasoline chemists are careful to see that refining processes remove excessive amounts of substances that could cause damage and engine trouble. In addition, certain substances have been developed which, when added to the gasoline, help to keep engines "clean."

§153. Fuel-system troubles

For normal engine operation, the fuel system must supply proper amounts of air-fuel mixture of the correct richness for the various operating conditions that the engine meets. Thus, if the fuel system fails to do its job, engine performance will suffer. Chapter 12, “Diagnosing Engine Troubles,” contains an engine trouble-shooting chart that relates various engine troubles to the fuel system and other engine components. Troubles that may be related to the fuel system include:

1. Excessive fuel consumption
2. Poor acceleration, lack of power, and high-speed performance
3. Poor idle
4. Failure of engine to start (except when primed)
5. Hard starting
6. Smoky, black exhaust
7. Stalling of the engine
8. Engine backfiring
9. Engine missing

Further information on these items will be found in Chap. 12. Another book in the McGraw-Hill Automotive Mechanics Series (Automotive Fuel, Lubricating, and Cooling Systems) discusses in detail fuel-system troubles and checking and servicing procedures for carburetors, fuel pumps, and other fuel-system components.

CHECK YOUR PROGRESS

Progress Quiz 16

Try the questions below to see how well you are remembering what you are studying in the book. If you have trouble answering the ques-
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tions, go back into the book and reread those pages that will help you find the answers. This review will help fix the facts in your mind.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. The tendency of a liquid to resist flowing is called its viscosity oiliness atomizing ability porosity
2. The ignition quality of a diesel fuel is referred to in terms of its cetane number octane number butane number propane number
3. The higher the temperature required to ignite diesel fuel, the higher the octane number lower the butane number lower the cetane number
4. Two varieties of LPG are propane and butane propane and octane butane and cetane cetane and octane
5. The ease with which a liquid changes to a vapor is called its viscosity boiling point volatility vaporability
6. A liquid that boils at a relatively high temperature is said to have a low volatility a high volatility a low viscosity a high viscosity
7. When gasoline evaporates in the fuel line or fuel pump, it produces a condition called engine lock fuel lock viscosity lock vapor lock
8. Antiknock value of gasoline is referred to in terms of cetane number heptane number octane number propane number
9. A gasoline that is highly resistant to knocking is called a low-octane fuel high-cetane fuel low-cetane fuel high-octane fuel
10. As compression ratio in an engine goes up, the octane requirements of the fuel also go up go down stay about the same

Scrambled Definitions

The list to the left below includes various terms relating to the fuels discussed in the past few pages. The list to the right contains brief definitions of these terms (but not in the same order). To unscramble the lists, take one item at a time from the list to the left, and then find the item in the list to the right that defines it. Write the results down in your notebook. For example, the first item in the list to the left is "vis-

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cosity." When you look down the list to the right, you will find "flow resistance," which defines the term.

- viscosity
- volatility
- cetane number
- octane number
- propane
- tel
- butane
- heptane

- an LPG
- tetrachlyleld
- flow resistance
- ease of evaporation
- antiknock value
- a fuel that knocks easily
- ignition quality
- an LPG

CHAPTER CHECKUP

Note: Since the following is a chapter review test, you should review the chapter before taking the test.

You are still moving along in your studies of the automotive engine and have just completed an important chapter on automotive fuel systems. The fuel system is, after all, a part of the engine, and you should have a good understanding of its action as well as of the types of fuel used. The following checkup gives you a chance to review everything that you have learned in studying the chapter. Be sure to write the answers in your notebook.

Scrambled Carburetor Actions

The list to the left below includes various engine and carburetor operating conditions discussed in the first part of the chapter. The list to the right describes what is going on with each of these various conditions (but not in the same order). To unscramble the lists, take one item at a time from the list to the left, and then find the item in the list to the right that describes what is going on in the carburetor. Write down the result in your notebook. For example, the first item to the left is "choking." When you look down the list to the right, you will find "choke valve closed" which describes what is going on.

- choking
- idling (hot)
- high-speed operation
- starting
- warming up
- low-speed operation
- full-power operation
- throttle moving to open
- float low

- accelerator pump working
- metering rod raised
- choke valve opening
- needle valve open
- throttle closed
- choke valve closed
- throttle slightly opened
- throttle cracked
- throttle open
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Definitions and Lists

In the following you are asked to make lists of or to define the purpose or operation of various items discussed in the chapter. Write these in your notebook. The act of writing these things down helps you in two ways; it tests your knowledge (so that you know how well you are doing), and it also helps fix the information more firmly in your mind. Turn back into the chapter if any of the questions stump you.

1. List the various circuits in the carburetor.
2. Opposite each circuit in the list you make, write down the purpose of the circuit.
3. What determines the position of the choke valve in the thermostatic type of automatic choke?
4. List characteristics of a good diesel-engine fuel.
5. List the characteristics of a gasoline that are necessary for good engine operation.
6. Make a list of the operating conditions that must be considered when the volatility blending of a gasoline is made.
7. Explain what causes knocking in a gasoline-engine cylinder.
8. Make a list of troubles related to the fuel system.

Suggestions for Further Study

There are other books that discuss the fuel system and automotive fuels in more detail than we did here. For example, Automotive Fuel, Lubricating, and Cooling Systems (another book in the McGraw-Hill Automotive Mechanics Series) contains several chapters on fuels and fuel systems. You can get additional information on fuels from your local service stations and oil companies. Your friendly service shop, or your school shop, will have carburetors and fuel pumps on hand. Some of these may be worn-out, replaced units, which you may have the chance to examine in detail and perhaps disassemble.
9: Automotive-engine cooling systems

THIS CHAPTER describes in further detail automotive-engine cooling systems. We described in Chap. 3, "Engine Fundamentals" (§63), the fundamentals and purpose of the engine cooling system. In this chapter we describe the system in more detail and supply information on the various components of the cooling system. We suggest that you review §63 before starting this chapter.

§154. Purpose of the cooling system As previously mentioned, the purpose of the cooling system is to remove heat from the engine cylinder walls and head. This prevents the engine from overheating to a point where it could be damaged. Excessive temperatures cause the lubricating oil to break down and lose its lubricating effectiveness. In addition, bearing materials and other parts wear faster at higher temperatures. Thus it is extremely important to avoid high temperatures, since they will lead to rapid engine wear and early engine failure.

Water is circulated between water jackets surrounding the engine cylinders and combustion chambers and the radiator. The water transfers heat from the engine to the radiator. Water circulation is shown in Fig. 3-33. Distributing tubes and water nozzles for improved valve and valve-seat cooling are shown in Figs. 7-32 and 7-33. Study these illustrations carefully.

§155. Water pump and engine fan Circulation of the water between the engine water jackets and the radiator is produced by the water pump. The water pump contains an impeller which is mounted on the pump shaft. When the impeller in rotated, blades or vanes on the impeller throw water outward by centrifugal force, thereby forcing the water to flow through the pump. Water is drawn from the bottom of the radiator (through a hose) and is [271]
forced out into the engine water jackets. From there it enters the
top of the radiator. The impeller shaft is supported on a bearing, and
a seal is used to prevent water leakage at the point where the shaft
passes through the pump body. Figures 9-1 and 9-2 show sectional
and disassembled views of a typical water pump.
Also assembled on the pump-impeller shaft are the fan pulley
and engine fan. The fan pulley is connected by a V belt to the
engine pulley as shown in Figs. 3-1, 5-2, and 5-5. The fan turns with
the pump impeller, causing a strong blast of air to move through
the radiator, which helps cool the radiator.
§156. Radiator  The radiator is a device for holding a large volume of water in close contact with a large volume of air. It is divided into two separate and intricate sets of passages. One set carries water from the water tank at the top of the radiator to the water tank at the bottom of the radiator. The other set allows air to pass through from the front to the back of the radiator. Figures 9-3 and 9-4 illustrate two types of radiators.
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The tubular radiator (Fig. 9-3) contains a series of water tubes that stretch from the upper to the lower water tank. Water passes down through these tubes. Fins are placed around the tubes to improve heat transfer to the air that passes around the tubes through the radiator.

Fig. 9-5. Location of thermostat in an L-head engine. Arrows show water circulation through thermostat when the engine is warm and the thermostat is open. (Studebaker-Packard Corporation)

The cellular radiator (Fig. 9-4) is made up of a series of narrow water passages formed by pairs of thin metal ribbons soldered together along their edges. The water tubes zigzag down from the upper to the lower tank so that water can pass down through them. The spaces between the water tubes form air passages through which air can pass as it moves from the front to the back of the radiator.

§157. Thermostat

The cooling system includes a thermostat (see Fig. 9-33). The purpose of this device is to close off the circulation between the engine and the radiator when the engine is cold. This prevents the cooling system from functioning and the engine there-
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fore warms up more rapidly. Then, when the engine approaches operating temperature, the thermostat opens the passage between the engine and radiator so that normal cooling can take place. The thermostat greatly shortens the time required for the engine to reach operating temperature. This is a great help in keeping down engine wear; most engine wear occurs when the engine is cold and the lubricating oil cannot do an effective lubricating job.

Figure 9-5 shows the thermostat in place in an L-head engine. Note that it is placed in the exit point where the water leaves the engine and passes up to the radiator. The thermostat contains a metal bellows filled with a substance having a low boiling point. When the temperature is low, the substance is a liquid, and the

![Fig. 9-6. When the engine is cold, the thermostatic bellows has contracted and pulled the valve down on its seat. This shuts off water circulation to the radiator. Water then circulates through the bypass as shown. (Buick Motor Division of General Motors Corporation)](image1)

![Fig. 9-7. When the engine warms up, the thermostatic bellows expands, lifting the valve off its seat to permit water circulation to the radiator so that normal cooling can take place. (Buick Motor Division of General Motors Corporation)](image2)
baffles has contracted to pull the thermostat valve down on its seat. In this position the valve prevents water circulation to the radiator (Fig. 9-6). When the engine begins to heat up, the liquid in the baffles boils, creating an internal pressure that expands the baffles. This raises the valve so that water can circulate to the radiator (Fig. 9-7).

Most engines have some sort of bypass arrangement to permit water to circulate through the pump and back to the engine when the thermostat is closed (Fig. 9-6). This prevents excessive pressure build-up in the pump.

§ 158. Radiator pressure cap

At sea level, where atmospheric pressure is about 15 psi (pounds per square inch), water boils at 212°F. At higher altitudes (lower pressures) the boiling point is lower.

But if the air pressure is increased, the boiling point goes up. Each additional pound per square inch increases the boiling point of water about \( \frac{3}{4} \)°F. This can be explained on the basis of the molecular theory of heat (§§ 10 and 11), as follows:

With higher pressures there are more air molecules above the water that is being heated. Thus more water molecules are knocked back into the water as they try to escape, by collisions with air molecules. The water therefore has to go to a higher temperature (so that the molecules are moving faster) before they can escape (or the water can boil).

If the cooling system were pressurized, or held under a pressure greater than atmospheric, then the water would circulate at a higher temperature without boiling. This would increase the effiience.
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ciency of the cooling system, since the difference between the temperature of the water in the radiator and that of the air passing through it would be greater, and the heat would therefore transfer faster from the water to the air.

Thus, to increase cooling-system efficiency, radiator pressure caps are used on many engines. The pressure cap (Fig. 9-8) seals the cooling system in order to hold in the pressure. It contains a blowoff valve, which opens if the pressure exceeds a safe maximum. It also has a vacuum valve, which opens to admit air into the radiator when the engine cools. If there were no vacuum valve, atmospheric pressure might cause collapse of the radiator or hose as a partial vacuum formed in the cooling system when the engine cooled off.

Pressure caps are designed to hold as much as 12 psi (above atmospheric pressure). This increases the boiling point of the water to as much as 250°F.

§159. Antifreeze solutions

Since water will freeze at temperatures below 32°F, it is necessary to add antifreeze substances to the water to prevent it from freezing. If the water froze in an engine, it would probably crack the cylinder block and head, and ruin the engine completely. Water expands as it turns to ice, and the expansive force is easily great enough to crack the cylinder block.

The most commonly used antifreeze substances are divided into two groups, the temporary antifreeze and the so-called “permanent” antifreeze. The temporary antifreeze substances have an alcohol base. They do an effective job but have a fairly low boiling point. Thus they evaporate rather easily and must be replaced at fairly frequent intervals. The permanent type contains ethylene glycol; this substance will not boil and does not evaporate at temperatures normally encountered. It is thus "permanent."

The quantity of antifreeze required for winter protection depends on the lowest temperature that will be experienced. The lower the temperature, the greater the proportion of antifreeze that must be mixed with the water. The containers in which the antifreezes are sold supply detailed information on how much antifreeze is required for the lowest temperature expected.

§160. Cooling-system troubles

For normal engine operation the cooling system must permit quick warm-up and must then provide adequate cooling when the engine reaches operating temperature.
Troubles related directly to the cooling system include slow warm-up and engine overheating. (Both of these troubles can also be caused by other conditions; for instance, the wrong ignition timing can cause the engine to overheat.) Slow warm-up could result from a thermostat sticking open. Engine overheating could be caused by a thermostat that is stuck closed, by low water level in the system, or by accumulations of rust or scale that have clogged water passages or filled water jackets. Chapter 12 “Diagnosing Engine Troubles,” contains a trouble-shooting chart that relates various engine troubles to possible causes. When you study that chart, you will learn more about how cooling-system troubles and engine troubles are related.


CHAPTER CHECKUP

Since this is a short chapter, we have not included any progress quizzes; the following checkup covers the material discussed in the chapter. You should have a good understanding of how the engine cooling system operates. The questions that follow will help you check your knowledge of cooling systems. If the questions stump you, reread the past few pages to get the correct answers.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. The pump part that rotates to cause water circulation between the radiator and engine water jackets is called the impeller fan body bypass
2. Two types of radiators discussed in the chapter are zigzag and horizontal and vertical tubular and cellular
3. In normal operation water in the radiator circulates from top to bottom from bottom to top in a circular path in radiator
4. The part of the cooling-system thermostat that functions to open and close the valve is called the seater bellows pressure valve vacuum valve

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5. The device in the cooling system that increases the boiling point of the water in the system is called the **pressure cap** vacuum valve radiator water jackets

6. The pressure cap contains two valves; these are the **pressure** valve and blow-off valve atmospheric valve and vacuum valve blow-off valve and vacuum valve

7. Two types of antifreeze are **alcohol base and ethylene glycol** ethylene glycol and permanent **iso-octane and ethylene glycol**

8. Troubles of the engine related directly to the cooling system include hard starting and slow warm-up slow warm-up and overheating slow cranking and warm-up

SUGGESTIONS FOR FURTHER STUDY

The *Automotive Fuel, Lubricating, and Cooling Systems* book, mentioned above, contains additional information on cooling-system operation, troubles, and servicing. You can also find out a good deal about the cooling system and its components in a friendly service shop or your school shop. Examine water-pump parts and thermostats and note the manner in which the radiator is mounted and connected with hose to the engine and water pump.
10: Automotive lubricants and lubricating systems

This chapter describes in further detail automotive lubricating systems and also supplies information on lubricating oil and other lubricants used in the automobile. We have already discussed, in various places in the book, some aspects of engine lubrication and the jobs that the lubricating oil does. Section 59 describes in brief the operation of the lubricating system. Section 103 explains how the engine bearings are lubricated. Sections 112, 114, and 115 discuss piston-ring, piston, and cylinder-wall lubrication. We suggest that you review all these sections before you start this chapter.

§161. Friction One of the important jobs of the lubricating oil in the engine lubricating system is to reduce friction between moving engine parts. Section 29 discusses friction in some detail, and explains that friction has been divided into three classes, dry, greasy, and viscous. If you are not sure about what these three classifications mean, you might wish to turn back to Chap. 1 and review §29.

§162. Purposes of the lubricating oil We often think of the engine lubricating oil as having only one job: to lubricate the engine parts and hold frictional losses and engine wear to a minimum. However, the oil has other jobs in the engine. Here’s what these jobs are:

1. Lubricate moving parts to minimize wear.
2. Lubricate moving parts to minimize power loss from friction.
3. Remove heat from engine parts by acting as a cooling agent.
4. Absorb shocks between bearings and other engine parts, thus reducing engine noise and extending engine life.
5. Form a good seal between piston rings and cylinder walls.
6. Help keep engine parts clean by carrying away dirt and other foreign matter.
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1. Minimizing wear and power loss from friction. Since the lubricating oil interposes a film of oil between moving engine parts, actual metal-to-metal contact is prevented. This minimizes wear and frictional power losses. However, it must be recognized that even though only viscous friction is present in the engine during normal operation, it can cause considerable power loss, especially at high speed. Figure 4-6 is the frictional horsepower curve of an engine. Note that 40 horsepower are used up at 4,000 rpm (revolutions per minute) by engine friction. It is also true that greasy friction may exist in a cold engine and during early engine warm-up. Since greasy friction is far less effective than viscous friction in preventing engine wear, it is obvious that the wear rate will be much greater for the first few minutes after the engine is started. This is the reason why the engine should not be raced or heavily loaded before it has had a chance to run several minutes and get warmed up. After the engine has started to warm up, the lubricating system has circulated oil to the moving parts so that viscous friction, rather than greasy friction, exists. Wear is much less with viscous friction.

2. Removing heat from engine parts. We have already noted in several places in the book that the engine oil, as it passes through the engine, picks up heat and carries it back to the oil pan. Air passing around and under the oil pan cools the oil. Thus the oil acts as a cooling agent and is an important factor in preventing excessive engine temperatures.

3. Absorbing shocks between bearings and other engine parts. As the air-fuel mixture is ignited toward the end of the compression stroke, combustion pressures in the cylinder quickly increase to several hundred psi (pounds per square inch). This means that a heavy load is suddenly imposed on the piston, piston pin, and connecting rod and on their bearings. For example, a 3-inch piston might have a load of as much as 2½ tons imposed on it. This load, carried through the bearings, attempts to "squeeze out" the oil in the bearing-oil clearance. The oil must resist the shock load which attempts to penetrate the oil film and squeeze it out. As it does this, the oil helps quiet the engine and prevents metal-to-metal contact which would greatly increase wear.

4. Forming a seal between piston rings and cylinder walls. Piston rings must form a gastight seal between the pistons and the cylinder
walls; the oil helps the rings do this job (see §114). The oil film on the cylinder wall, rings, and piston helps to compensate for any small irregularity and, in effect, fills in the gaps through which gas might escape. Also, since the oil clings to the metal surfaces, it resists any attempt for gas to blow by, or pass through the oil film between the metal surfaces.

5. Cleaning the engine. Since the oil is in constant circulation between the oil pan and the engine parts, it tends to wash away any foreign material that may enter the engine. For example, particles of dust may pass the air filter and enter the engine with the air-fuel mixture. Particles of carbon may form in the combustion chambers and then work down onto the cylinder walls or rings. The oil tends to flush such particles back into the oil pan. Helping the oil in this job are the cleaning agents, or detergents, now added to many brands of lubricating oil (see §168).

§163. Types of lubricating systems

The lubricating system, no matter what type, has the job of supplying adequate amounts of oil to all moving engine parts so that the oil can do the various jobs outlined in the previous section. In some heavy-duty engines, where the oil has a harder and hotter job to do, an oil cooler is included in the lubricating system. The oil cooler has a radiator much like the cooling-system radiator (§156), through which the oil passes; this cools the oil. All engines have some sort of oil-level indicator, which usually consists of a dip stick, or oil-level stick, that enters the crankcase from the side of the block. A dip stick can be seen on the engine shown in Fig. 10-3 (between the cranking motor and the distributor). To check the oil level in the open pan, the dip stick can be pulled out and the height of the oil on the stick noted. Oil can then be added if the oil level is too low for adequate engine protection.

Engine lubricating systems are divided into three types: splash, pressure feed, and combination splash and pressure feed.

1. Splash. In the splash lubricating system there are dippers on the lower part of the connecting-rod bearing caps; these dippers enter oil trays in the oil pan with each crankshaft revolution. The dippers splash oil to the upper part of the engine. The oil is thrown up as a fine oil spray which provides adequate lubrication to valve mechanisms, cylinder walls, piston rings, and bearings.
An oil pump is used to maintain a constant level of oil in the oil trays.

2. Pressure feed. In the pressure-feed lubricating system (Figs. 10-1 and 10-2) the oil is forced by the oil pump through holes drilled in the crankshaft and connecting rods to the connecting rod and piston-pin bearings. Valve mechanisms are lubricated by oil galleries in the cylinder block or by oil lines. Cylinder walls are lubricated by oil thrown off from the connecting-rod bearings and,

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**Fig. 10-1.** Lubrication system of a six-cylinder overhead-valve engine. Arrows show oil flow to the moving parts in the engine. *(Ford Division of Ford Motor Company)*

in some engines, by split holes in the connecting rods. Sections 103, 112, and 114 discuss lubrication of bearings, cylinder walls, and piston rings in some detail.

3. Combination splash and pressure feed. The combination splash and pressure-feed lubricating system depends on oil splash to lubricate some engine parts and on pressure feed to lubricate other engine parts.

4. Oil passages. Oil passages in the engine block and head permit
circulation of oil to bearings and moving parts (Fig. 10-3). Many engines have holes drilled in the connecting rods and crankpins as shown in Fig. 10-4 to lubricate the cylinder walls and pistons.

§164. Oil pumps The oil pump is usually driven from a gear on the camshaft (the same gear that drives the ignition distributor) as shown in Fig. 10-1. Oil pumps may be located in the crankcase as shown in Fig. 10-1 or externally as shown in Fig. 10-2.

Fig. 10-2. Lubrication system of a V-8 overhead-valve engine. Arrows show oil flow to moving parts in engine. (Mercury Division of Ford Motor Company)

One type of oil pump is shown in disassembled view in Fig. 10-5. This is a gear-type pump. As the gears rotate, the spaces between the gear teeth become filled with oil from the oil pan. The oil is then carried around to the oil outlet and here the gear teeth mesh to force the oil out through the outlet. It then flows to the various engine parts.

Another type of oil pump is shown with the cover removed in Fig. 10-6. This pump has an internal rotor and an external rotor. The internal rotor is driven, causing the external rotor to turn with it. The action is much like that in the gear-type pump. Oil enters at one side where the spaces between the rotors are increasing, and is
FIG. 10-3. Oil passages in the engine block carry the oil to the crankshaft main and the camshaft bearings. The oil passages in the block connect with oil passages in the head so that the valve mechanisms are lubricated. (Mercury Division of Ford Motor Company)

FIG. 10-4. When a hole in the connecting rod aligns with a hole in the crankpin, oil is sprayed onto the cylinder wall, as shown, to provide lubrication of the piston and rings. (Mercury Division of Ford Motor Company)

carried around to the other side where the spaces are decreasing. There the inner rotor lobes move into the spaces and force the oil out.

§165. Relief valve In any pressure-feed system a relief valve must be incorporated to prevent excessive pressure build-up. Without a
relief valve, pressures could go so high at high speed, for example, that the oil-control rings would be utterly unable to cope with the quantity of oil thrown on the cylinder walls. The relief valve [286]
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Usually consists of a spring-loaded ball or plunger which opens when the pressure exceeds the specified amount. This then allows some of the oil to return to the oil pan. The relief valve may be incorporated in the oil pump (Fig. 10-5), or it may be separately located in the oil line from the oil pump (Fig. 10-7).

Oil filters

As we have already mentioned, one of the jobs that the oil has in the engine is to flush dirt, dust particles, and other foreign matter from the engine parts and carry it to the oil pan. There most of it settles out and drops to the bottom of the oil pan. (Dodge Division of Chrysler Corporation)

Fig. 10-7. End sectional view of an L-head engine showing location of oil pump, oil filter, and oil-pressure relief valve. Direction of oil flow is shown by arrows. (Dodge Division of Chrysler Corporation)
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Pan where it remains until the oil is drained. Some of the smaller particles, however, may remain in suspension in the oil and thus could be carried back to the engine bearings and other parts. There they could embed and cause rapid wear. In order to clean these smaller particles from the oil, the oil is passed through a filter (Fig. 10-7). The filter contains porous cellulose material, metal mesh, or a similar substance which passes the oil but retains most of the solid impurities in the oil. Filters are of two types, bypass and full-flow.

The bypass filter filters only part of the oil from the oil pump. That is, the line is so connected that oil is fed to the engine through one line, and to the filter through another (Fig. 10-7). Although only part of the oil from the pump is filtered, the fact that some oil is always going through the filter keeps the oil clean.

The full-flow filter is directly in the line from the oil pump, and all oil from the pump goes through the filter. This type of filter contains a bypass valve which opens if the filter becomes clogged. This permits lubrication of the engine when the filter has become too clogged with impurities to pass an adequate amount of oil.

Since the oil filters are effective only so long as they are sufficiently clean to pass oil, it is obvious that the filter elements should be changed periodically or before they have become completely clogged.

§ 167. Crankcase ventilation  During the combustion process, oxygen in the air and hydrogen in the gasoline unite to form \( H_2O \), or water (see §9). Most of this water passes out of the engine in the exhaust gases as steam, or vapor. But if the engine parts are cold, some of it will condense and work its way down into the oil pan. Water in the oil pan causes trouble. It mixes with the oil, and the churning effect of the rotating crankshaft whips the mixture into a thick, gummy sludge (something like mayonnaise). Another condition brought on by a cold engine is the condensation of gasoline vapor on the cold engine parts. The gasoline also works down into the oil pan where it thins the oil and reduces its lubricating ability.

After the engine has reached operating temperature, the water and gasoline will evaporate. But there must be some means of getting these vapors out of the crankcase. The crankcase ventilating system does this (Fig. 10-8). The system uses an air inlet toward the front of the engine (often in the oil-filler cap) and an outlet [388]
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Toward the back of the engine. The rotation of the crankshaft sets up a whirling motion of the air in the crankcase and this sweeps through the crankcase, carrying out the vaporized water and gasoline, as shown in the illustration.

Fig. 10-8. Crankcase ventilating system of a six-cylinder engine. Flow of air is shown by arrows. Air enters through the combination oil filler and breather cap. (Ford Division of Ford Motor Company)

§168. Source and properties of oil As we mentioned in §148, we do not know how the crude oil, or petroleum, was originally formed, nor how it came to collect in pools or reservoirs underground. But we do know that petroleum is a very versatile substance and that many grades and kinds of engine fuel and engine oil can be made from it by various refining procedures. During that part of the refining process that results in engine oil, the petroleum chemists make sure that the lubricating oil has the proper (1) body and fluidity, or viscosity; (2) resistance to carbon formation; (3) resistance to oxidation; and (4) resistance to foaming, among other characteristics.
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1. Viscosity (body and fluidity). Viscosity is probably the most important characteristic of a lubricating oil. Viscosity refers to the tendency of a liquid to resist flowing. Viscosity of lubricating oil may be divided into two characteristics for discussion, body and fluidity. Body gives the oil its resistance to oil-film puncture or penetration during application of heavy loads. For example, when combustion pressures suddenly increase, heavy loads are applied to the piston-pin and connecting-rod bearings. Oil body prevents the loads from squeezing out the oil film on the bearing surfaces. Oil body cushions shock loads, helps maintain a good seal between piston rings and cylinder walls, and maintains an adequate oil film on bearing surfaces under load.

Fluidity is related to the ease with which the oil flows through oil lines and spreads over bearing surfaces. In some ways, body and fluidity are opposing characteristics since the more fluid an oil is, the less body it has. Both change with viscosity. As viscosity goes up, body goes up and fluidity goes down.

Viscosity changes with temperature. Increasing temperature causes the viscosity to drop so that the oil loses body and gains fluidity. Decreasing temperature causes the viscosity to increase so that the oil gains body and loses fluidity. Since engine temperatures vary several hundred degrees from cold-weather starting to operating temperature, the oil must have sufficient fluidity (low enough viscosity) at low temperature to provide lubrication during warm-up. At the same time, it must have sufficient body for high temperature operation.

2. Viscosity ratings. Oil is rated in terms of viscosity number. The lower numbers mean lower viscosity. SAE 10 oil is less viscous than SAE 20 oil, for example.

3. Service classifications. Automotive-engine oils are also classified according to the sort of service the engine meets into three types; MS, MM, and ML. (These classifications are Severe, Medium, and Light service.) MS-type oil should be used in engines operating under severe conditions, which include heavy-load, high-temperature operation and also short-trip, cold-weather driving (where sludge is apt to occur). MM-type oil should be used under medium conditions, which include what might be called ordinary operation (long trips at moderate speed, short periods of high
speed, mixture of short and long trips). ML-type oil should be used for light service; this means moderate speed with most trips longer than ten miles and with no extremes of air temperature.

4. Resistance to carbon formation. The cylinder walls, pistons, rings, and valves operate at high temperatures. Such temperatures tend to cause the oil to break down, or carbonize. As carbon forms on the cylinder walls, the rings tend to scrape it off. Some of the carbon then passes on down into the oil pan. But some packs in and around the rings. This accumulating carbon reduces ring efficiency; compression is lost, and blow-by increases. In addition, oil control is reduced; more oil works up past the rings and gets into the combustion chamber where it is burned to increase the carbon. Carbon also fouls the spark plugs and valves, causing them to malfunction. A good lubricating oil must be able to resist the temperatures encountered sufficiently so that it does not form excessive amounts of carbon.

5. Resistance to oxidation. Hot oil sprayed into hot air (as in the engine) tends to oxidize; that is, it tends to combine with the oxygen in the air. Some products of oil oxidation include sticky, tarlike substances, which clog oil lines and restrict piston-ring and valve action. In the refining process, oil chemists make sure that the oil will have adequate oxidation resistance. They also may add certain chemicals, called oxidation inhibitors, which combat oxidation.

6. Resistance to foaming. The churning action in the engine crankcase tends to cause the oil to foam, just as an egg beater whips egg white into a foam. If oil foams, it may overflow and be lost through the crankcase ventilator. Foaming oil does not circulate normally in the engine to provide adequate lubrication. Thus, foaming of oil is an unfavorable characteristic. Oil chemists may add antifoaming chemicals to the oil to control foaming.

7. Detergents. To help the oil keep the engine clean, some oils have a cleaning agent, or detergent, added to them. The detergent acts somewhat like ordinary hand soap (except it does not foam). When you wash your hands, soap film surrounds the dirt particles so that they are detached from your hands. Water can then rinse them away. In a like manner, the detergent in the oil loosens, detaches, and washes away the particles of dirt, carbon, and gum that have adhered to engine parts. Much of this solid matter remains
suspended as fine particles in the oil (too fine for the filter to remove) and is flushed out or removed with the oil when the oil is changed.

§169. Automotive lubricants While we are on the subject of lubrication, we might say a few words about the lubricants that are required on the automobile in addition to engine oil. Lubricants are required for the wheel bearings, differential, transmission, brake parts, chassis suspension, steering system, electrical parts such as generator and distributor, and so on. Special lubricants are required for these various units. For example, the transmission and differential must have heavy oils with sufficient body to resist oil-film puncture from the high pressures between gear teeth. At the same time, the oils must be fluid enough to flow readily even at low temperature. For many lubricating jobs such as chassis or wheel-bearing lubrication, oils will not do: Greases are required. Grease is essentially oil mixed with a thickening agent (which may be aluminum, sodium, or calcium compounds). The thickening agent is usually called soap; its job essentially is to hold the oil in place so that it can lubricate. Without the soap, the oil would run off and lubrication would be lost.

§170. Lubricating-system troubles Lubricating-system troubles are engine troubles, since the lubricating system is, after all, a part of the engine. Troubles related to the lubricating system include

1. Excessive oil consumption
2. Low oil pressure
3. High oil pressure
4. Oil dilution and sludge

1. Excessive oil consumption. This is discussed in detail in Chap. 12, “Diagnosing Engine Troubles” (§194). Note that few of the causes of high oil consumption are actually due to conditions within the lubricating system itself. Usually, it is due to high-speed operation, external leaks, worn bearings, worn valve guides, or worn or stuck piston rings.

2. Low oil pressure. Low oil pressure can result from a weak relief-valve spring, a worn oil pump, a leaky oil line, obstructions in the line, insufficient or excessively thin oil, or worn bearings. One
cause of low oil pressure in old engines is worn bearings; they pass so much oil that the oil pump cannot maintain pressure.

3. High oil pressure. This could be due to a stuck relief valve, strong valve spring, a clogged oil line, or excessively heavy oil.

4. Oil dilution and sludge. Oil dilution is generally an engine problem related to operating conditions. For example, if the car is used for short runs in cold weather, the engine seldom has a chance to really warm up. It is operating most of the time on warm-up. With this condition, the oil will be diluted by unburned gasoline seeping down into the oil pan past the rings. Also, water will collect as already explained (§ 167). Since the engine does not warm up enough to evaporate these substances so that the crankcase ventila­tor can dispose of them, they continue to collect. Soon the oil is so diluted that it loses much of its lubricating ability. In addition, the water and oil are whipped into a mayonnaise-like sludge by the rotating crankshaft. This sludge clogs oil screens and oil lines and thus may oil-starve the engine. In winter, short-trip service, the sludge may collect so fast that within a few hundred miles it will begin to reduce engine lubrication seriously. Thus, under this severe type of service, the oil should be changed every few hundred miles.

5. Oil changes. Changing oil isn't a lubricating-system “trouble” but it is discussed here since regular changing of oil is a means of preventing trouble. After so many miles of service, the old oil be­comes contaminated with impurities, both solid and liquid. It there­fore loses its full effectiveness as a lubricant. Furthermore, it may become so loaded with solid particles that it puts back into the bearings and onto cylinder walls more dirt than it washes away. This means that the engine wear will go up very rapidly. Also, as explained in the previous paragraph, the sludge that forms in cold-weather, short-trip service loads the oil with a thick “goo” which prevents oil circulation.

The actual mileage at which oil should be changed varies some­what with the type of service. For normal, or average, service the usual recommendation is to change oil every 1,000 miles or every month. But when the car is used in severe service (which means cold-weather, short-trip operation), the oil should be changed more frequently. Remember that when the engine is operating cold, gaso­line and water are accumulating in the oil pan. And a car must run
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several miles before the engine warms up enough to start getting rid of this accumulated water and gasoline. As a matter of fact, in some Northern cities, light delivery trucks in door-to-door service (in winter) have been known to require an oil change every 3 days just to get rid of the water. Oil should also be changed more frequently in dusty operating conditions. And if a car goes through a dust storm, it should have an oil change immediately! For some of that dust is bound to get into the engine, and it can cause serious trouble if it isn’t removed by draining the old oil.


CHAPTER CHECKUP

We have not included any progress quizzes in this chapter since it is so short. However, the following checkup covers the material discussed in the chapter. A good understanding of the function of the lubricating system and of the engine oil will help you understand the various causes of engine trouble and why engines wear. The questions that follow will help you check your knowledge of lubricating systems. If you have trouble with the questions, reread the chapter. It is hard to remember all the important facts the first time you read the material: most good students make a practice of rereading their lesson several times.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. Three classes of friction are dry, greasy, and viscous dry, wet, and liquid dry, damp, and wet dry, greasy, and oily
2. In addition to providing lubrication and acting as a cooling agent, the engine oil must clean, dry, and absorb shocks dry, oxidize, carbonize, and burn absorb shocks, seal, and clean
3. Two types of engine lubricating systems are pressure feed and force feed pressure feed and splash oil pump and pressure feed splash and nozzle

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4. The purpose of the relief valve in the pressure-feed system is to
   prevent insufficient lubrication and ensure adequate pressure
   prevent excessive pressure and assure adequate oil circulation

5. Two types of oil filter used in automotive engines are bypass
   and full-flow. Open and closed low-pressure and high
   pressure full-flow and flow-through

6. The purpose of crankcase ventilation is to remove liquid gasoline and water
   and remove vaporized water and gasoline
   cool the oil and supply oxygen to crankcase

7. Viscosity can be divided into two properties ease of flow and
   fluidity, foaming, and flowing body and fluidity
   body and penetration

8. The substance added to the oil which helps keep the engine clean is
   called a detergent, a soap, a grease, and a thickening agent

9. Most of the dilution of the oil in the crankcase takes place during
   high-speed operation, long trips, engine overheating
   engine warm-up

10. Common causes of excessive oil consumption include heavy oil
    and tight bearings, high speed and worn engine parts
    short trips and cold weather, frequent oil changes and weak
    valve spring

Unscrambling the Oil Jobs

The list to the left below includes the various jobs that the oil does in
the engine. The list to the right includes phrases which explain why or
how these jobs are done (but not in the same order). To unscramble
the list, take one item at a time from the list to the left, and then find the item
to the right that explains why or how the job is done. Write down the
result in your notebook. For example, the first item to the left is “lubricates.” When you look down the list to the right, you will find two phrases
that apply to “lubricates.” One of these is “to minimize wear.” (“The other
phrase goes after the second “lubricates.”) So you put the two together
to form “lubricates to minimize wear,” which is one of the jobs the oil does.

lubricates by carrying dirt from engine parts
lubricates by carrying heat from engine parts
cools to minimize wear
absorbs shocks to minimize power loss
seals between bearings and other engine parts
cleans between piston rings and cylinder walls
SUGGESTIONS FOR FURTHER STUDY

Another book in the McGraw-Hill Automotive Mechanics Series (Automotive Fuel, Lubricating, and Cooling Systems) discusses in greater detail the operation and maintenance of the lubricating system and also supplies more information on the composition and action of oil. You may be able to obtain additional information on lubricating systems in your local service stations and oil companies. Your local service shop and your school shop may have oil pumps and filters on hand that you can examine so that you can see how they are made.
11: Engine-testing procedures and tools

THE PURPOSE of this chapter is to describe the different engine-testing procedures and the tools used to make the tests. Later chapters in the book discuss engine troubles (or faulty conditions), as disclosed by the engine tests, and the methods for correcting these conditions.

§ 171. Engine-testing procedures Testing procedures are of two types. One type is used when there is an obvious specific trouble that seems related to the engine. For example, if there is a miss in the engine or a complaint of excessive fuel or oil consumption, then there are definite trouble-shooting checks that can be made that will pin-point the cause of trouble.

The second type of testing procedure uses a general approach; that is, every engine component is tested as the procedure is carried out; any worn condition, subnormal operation, or other defect will be detected. This general-approach procedure is often referred to as engine tune-up since correction of troubles found during the testing procedure "tunes up" the engine; that is, it improves engine performance.

Actually, both types of testing procedure have their place in the automotive business. When you encounter a specific trouble, you want to follow a specific procedure to find its cause so you can correct it. On the other hand, it is often proper procedure to make a complete check of the engine and its components. For example, many automotive authorities recommend that the engine and its components be checked periodically (for example, every 10,000 miles or at least once a year). Such an engine analysis will show up worn units, parts, or improper adjustments that soon might cause real trouble. Correction can then be made before serious trouble develops. In other words, the general-procedure diagnosis
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eliminates trouble before it happens. This is called preventive maintenance. You prevent trouble by maintaining the engine in good operating condition. It is the old “a stitch in time saves nine” idea.

This chapter outlines the general-approach, or tune-up, testing procedure. The next chapter discusses in detail the trouble-shooting procedures to be used when various specific troubles are encountered.

§172. Instruments used in engine testing A number of different testing instruments can be used to analyze the condition of the engine and engine components. These include the tachometer (for measuring engine speed), the cylinder compression tester, the engine vacuum gauge, the combustion tester (or exhaust-gas analyzer), electric meters (for testing electrical components), and so on. There is also the chassis dynamometer which checks engine performance in a way that is comparable to a road test. The car is driven onto the chassis dynamometer; the car wheels then drive a pair of rollers in the dynamometer. The output of the engine can then be checked at various car speeds. If the output is within specified limits, the engine is assumed to be in normal condition. The following sections describe different testing instruments and how to use them.

§173. Tachometer Many engine tests must be made at certain specified speeds. For example, during the combustion test (with the exhaust-gas analyzer), combustion efficiency, or carburetor...
action, is checked at idle, at a specified intermediate speed, and at high speed. The tachometer normally used for automotive work operates electrically from the ignition system. It measures the number of times the primary circuit is interrupted and translates this into engine rpm (revolutions per minute). The tachometer has a selector knob that permits adjustment for four-, six-, and eight-cylinder cars. Its use is simple. One lead of the tachometer unit is connected to ground (to the engine block, for example), and the other to the distributor primary terminal (Fig. 11-1). The selector knob is then turned to the position corresponding to the number of lobes on the distributor cam (normally one lobe per cylinder). Finally, the engine is started and the engine speed is read directly from the meter dial. The idling speed is adjusted by means of an idle-speed adjustment screw on the carburetor (Fig. 8-1).

§ 174. Cylinder compression tester The cylinder compression tester (Fig. 11-2) measures the pressure, in psi (pounds per square inch), that develops in the cylinder as the piston moves up to TDC (top dead center) on the compression stroke. If the compression does not come up to normal specified psi, it is obvious that there is a leak somewhere; the cylinder cannot hold compression.
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To use the compression tester, remove all spark plugs, hold the tester fitting tightly in the spark-plug hole of a cylinder, and crank the engine with the cranking motor. Be sure to hold the throttle valve wide open so that the fuel system does not deliver fuel to engine during the test. Note the maximum compression as indicated by the needle on the compression-tester dial.

If compression is too low, then there is leakage past the valves, piston rings, or cylinder-head gasket. This means that in order to correct the trouble, the head must come off and the various engine parts must be inspected. But before this is done, you can make one further check to pin-point the trouble more accurately. Pour a small quantity of heavy oil into the cylinder through the spark-plug hole and then retest the compression pressure. If the compression pressure increases to a more normal figure, it means that the loss of compression is due to leakage past the piston rings. This can result from worn or scored piston rings, pistons, or cylinder walls, or to piston rings being weak, broken, or stuck in their grooves. If adding oil does not help the compression pressure, chances are the leakage is past the valves. This could be due to weak or broken valve springs; improper valve adjustments; carboned valve stems; burned, warped, worn or pitted valves; or worn, burned, or pitted valve seats. If the compression leakage is not past rings or valves, then the cylinder-head gasket is not holding the compression, due to its being burned (or "blown") or to improper tightening of the cylinder-head attaching bolts or nuts.

Low compression in two adjacent cylinders indicates that there is a blown gasket between the cylinders that allows leakage between them.

Note: Unequal compression between cylinders, from whatever cause, can often be detected by operating the engine slightly above idle and then listening to the exhaust. If the exhaust is uneven, it could be due to unequal compression between cylinders. But remember that faulty carburation or ignition could also cause an uneven exhaust. The only accurate means of determining compression in the engine cylinders is to use the compression tester.

§175. Engine vacuum gauge The engine vacuum gauge (Fig. 11-3) measures intake-manifold vacuum. The intake-manifold vacuum varies with different operating conditions, and also with different [300]
engine defects. Therefore, the vacuum-gauge reading is a good indication of the condition of the engine. The vacuum gauge is connected to the intake manifold according to the means provided. For example, on cars where the fuel pump includes a vacuum

**Fig. 11-3.** Vacuum gauge for measuring intake-manifold vacuum. (Kent-Moore Organization, Inc.)

**Fig. 11-4.** Instrument connections for making manifold-vacuum test. The vacuum gauge shown here is built into a panel as part of a test stand. (Sun Electric Corporation)

pump (for operating the windshield wipers) the vacuum-pump line can be disconnected from the intake manifold. On other cars, the windshield-wiper line can be disconnected from the intake manifold and the vacuum gauge then connected to the fitting (Fig. 11-4).
Note that the vacuum readings are in terms of "inches," or inches of mercury. Vacuum gauges are usually marked in this manner in order to avoid confusion with pressure which is measured in psi. We have already seen that varying the vacuum at the top of a glass tube will "draw" mercury various distances up into the tube. This was discussed in §56 in which we explained venturi action. The effect is shown in Fig. 3-22; the highest vacuum "draws" the mercury the greatest distance up in the tube (the pressure of the atmosphere pushes it up the farthest). The distance is measured in inches of mercury. With a perfect vacuum at sea level the mercury would rise about 30 inches. With higher altitudes and reduced air pressure the mercury would not rise so far (see §22 on vacuum and the barometer).

Similarly, with less than perfect vacuum the mercury will not rise so far. The distance that it rises depends on atmospheric pressure (which pushes it up), and the extent of vacuum (which gives it "room" to rise).

NOTE: The vacuum gauge does not, of course, have a 30-inch column of mercury in it. Instead, it has a balanced diaphragm (or a bellows), which moves as air is removed from one side of it (by application of vacuum). The diaphragm is geared to the indicating needle so that the needle moves with the diaphragm. The greater the vacuum, the more the diaphragm and needle move.

To check engine vacuum, the vacuum gauge is connected as shown in Fig. 11-4 and the engine is started and operated at specified idling speed (measured with the tachometer). The vacuum-gauge reading is taken with the engine idling at operating temperature. The meanings of various readings are discussed below.

1. A steady and fairly high reading (17 to 22 inches, depending on altitude and engine) indicates normal performance. The reading will be lower at higher altitudes because of the lowered atmospheric pressure. For every 1,000 feet above sea level, the reading will be reduced about one inch.

2. A steady and low reading indicates late ignition or valve timing; or possibly leakage around pistons due to stuck piston rings or to worn or scored rings, pistons, or cylinder walls. Any of these reduce power output. With reduced power the engine does not "pull" as much vacuum.

3. A very low reading indicates a leaky intake manifold or
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carburetor gasket or leaks around the throttle-valve shaft. Air leaks into the manifold cause loss of vacuum and low engine output.

4. Oscillations of the needle increasing with engine speed indicate weak valve springs.

5. A gradual falling back of the needle toward zero with the engine idling indicates a clogged exhaust line.

6. Regular dropping back of the needle indicates a valve sticking open or a plug not firing.

7. Irregular dropping back of the needle indicates sticking valves that stick irregularly.

8. Floating motion or slow oscillation of the needle indicates an excessively rich air-fuel mixture. See item 17, Excessive fuel consumption, in the “Engine Trouble-shooting Chart” in §184 for troubles in the fuel system that could cause an excessively rich mixture.

9. A test for loss of compression due to leakage around pistons as a result of stuck piston rings or of worn or scored rings, pistons, or cylinder walls can be made as follows. Race the engine momentarily and then quickly close the throttle. If the needle swings around momentarily to 23 to 25 inches as the throttle is closed, the compression is probably satisfactory. If the needle fails to swing this far around, there is loss of compression.

§176. Exhaust-gas analyzer

The exhaust-gas analyzer, or combustion tester, checks the exhaust gas to determine what percentage of the gasoline has not been burned. When mixture ratios are not correct, or when there is a fouled plug or sticky valves (among other things), not all the gasoline burns. Combustion efficiency is low and gasoline is being wasted. The exhaust-gas analyzer draws a small part of the exhaust gas from the tail pipe and runs it through an analyzing device which then reports, by an indicating needle on a dial, the fuel ratio (mixture richness) or combustion efficiency (see Fig. 11-5). When not influenced by abnormal engine factors, the combustion efficiency and fuel ratio can be said to be directly related. The richer the ratio, the lower the efficiency (that is, a smaller percentage of the gasoline burns).

§177. Ignition timing  The ignition must be timed correctly when the engine is idling so that the compressed air-fuel mixture will be ignited at the proper instant at the end of the compression stroke. In order to time the ignition, most engines have markings on the flywheel or crankshaft pulley (or vibration damper). When cor-

Fig. 11-5. Instrument connections for making a combustion-efficiency (or exhaust-gas) analysis. Note that pickup gun is installed in tail pipe and is connected by a hose to the analyzer. A small pump, or booster, draws exhaust gas through the hose to the analyzer. (Sun Electric Corporation.)

§177. Ignition timing  The ignition must be timed correctly when the engine is idling so that the compressed air-fuel mixture will be ignited at the proper instant at the end of the compression stroke. In order to time the ignition, most engines have markings on the flywheel or crankshaft pulley (or vibration damper). When cor-

Fig. 11-6. Using stroboscopic, or ignition-timing, light to check ignition timing. Light flashes with each firing of plug 1. Timing is correct when pointer and marking on flywheel or pulley align. (Sun Electric Corporation)
rectly timed these markings align with stationary pointers at the instant that the plug in cylinder 1 fires. This alignment can be observed with a device called stroboscopic light (also referred to as a timing light) as shown in Fig. 11-6. Power for the light is obtained from the battery. The light flashes are triggered by the firing of plug

1. At the instant that plug 1 fires, the light flashes on. It goes off again almost at once. Thus the repeated flashes make the flywheel or pulley seem to stand still. (This is the stroboscopic effect.) The timing of the ignition can therefore be observed. Correction is made by loosening and turning the distributor in its mounting. Earlier model Fords have the timing set with the distributor off the car.
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Also, when checking timing of Fords with the vacuum-advance mechanism connected into the carburetor venturi (see Fig. 3-32), the vacuum line should be disconnected.

§178. Electrical checks For the electrical checks of the electric system, various electric meters are required. Figure 11-7 shows various meters needed to make some of the electrical checks, as well as other testing devices previously discussed in this chapter, all conveniently mounted on a single movable test stand. This test stand can be rolled up to a car about to be tested. Details of using the meters and of making the various tests to the different electrical components (battery, cranking motor, generator, regulator, ignition system) are discussed in another book in the McGraw-Hill Automotive Mechanics Series (Automotive Electrical Equipment).

§179. Chassis dynamometers Figure 11-8 illustrates a chassis dynamometer for use in the service garage. The car is driven onto the dynamometer as shown in Fig. 11-9 so that the rear wheels can...
Engine-testing Procedures and Tools

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drive the two rollers. Then, with the instruments connected up to the engine, the engine is started and the transmission is put in gear; the engine then drives the dynamometer. You might wish to reread §§72 and 73 on dynamometers and interpreting dynamometer test results. Various instruments used in connection with the dynamometer test include a car-speed meter, power-output meter, tachometer, vacuum gauge, distributor tester, and combustion analyzer. All these instruments give a fairly complete picture of engine operation under various conditions. With the chassis dynamometer, hill-climbing, level-road, low-speed, accelerating, and high-speed driving conditions can be simulated. This means that the car and the engine can be tested under conditions that very closely approximate actual driving conditions on the highway. The chassis dynamometer can be used to test not only the engine, but
§180. Also the transmission and differential. It is proving of special value in the testing of automatic transmissions.

§180. The tune-up procedure The various steps of the general-analysis procedure, or tune-up, are fairly well standardized. Automotive service engineers have in general agreed that a procedure similar to that outlined below will disclose most subnormal conditions, wear, incorrect adjustments, and so forth, in the engine and engine accessory systems. Except in the case of cylinder balance, details of the tests or checks are not given below. Refer to other pages in this book for details of the engine checks and refer to other books in the McGraw-Hill Automotive Mechanics Series for details of checking other automotive components. A typical procedure is as follows:

1. Check the battery. Visually inspect for signs of damage and make sure that cables are good and connections are tight. Check specific gravity and, if above 1.225, make a load test.
2. Check cranking system. A battery load test using the cranking motor is also a test of the cranking motor. But voltage drop in circuit, as well as amperage draw, should be checked.
3. Check engine idle speed with engine at operating temperature and adjust if necessary (§173).
4. Check generator-regulator system, including regulator settings, generator output, relay closing and opening settings, voltage drop in charging circuit, and condition of generator and fan belt.
5. Check ignition timing (§177) and adjust if necessary.
6. Check intake-manifold vacuum (§175).
7. Check for cylinder balance to determine whether any cylinders are weak or missing. This is done by running the engine on only two cylinders at a time. Two cylinders are used because running the engine on only one cylinder at a time is not conclusive. The procedure is as follows:
   a. Connect tachometer and vacuum gauge (Fig. 11-10), start engine, and run it until it reaches operating temperature. Then operate it at 1,000 rpm if it is a six-cylinder engine or 1,500 rpm if an eight.
   b. Ground out (or disconnect spark-plug leads from) all but two cylinders so that engine will run on two cyl-
inders only. Determine which cylinders to use by taking engine firing order and putting the first half over the second, as:

1-2-7-8-4-5-6-3 would be 1-2-7-8
4-5-6-3

Then select the cylinders whose numbers are directly above and below each other, as 1 and 4. After running on 1 and 4, run engine on 2 and 5, then 7 and 6, then 8 and 3.

c. Note engine rpm and intake-manifold vacuum for each pair of cylinders. If one pair shows definitely lower readings, one of the two cylinders is weak or missing. To determine which one it is, short out half the cylinders (front or rear half in an in-line engine, one bank in a V-8). The half or bank giving the lower readings will contain the weak cylinder.

8. Check fuel system visually and by use of combustion tester (§ 176). The fuel pump action can be tested to note whether it develops specified pressure and vacuum and can deliver specified amounts of gasoline.

9. Spark plugs should be removed, tested, cleaned, and regapped.

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I. COL. 1 Contains Specifications for your Car
COL. 2 Contains Nominal Test Readings from Your Car
COL. 3 An X Here Indicates a Satisfactory Condition
COL. 4 An X Here Indicates An Unsatisfactory Condition Further Explained at the right.
A Circle () Indicates an Unsatisfactory Condition Corrected During Diagnosis.

1. BATTERY

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cold Voltage</td>
<td>Must be within specified limits</td>
</tr>
<tr>
<td>2.</td>
<td>Cold Resistance</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

2. STARTING SYSTEM

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Starting Motor</td>
<td>Must start within specified time</td>
</tr>
</tbody>
</table>

3. DISTRIBUTOR

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.</td>
<td>Timing</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

4. ENGINE OIL P.M.

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Oil Pressure</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

5. CHARGING SYSTEM

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.</td>
<td>Alternator Output</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

6. SPARK TIMING

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.</td>
<td>Spark plugs</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

7. MANIFOLD VACUUM

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>Vacuum advance</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

8. SECONDARY EFFICIENCY

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.</td>
<td>Fuel economy</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

9. CYLINDER BALANCE

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.</td>
<td>Engine balance</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

10. FUEL SYSTEM

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.</td>
<td>Fuel pressure</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

11. FUEL PUMP

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.</td>
<td>Fuel pump</td>
<td>Must function properly</td>
</tr>
</tbody>
</table>

12. SPARK PlUGS

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.</td>
<td>Spark plugs</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

13. COMPRESSION

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.</td>
<td>Compression</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

14. IGNITION PRIMARY CIRCUIT

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.</td>
<td>Ignition module</td>
<td>Must function properly</td>
</tr>
</tbody>
</table>

15. CODE

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.</td>
<td>Code</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

16. SECONDARY CIRCUIT INSULATION

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.</td>
<td>Insulation</td>
<td>Must be within specified limits</td>
</tr>
</tbody>
</table>

17. CONDENSER

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.</td>
<td>Condenser</td>
<td>Must function properly</td>
</tr>
</tbody>
</table>

18. DISTRIBUTOR (Removal)

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.</td>
<td>Distributor</td>
<td>Must function properly</td>
</tr>
</tbody>
</table>

19. SPEEDOMETER

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.</td>
<td>Speedometer</td>
<td>Must function properly</td>
</tr>
</tbody>
</table>

20. RADIATOR, PUMPS, HOSES

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.</td>
<td>Radiator</td>
<td>Must function properly</td>
</tr>
</tbody>
</table>

21. EXHAUST SYSTEM

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.</td>
<td>Exhaust</td>
<td>Must function properly</td>
</tr>
</tbody>
</table>

22. OTHER ELECTRICAL SYSTEMS

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.</td>
<td>Electrical</td>
<td>Must function properly</td>
</tr>
</tbody>
</table>

* AUXILIARY TESTS TO BE MADE ONLY WHEN PREVIOUS TESTS OF SECTION ARE UNSATISFACTORY

Fig. 11-11. A test report supplied by a test-instrument manufacturer as a guide to the engine serviceman. By following the report step by step the tester will avoid overlooking any important check. (Sun Electric Corporation)
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10. With the plugs out, check compression (§174).

11. Ignition system should then be checked. This includes tests of distributor-point setting, condition of points, rotor, cap, advance mechanisms, coil, condenser, and wiring.

12. During the above procedure, various other automotive components should be checked. For instance, radiator hose should be checked for wear and tightness of fastenings. Block, radiator, and hose should be examined for evidence of leaks. Mounting nuts, bolts, clamps, and so forth, should be checked for tightness on all accessory parts such as generator, carburetor, manifolds, regulator, cranking motor, and so on. Oil level in oil pan, water level in radiator, and air pressure in tires should be checked. In addition, the need for lubrication (oil change, oil filter change, cleaning and reoiling air cleaner, chassis lubrication and so forth) should be checked. Note mileages marked on the door-jamb sticker and advise driver if any lubrication service is needed.

§181. Test reports  Test-instrument manufacturers may supply test-report sheets, such as the one shown in Fig. 11-11, to assist the engine serviceman in making the necessary tests on the car that is being diagnosed. The test report lists step by step the procedure to follow and the tests to be made. If the serviceman follows the procedure listed, he will not overlook any important check and will therefore arrive at a complete analysis of the engine condition. Since different testing instruments may operate in somewhat different ways, the test-report sheets issued by different companies will not be identical. Essentially, however, all are designed to give the same over-all information and to disclose any condition in the engine that could cause trouble.

The advantage of the test-report sheets from the standpoint of customer relations is that they nearly always make a very favorable impression on the customer. The customer is convinced that his car is getting a thorough check and that no important point will be overlooked.

CHAPTER CHECKUP

There are no progress quizzes in this chapter because it is so short. The following checkup covers the material in the entire chapter. You can appreciate the fact that the skillful diagnosis of engine troubles and
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the ability to check the various engine components so as to find any item that might cause trouble are of great value. The material we have just covered in the chapter is designed to help you have this ability. Check how well you remember this material by taking the test below.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. Two types of engine-testing procedures are trouble-shooting and fault-find trouble-shooting and tune-up preventive maintenance and tune-up
2. The general-procedure diagnosis which eliminates trouble before it happens is called preventive maintenance trouble-shooting timing test
3. When the tachometer is connected between the distributor primary terminal and ground it indicates engine speed engine vacuum engine compression
4. If pouring heavy oil into the cylinder increases the compression pressure, then the chances are the loss of compression is due to leakage past the valves past the head gasket past the piston rings
5. If the vacuum-gauge needle swings around to 23 to 25 inches as the throttle is quickly closed after the engine has been raced, it indicates stuck valves low compression satisfactory compression leaky valves
6. A steady but low vacuum reading with the engine idling indicates that the engine is losing power has a stuck valve exhaust line is clogged
7. A very low vacuum reading with the engine idling indicates stuck valves air leakage into manifold loss of compression faulty piston rings
8. A valve that sticks open or a plug that is not firing will cause the vacuum-gauge needle to oscillate slowly drop back regularly fall back slowly to zero read too high
9. The combustion tester determines the air-fuel-mixture ratio by analyzing the fuel charge the compression ratio the compression mixture the exhaust gas
10. The device which can give a very close approximation of a road test in the garage is called the engine dynamometer chassis dynamometer tachometer engine tester
Engine-testing Procedures and Tools

Unscrambling the Test Instruments

Listed to the left below are various test instruments discussed in the chapter. Listed to the right below, but not in the same order, are the purposes of the instruments. To unscramble the lists take each item on the left, in turn, and then find the purpose of the instrument as listed to the right. Put the two together and write the result in your notebook. For instance, the first test instrument listed is "the compression tester." When you look down the list to the right, you come to "checks cylinder compression." So you put the two together to get "the compression tester checks cylinder compression."

- the compression tester
- the tachometer
- the vacuum gauge
- the combustion tester
- the timing light
- analyzes exhaust gas
- checks intake-manifold vacuum
- checks ignition timing
- checks engine speed
- checks cylinder compression

Suggestions for Further Study

Test-instrument manufacturers issue printed information on how to use their instruments and what the test results mean. If you can find this printed information at your local service station or garage or in your school shop, you will find it of considerable interest. You should also examine test instruments in the shop and watch carefully to note how they are used. In this connection, a word of caution. These instruments can be damaged by handling them carelessly or connecting them improperly. Therefore, you must know what you are doing before you attempt to use the test instruments. Study the information on how to use the instruments carefully, and make sure you know what you are doing before you attempt to use any test instrument.
12: Diagnosing engine troubles

THIS CHAPTER discusses various engine troubles and relates them to possible causes and corrections; that is, it describes engine trouble-shooting procedures. It is not an easy chapter to study, but at the same time it is probably the most important chapter in the book. It gives you the information you need to understand the various ways that engine trouble develops, how to determine the cause of a trouble, and how to correct it. Regardless of what you plan to do in the automotive field, whether you want to work in the service shop, plant, office, or laboratory, a knowledge of engine troubles and corrections will be of great value to you.

§182. How to study this chapter

There are different ways to study this chapter. You can go through it page by page, just as you have studied the previous chapters. Perhaps a better way would be to take one complaint at a time (as listed in the trouble-shooting chart), read through the possible causes and checks or corrections, and then study the section later in the chapter that discusses the complaint. For example, you could take complaint 1. Engine will not turn over, and after reading the causes and checks or corrections listed in the second and third columns in the chart, you would turn to §185 (referred to under the complaint) and study it.

Since a knowledge of trouble causes and corrections is so helpful, you will probably be referring to the trouble-shooting chart many times. One way to help yourself remember the complaints, causes, and corrections is to write each complaint, with its list of causes and corrections, on a separate 3- by 5-inch card. Then carry the cards around with you. At odd moments, when you are riding a bus, eating a sandwich, or getting ready for bed, you can take out a card and read it over. Soon you will know the troubles and their causes and corrections “backward and forward.”

§183. Need for logical procedure

After a trouble has been located in an engine, it is usually not too difficult to make the necessary
corrections to eliminate the conditions causing the trouble. Careful analysis and straight thinking, however, are often needed to find the cause of trouble. Following chapters discuss the various engine services and explain in detail the corrections to be made to eliminate different causes of trouble.

This chapter is devoted to trouble-shooting, to the detective work that a mechanic is called upon to do when a case of engine trouble comes his way. If a logical procedure is followed, the cause of trouble can usually be spotted without delay. But haphazard guesswork wastes time and may cause you to overlook entirely the basic cause of the trouble. For example, suppose you found a car that would not start because it had a run-down battery. You might send the driver on his way with a recharge or a new battery, blaming the run-down battery for the trouble. But you might search further to find out why the battery ran down. Perhaps it was old, or possibly the generator or regulator was not operating properly. On the other hand, the driver might be at fault because he drove mostly at night with lights and radio on. The trouble might have been due to hard starting or to frequent starts and stops which caused the driver to use the cranking motor excessively with the result that the battery ran down. In any event, unless the real cause of trouble is found and corrected, the driver will soon be in trouble again.

The chart that follows lists various troubles that might be blamed on the engine, together with their possible causes, checks to be made, and corrections needed. Following the chart are detailed explanations of the checking procedures to use with each of the trouble complaints. Some causes of trouble will be found to be in the engine itself; the latter part of this book is devoted to the various engine service operations that correct these troubles. Other causes of trouble may be in the fuel, cooling, lubricating, or electric system; trouble corrections on these are detailed in other books in the McGraw-Hill Automotive Mechanics Series.

§184. Engine trouble-shooting chart A variety of complaints bring the driver to the mechanic, but it is rather rare for the driver to have a clear idea of what has caused his trouble. Most complaints, however, can be grouped under a few basic headings. These include: engine will not turn over, engine turns over but will not
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start, engine misses, engine lacks power or high-speed performance, engine overheats, engine uses excessive oil or gasoline, or engine is noisy. The chart that follows lists possible causes of each of these troubles, and then refers to numbered sections after the chart for fuller explanations of how the troubles can be located and eliminated. When trouble has been traced to the fuel, cooling, lubricating, or electric system, reference is made to the book in the McGraw-Hill Automotive Mechanics Series that explains how to correct the trouble.

**NOTE:** The troubles and possible causes are not listed in the chart in the order of frequency of occurrence. That is, item 1 (or item a under Possible Cause) does not necessarily occur more frequently than item 2 (or item b).

**ENGINE TROUBLE-SHOOTING CHART**

(See §§185 to 196 for detailed explanations of trouble causes and corrections listed below.)

<table>
<thead>
<tr>
<th>Complaint</th>
<th>Possible Cause</th>
<th>Check or Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Engine will not turn over (§185)</td>
<td>a. Run-down battery</td>
<td>Recharge or replace*</td>
</tr>
<tr>
<td></td>
<td>b. Starting circuit open</td>
<td>Locate and eliminate open*</td>
</tr>
<tr>
<td></td>
<td>c. Bendix drive jammed</td>
<td>Free drive*</td>
</tr>
<tr>
<td></td>
<td>d. Cranking motor jammed</td>
<td>Remove for tear down and correction*</td>
</tr>
<tr>
<td></td>
<td>e. Engine jammed</td>
<td>Check engine to find trouble</td>
</tr>
<tr>
<td>f. Also causes listed under item 3. Engine turns over at normal speed but does not start, below. Driver may have run battery down trying to start</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Engine turns over slowly but does not start (§186)</td>
<td>a. Run-down battery</td>
<td>Recharge or replace*</td>
</tr>
<tr>
<td></td>
<td>b. Defective cranking motor</td>
<td>Replace or repair*</td>
</tr>
<tr>
<td></td>
<td>c. Bad connections in starting circuit</td>
<td>Clean and tighten*</td>
</tr>
<tr>
<td></td>
<td>d. Undersized battery cables</td>
<td>Replace*</td>
</tr>
</tbody>
</table>

See *Automotive Electrical Equipment.*

See *Automotive Fuel, Lubricating, and Cooling Systems.*

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### Diagnosing Engine Troubles

**Complaint**

<table>
<thead>
<tr>
<th>Complaint</th>
<th>Possible Cause</th>
<th>Check or Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Engine turns over at normal speed but does not start</td>
<td>a. Ignition system defective</td>
<td>Try spark test; check timing, ignition system*</td>
</tr>
<tr>
<td></td>
<td>b. Fuel system defective</td>
<td>Prime engine; check fuel pump, line, choke, carburetor</td>
</tr>
<tr>
<td></td>
<td>c. Air leaks in intake manifold or carburetor</td>
<td>Tighten mounting; replace gasket as needed</td>
</tr>
<tr>
<td></td>
<td>d. Engine defective</td>
<td>Check compression (see §174), valve action, timing, etc.</td>
</tr>
<tr>
<td></td>
<td>e. Also causes listed under item 3. Engine turns over at normal speed but does not start, below. Driver may have run battery down trying to start</td>
<td></td>
</tr>
<tr>
<td>4. Engine runs but misses—one cylinder (§188)</td>
<td>a. Defective spark plug</td>
<td>Clean or replace*</td>
</tr>
<tr>
<td></td>
<td>b. Distributor cap or lead defective</td>
<td>Replace*</td>
</tr>
<tr>
<td></td>
<td>c. Stuck valve</td>
<td>Free valve; service stem and guide</td>
</tr>
<tr>
<td></td>
<td>d. Defective rings or piston</td>
<td>Replace; service piston, cylinder wall, as needed</td>
</tr>
<tr>
<td></td>
<td>e. Defective head gasket</td>
<td>Replace</td>
</tr>
<tr>
<td>5. Engine runs but misses—different cylinders (§188)</td>
<td>a. Defective ignition</td>
<td>Check timing and ignition*</td>
</tr>
<tr>
<td></td>
<td>b. Defective fuel system</td>
<td>Check fuel pump, carburetor</td>
</tr>
<tr>
<td></td>
<td>c. Loss of compression</td>
<td>Check compression (see §174)</td>
</tr>
<tr>
<td></td>
<td>d. Defective valve action</td>
<td>Check valve action with compression or vacuum test (see §§174 and 175)</td>
</tr>
<tr>
<td></td>
<td>e. Defective rings</td>
<td>Check compression and vacuum; replace rings, service pistons, cylinder walls as needed</td>
</tr>
</tbody>
</table>

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### §184

**Complaint**

5. Engine runs but misses—different cylinders (§188) *(Continued)*

6. Engine lacks power, acceleration or high-speed performance, hot or cold (§189)

<table>
<thead>
<tr>
<th>Possible Cause</th>
<th>Check or Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>f.</strong> Overheated engine</td>
<td>Check cooling system†</td>
</tr>
<tr>
<td><strong>g.</strong> Manifold heat-control valve sticking</td>
<td>Free valve</td>
</tr>
<tr>
<td><strong>h.</strong> Clogged exhaust</td>
<td>Check tail pipe, muffler; eliminate clogging</td>
</tr>
<tr>
<td><strong>a.</strong> Ignition defective</td>
<td>Check timing, distributor, wiring, condenser, coil, plugs*</td>
</tr>
<tr>
<td><strong>b.</strong> Fuel system defective</td>
<td>Check carburetor, air cleaner, fuel pump†</td>
</tr>
<tr>
<td><strong>c.</strong> Throttle valve not fully opening</td>
<td>Adjust linkage†</td>
</tr>
<tr>
<td><strong>d.</strong> Clogged exhaust</td>
<td>Check tail pipe, muffler; eliminate clogging</td>
</tr>
<tr>
<td><strong>e.</strong> Loss of compression</td>
<td>Check compression (see §174)</td>
</tr>
<tr>
<td><strong>f.</strong> Excessive carbon in engine</td>
<td>Remove carbon</td>
</tr>
<tr>
<td><strong>g.</strong> Defective valve action</td>
<td>Check with compression or vacuum tester (see §§174 and 175)</td>
</tr>
<tr>
<td><strong>h.</strong> Excessive rolling resistance from low tires, dragging brakes, wheel misalignment, etc.</td>
<td>Correct the defect causing rolling resistance†</td>
</tr>
<tr>
<td><strong>i.</strong> Heavy oil</td>
<td>Use lighter oil†</td>
</tr>
<tr>
<td><strong>j.</strong> Wrong or bad fuel</td>
<td>Use good fuel of correct octane</td>
</tr>
</tbody>
</table>

7. Engine lacks power, acceleration or high-speed performance

<table>
<thead>
<tr>
<th>Possible Cause</th>
<th>Check or Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a.</strong> Engine overheats</td>
<td>Check cooling system† (see item 9 below)</td>
</tr>
<tr>
<td><strong>b.</strong> Defective choke</td>
<td>Repair or replace†</td>
</tr>
</tbody>
</table>

* See Automotive Electrical Equipment.
† See Automotive Fuel, Lubricating, and Cooling Systems.
†† See Automotive Chassis and Body.
### Diagnosing Engine Troubles

<table>
<thead>
<tr>
<th>Complaint</th>
<th>Possible Cause</th>
<th>Check or Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free valve</td>
<td>Use different fuel or shield fuel line†</td>
<td></td>
</tr>
<tr>
<td>Vapor lock</td>
<td>Repair or replace †</td>
<td></td>
</tr>
<tr>
<td>Sticking manifold heat-control valve</td>
<td>Repair or replace †</td>
<td></td>
</tr>
<tr>
<td>Automatic choke stuck</td>
<td>Repair or replace †</td>
<td></td>
</tr>
<tr>
<td>Manifold heat-control valve stuck</td>
<td>Repair or replace †</td>
<td></td>
</tr>
<tr>
<td>Cooling-system thermostat stuck</td>
<td>Repair or replace †</td>
<td></td>
</tr>
<tr>
<td>Stuck engine valves</td>
<td>Free valves; service valve stems and guides as needed</td>
<td></td>
</tr>
<tr>
<td>Lack of water</td>
<td>Add water</td>
<td></td>
</tr>
<tr>
<td>Ignition timing late</td>
<td>Retime*</td>
<td></td>
</tr>
<tr>
<td>Loose or broken fan belt</td>
<td>Replace †</td>
<td></td>
</tr>
<tr>
<td>Defective thermostat</td>
<td>Clean out †</td>
<td></td>
</tr>
<tr>
<td>Clogged water jackets</td>
<td>Replace †</td>
<td></td>
</tr>
<tr>
<td>Defective radiator hose</td>
<td>Repair or replace †</td>
<td></td>
</tr>
<tr>
<td>Defective water pump</td>
<td>Add oil</td>
<td></td>
</tr>
<tr>
<td>Insufficient engine oil</td>
<td>Drive more slowly; keep radiator filled</td>
<td></td>
</tr>
<tr>
<td>High altitude, hot-climate operation</td>
<td>Retime</td>
<td></td>
</tr>
<tr>
<td>Valve timing late</td>
<td>Readjust idle mixture and speed †</td>
<td></td>
</tr>
<tr>
<td>Carburetor idle adjustment incorrect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other causes, which are listed under Engine Lacks Power, etc. (items 6, 7, and 8, above)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rough idle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine stalls as it warms up</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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§184

§189

§190

§191

§192
§184

Complaint

11. Engine stalls as it warms up (§192)
   d. Engine idling speed set too low
      a. Defective fuel pump
      b. Overheating
      c. High float level
      d. Idling adjustment incorrect

12. Engine stalls after idling or slow-speed drive (§192)
   a. Vapor lock
   b. Carburetor anti-percolator defective
   c. Engine overheats

13. Engine stalls after high-speed drive (§192)
   a. Ignition timing off
   b. Spark plugs of wrong heat range
   c. Excessively rich or lean mixture
   d. Overheating of engine
   e. Carbon in engine
   f. Valves hot or sticking
   g. Cracked distributor cap

14. Engine backfires (§193)
   a. Ignition timing off
   b. Spark plugs of wrong heat range
   c. Excessively rich or lean mixture
   d. Overheating of engine
   e. Carbon in engine
   f. Valves hot or sticking
   g. Cracked distributor cap

15. Smoky exhaust
   1. Blue smoke
   2. Black smoke

16. Excessive oil consumption (§194)
   a. External leaks
   b. Burning oil in combustion chamber

Possible Cause

Automotive Engines

Check or Correction

Increase idling speed to specified value
Repair or replace fuel pump
See item 9. Engine overheats, above
Adjust
Adjust
Use different fuel or shield fuel line
Check and repair
See item 9. Engine overheats, above
Retime*
Install correct plugs
Repair or readjust fuel pump or carburetor
See item 9. Engine overheats, above
Clean out
Adjust; free; clean; replace if bad
Replace cap

Excessive oil consumption
Excessively rich mixture
Correct seals; replace gaskets†
Check valve-stem clearance, piston rings, cylinder

† See Automotive Fuel, Lubricating, and Cooling Systems.
* See Automotive Electrical Equipment.
† See Automotive Chassis and Body.
Diagnosing Engine Troubles

<table>
<thead>
<tr>
<th>Complaint</th>
<th>Possible Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>17. Excessive fuel consumption</strong> (§195)</td>
<td>§184</td>
</tr>
</tbody>
</table>
| c. High-speed driving | Check or Correction: walls, rod bearings, vacuum-pump dia-
| a. "Nervous" or "jack-rabbit" driver | phragm† |
| b. High speed | Drive more slowly† |
| c. Short-run operation | Drive more reasonably† |
| d. Excessive fuel-pump pressure or pump leakage | Make longer runs† |
| e. Choke closed | Reduce pressure; re-
| f. Clogged air cleaner | pair pump |
| g. High carburetor float level | Open; repair or re-
| h. Stuck or dirty float needle valve | place automatic choke† |
| i. Worn carburetor jets | Clean† |
| j. Stuck metering rod or full-power piston | Adjust† |
| k. Idle too rich or too fast | Free and clean† |
| l. Stuck accelerator-pump check valve | Replace† |
| m. Faulty ignition | Free† |
| n. Loss of engine compression | Check coil, condenser, timing, plugs, contact points, wiring* |
| o. Defective valve action | Check compression (see §174) |

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## §184

### Complaint

#### 17. Excessive fuel consumption

**Possible Cause**

- Excessive rolling resistance from low tires, dragging brakes, wheel misalignment, etc.

**Check or Correction**

- Correct the defects causing rolling resistance

#### 18. Engine is noisy

**Possible Cause**

- Valve and tappet
- Spark knock due to low-octane fuel, carbon, advanced ignition timing, or causes listed under 14. Engine backfires, above
- Worn connecting-rod bearing or crankpin, misaligned rod, lack of oil
- Worn or loose piston pin or bushing or lack of oil
- Worn rings, cylinder walls, low ring tension, broken rings
- Piston slap due to worn pistons, walls, collapsed piston skirts, excessive clearance, lack of oil, misaligned rods
- When noise is regular, because of worn main bearings; ir...

**Check or Correction**

- Readjust valve clearance
- Use higher-octane fuel; remove carbon; retiming
- Replace or adjust bearings; service crankpins; realign rod; correct lack of oil
- Service pin and bushing, correct lack of oil
- Service walls; replace rings
- Replace or resize pistons; service walls; align rods; correct lack of oil
- Replace or service bearings and crankshaft

---

1 See *Automotive Chassis and Body.*

2 See *Automotive Transmissions and Power Trains.*

3 Refer to other books in the McGraw-Hill Automotive Mechanics Series for the analysis of noises in other automotive components such as transmission, differential, etc.
Diagnosing Engine Troubles

<table>
<thead>
<tr>
<th>Complaint</th>
<th>Possible Cause</th>
<th>Check or Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration, especially when cold</td>
<td>regular, because of worn end-thrust bearings</td>
<td></td>
</tr>
<tr>
<td>8. Miscellaneous noises</td>
<td>Rattles, etc., from loosely mounted accessories such as generator, horn, oil pan, etc.</td>
<td>Tighten mounting</td>
</tr>
</tbody>
</table>

§185. Engine will not turn over  If the engine fails to turn over when the cranking-motor switch is closed, turn on the headlights or dome lights, and then close the cranking-motor switch. The lights will (1) stay bright, (2) dim considerably, (3) dim slightly, or (4) go out. Or (5) the lights will burn dimly or not at all when turned on without closing the cranking-motor switch.

1. If the lights stay bright, there is an open circuit between the cranking motor and the battery, probably at the cranking-motor-switch circuit or in the cranking motor itself. The cranking motor, the circuit, and the switch may be checked further as outlined in Automotive Electrical Equipment.

2. If the lights dim considerably as the cranking-motor switch is closed, the battery may be run down, or there may be mechanical trouble in the cranking motor or engine that puts a terrific load on the battery. The battery condition should be checked with a hydrometer. If the battery is in a good state of charge, remove the cranking-motor cover band and try to turn the armature by hand. Do not use a screw driver, since this may damage the armature. If the armature does not turn, remove the cranking motor for further analysis. On the Bendix-type cranking motor (type without a shift lever mounted on it) the drive pinion may jam in the flywheel so that it will not turn over (rare). If the armature turns readily, the trouble is probably in the engine.

3. If the lights dim only slightly as the cranking-motor switch is closed, listen for cranking-motor action (sound of an electric motor running), or remove the cover band to determine whether or not the cranking-motor armature is rotating when the switch is closed. If it is, the drive pinion is not engaging the flywheel. This condition occurs only on Bendix-drive cranking motors and is usually caused by gum or dirt on the pinion or the sleeve. If the armature does not rotate, the pinion may be engaging the flywheel, but ex-
cessive resistance or an open circuit in the cranking motor is preventing normal operation.

4. If the lights go out as the cranking-motor switch is closed, it is probable that there is a bad connection between the battery and the cranking motor, probably at a battery terminal.

5. If the lights burn dimly or not at all when the light switch is turned on without closing the cranking-motor switch, the battery is probably run down.

§186. Engine turns over slowly but does not start

If the engine turns over slowly but does not start when the cranking-motor switch is closed, the battery may be discharged, the cranking motor may be defective, undersized battery cables may have been installed, or there may be mechanical trouble in the engine. The battery and the cranking motor may be checked as detailed in Automotive Electrical Equipment. If they are in normal condition, the trouble lies in the engine. Consider the possibility, if the battery is found to be run down, that the driver has discharged the battery in a vain attempt to start and that failure to start could originally have been caused by ignition or engine troubles. A new battery may be installed and the car checked further as outlined in the following paragraphs.

§187. Engine turns over at normal cranking speed but does not start

When the engine turns over at normal cranking speed but does not start, the battery and the cranking motor can be considered in satisfactory condition. The cause of trouble probably lies in the ignition or the fuel system. Disconnect the lead from one spark plug and hold it about $\frac{3}{16}$ inch from the engine block while cranking, to see if a good spark occurs. (Or pull lead from center terminal or distributor cap and hold it close to engine block.) If a good spark occurs, the ignition system is probably operating normally, although it could be out of time and the timing should be checked. If no spark occurs, check ignition system.

If the ignition system is in normal condition and the engine does not start when it is cranked at normal speed, the fuel system should be analyzed. The engine may be primed by operating the carburetor accelerator pump several times or by removing the air cleaner from the carburetor and squirting a small amount of gasoline from an oil can into the carburetor air horn.
Diagnosing Engine Troubles

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Caution: Gasoline is highly explosive. Keep back out of the way while priming the engine; the engine might backfire through the carburetor.

If the engine now starts and runs for a few seconds, the fuel system probably is at fault, since it is not delivering gasoline normally to the carburetor. The gasoline inlet to the carburetor may be disconnected temporarily to determine whether gasoline is being delivered during cranking. If it is not, the fuel pump or line is defective. (It is naturally assumed that there is gasoline in the fuel tank.) Catch the fuel pumped from the line in a container or in a cloth, and then put cloth outside to dry.

If gasoline is being delivered to the carburetor during cranking, then the probability is that the carburetor itself is at fault and is not providing the proper fuel-air mixture to the engine. The fuel passages or jets in the carburetor will need to be disassembled for cleaning. There is a chance that failure to start might be due to air leaks into the intake manifold or carburetor, due to a defective gasket or a worn throttle shaft bearing in the carburetor. This, however, would be a rather rare condition.

Caution: Clean up any spilled gasoline promptly and put gasoline-soaked rags outside to dry so as to reduce danger of fire.

If the engine does not start when primed, the valve action or timing or ignition timing is probably at fault.

Note: If there is an automatic choke on the carburetor, it is possible that the choke is not opening normally. Thus a warm engine would load up (that is, be supplied with an excessively rich mixture) and not start. With the engine cold, however, starting should be normal. If the engine is warm, check the position of the choke valve. It should be open. If it is not, open it by hand or allow the engine to cool off and then attempt to start it. If the engine now starts normally, the choke is faulty.

§188. Engine runs but misses A missing engine is a rough engine, since failure of cylinders to fire normally and in sequence throws the engine out of balance, and roughness and loss of power are evident. Missing may take place under various operating conditions, at low speed, at high speed, at all speeds, intermittently; it may [325]
§188 Automotive Engines

occur in one cylinder, or it may skip around from cylinder to cylinder. The first step in analyzing a missing engine is to run the engine at various speeds and under load to determine, if possible, whether the missing is steady or irregular.

1. To check whether a cylinder is or is not missing, hold the engine speed and load steady and short out the spark plug with a screw driver. Use a screw driver with an insulated handle to avoid getting a shock. Short out the spark plug by placing the screw-driver bit between the spark-plug terminal and the engine block. This prevents a spark from occurring at the spark plug and causes the cylinder to miss. If the engine rhythm or speed changes when the plug is shorted out, that cylinder was delivering power before being shorted out. If no change in the operation of the engine occurs when a spark plug is shorted out, that cylinder is not delivering power; it is missing. By the shorting out of each cylinder in turn, all cylinders in an engine may be quickly checked.

2. A second and somewhat more complicated (but more accurate) way to check for a weak or missing cylinder is to operate the engine on two cylinders at a time as explained in §180 (item 7).

3. If a particular cylinder is found to be weak or missing, remove the lead from the spark plug (with the other cylinders operating) and hold it close to the engine block to see if a good spark occurs. If it does not, the cause of trouble is in the secondary circuit of the ignition system and could be due to defective cable insulation or to a cracked or burned distributor cap, which causes high-tension leakage to ground. If a good spark occurs, remove the spark plug and install a new plug or a plug from a cylinder that operated satisfactorily. If the cylinder now performs normally, the cause of the trouble was the plug. If changing the plug does not improve the performance, the cause of the trouble is probably due to malfunctioning of some engine part, such as valves or rings.

4. If the missing cylinder cannot be readily located, a general tune-up is indicated (§180), since many conditions may be causing the intermittent skipping or irregular missing. These conditions include: defective ignition system that fails to deliver sufficiently strong sparks in regular order; defective fuel system that does not deliver proper air-fuel mixture; loss of compression in the engine; engine valves not operating correctly; overheated engine; manifold heat-control valve sticking; or a clogged exhaust.

[326]
§189. Engine lacks power, acceleration, or high-speed performance

A complaint of this nature is usually rather difficult to analyze, since the complaint is, after all, somewhat vague, and almost any component in the vehicle, from the driver to the tires, might be causing the trouble. More than one complaint of “poor high-speed performance” has been solved by an adjustment of the speedometer that caused it to read higher. The fact that it would register 80 instead of 70, even though the car went no faster, satisfied the driver. At the other extreme, underinflated tires or misalignment of the front wheels may appreciably affect high-speed performance. While the best procedure to follow when dealing with this complaint is to perform a complete tune-up (§180), some idea of the location of the trouble can be gained by operating the engine to determine whether the engine lacks power when cold, or whether this trouble is experienced only when the engine is hot.

Note: As a first step in analyzing a complaint of poor acceleration, some mechanics make an actual performance test over a good road with a stop watch to determine how long it takes to reach a given speed. The test should be made on the road first in one direction and then in the opposite direction, and the results averaged. This balances out any difference in wind or road grade. Of course, with the chassis dynamometer (§179), a similar test can be made in the shop, without the necessity of taking the car out on the road.

1. If the engine lacks power, acceleration, and high-speed performance whether hot or cold, it seems likely that the cooling system is not causing the trouble. The trouble could be due to one or more weak or missing cylinders, and the vacuum-gauge test, compression test, and the cylinder-balance check (§180) would give more information on that. Many conditions can cause loss of power, acceleration, and high-speed performance. The ignition system may not be operating normally because of incorrect timing, a “weak” coil, or because of spark plugs of the wrong heat range. The fuel or exhaust system may be operating improperly. The throttle valve may not be opening fully. The carburetor air cleaner may be clogged so that it does not admit sufficient air, or the carburetor may not be delivering proper amounts of gasoline. Improper valve operation, lack of compression, use of heavy oil, use of wrong grade of fuel, or excessive carbon in the engine will cause
loss of power. The muffler, if clogged, or the tail pipe, if bent, could create back pressure in the exhaust manifold that would cause poor engine performance. Dragging brakes or underinflated tires will give the impression of lack of engine power, since they absorb an excessive amount of power when the car is moving.

2. If the engine lacks power only when hot, that is, if it loses power as it warms up, it is possible that the trouble is resulting from overheating of the engine (§190), but a number of other conditions should be considered. Defective automatic-choke operation on cars so equipped may cause the engine to load up (be supplied an excessively rich mixture) at operating temperature, so that performance will be poor. Position of the choke valve with the engine warm should be noted. If the manifold heat-control valve is not operating properly, the intake manifold will be supplied with excessive heat after the engine reaches operating temperature. This will prevent adequate amounts of air-fuel mixture from reaching the cylinders, causing the engine to lack power when warm. If a vapor lock occurs in the fuel line, the engine will not receive enough fuel; it will perform poorly and may stall.

3. If the engine lacks power when cold or reaches operating temperature too slowly, several conditions should be considered. The automatic choke may not be operating correctly, allowing the air-fuel mixture to become too lean with the engine cold. The manifold heat-control valve may not be operating, causing insufficient heat to be supplied to the intake manifold when the engine is cold. If the thermostat in the cooling system is sticking in the open position, water will circulate through the water jackets and the radiator during the warm-up period; in this case, excessively long periods will be required for the engine to reach operating temperature. Occasionally engine valves may stick with the engine cold, but as the engine approaches operating temperature, the valves become free and begin to work normally. This causes lack of power with the engine cold.

§190. Engine overheats The first thought that comes to mind when an engine is reported to be overheating is that the cooling system is not functioning properly. As was mentioned in §189, other conditions besides faulty cooling-system operation may cause overheating of the engine. It is wise to make sure first that the engine is
Diagnosing Engine Troubles

§192

Actually overheating and that the temperature gauge is not defective and just reading high. At high altitude and in hot climates the engine has an increased tendency to overheat. Insufficient oil may cause the engine not only to overheat but eventually to fail from lack of lubrication. Improperly timed ignition or valves (set too late) will cause the engine to overheat. A loose and slipping engine fan belt causes poor fan and water-pump performance and overheating. In the cooling system an improperly operating thermostat, clogged radiator water lines or jackets, or a defective water pump will reduce water circulation so that overheating of the engine will result. If the water freezes in the cooling system, normal water circulation cannot take place. Hot spots and boiling will develop before the ice has a chance to melt.

§191. Rough idle If the engine idles roughly but runs normally above idle, the chances are that the trouble is due to an incorrectly adjusted carburetor, and the idling speed and mixture should be readjusted. There is also a possibility that the rough idle is due to any of the causes described in § 189.

§192. Engine stalls If the engine starts and runs, and then stalls after it has been in operation, note first whether it stalls as it warms up, stalls after idling or slow-speed driving, or stalls after a period of high-speed or full-load driving.

1. Engine stalls as it warms up. This condition might result if the choke valve is stuck closed. The mixture becomes too rich for a hot engine and the engine stalls. Also, if the manifold heat-control valve is stuck, the ingoing air-fuel mixture might become overheated and too lean, causing the engine to stall. If the hot-idle setting is too low, the engine may stall when it warms up because its idling speed will drop too low. It is also possible that the engine is overheating (§ 190).

2. Engine stalls after idling or slow-speed driving. This is apt to occur if the fuel pump is defective and has a cracked diaphragm, weak spring, or defective valve. In such a case the pump cannot deliver enough gasoline at low speed to replace that used by the engine. The carburetor float bowl therefore runs dry and the engine stops. On the other hand, if the float level is set too high or the idle adjustment is too rich, the engine may “load up” with an overrich mixture and stall. A lean idle adjustment also will cause stalling
when the engine is hot. The engine may overheat during sustained idling or slow-speed driving, since with this condition the air movement through the radiator may not be great enough to keep the engine temperature down. If overheating is excessive or abnormal, consider the conditions listed under §190.

3. Engine stalls after high-speed driving. This may occur if sufficient heat accumulates to cause the fuel to boil in the line and produce a vapor lock. Shielding the fuel line or using a less volatile fuel reduces the tendency for vapor lock to occur. Another condition that might cause stalling after high-speed driving is failure of the antipercolator in the carburetor, which causes the mixture to become too rich and the engine to stall. Stalling might also result from engine overheating (see §190).

§193. Engine backfires   When an engine is cold, it may backfire through the carburetor due to a temporarily improper air-fuel-mixture ratio. However, as the engine warms up, the condition will correct itself provided everything else is normal. If the engine continues to backfire, or if it backfires when hot, the trouble could be due to incorrect ignition timing (timed too late), defective secondary-cable insulation or distributor cap (either of which might permit cross firing), spark plugs of the wrong heat range (which overheat and cause preignition), excessively rich or lean mixtures (due to carburetor or fuel-pump defects), overheating of the engine (see §190), carbon in the engine, hot valves, or intake valves that stick or seat poorly. Carbon in the engine, if excessive, sometimes retains enough heat to cause preignition of the air-fuel mixture entering the cylinder, causing backfiring to occur. Excessive carbon also increases the compression ratio and thus the tendency for ping­ning and preignition. Excessively hot spark plugs will cause preignition; cooler-running plugs should be installed. If valves hang open, combustion may be carried back into the carburetor in a backfire; they should be cleaned and freed. Also, valves that have been ground excessively so that they have sharp edges, or that seat poorly, or are carboned up may overheat, burn, and cause backfiring. Excessively ground or burned valves should be discarded. Others should be serviced.

§194. Excessive oil consumption   Oil is lost from the engine in three ways: by burning in the combustion chamber, by leakage in liquid form, and by passing out of the crankcase through the crankcase [330]
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ventilation system in the form of vapor or mist. Excessive oil con-
sumption is not difficult to detect, since the necessity for frequent
additions of oil to maintain the proper oil level in the crankcase
makes the condition obvious. The actual amount of oil consumption
can be accurately checked by filling the crankcase to the correct
level with oil, operating for several hundred miles, and then meas-
uring the additional oil that must be added to bring the oil back to
the original level.

External leaks can often be detected by inspecting the seals
around the oil pan, valve-cover plate, timing-gear housing, or at oil-
line and oil-filter connections. Presence of excessive amounts of oil
indicates leakage. Some authorities suggest that a white cloth at-
tached to the underside of the engine during a road test will be
helpful in determining the location of external leaks.

The burning of oil in the combustion chamber usually produces
a bluish tinge in the exhaust gas. Oil can enter the combustion
chamber in three ways: through a cracked vacuum-pump dia-
phragm when the car is equipped with a combination fuel and vac-
uum pump, through the clearance between the intake-valve guides
and stems, or around the piston rings.

When the exhaust smoke has a bluish tinge and the car is
equipped with a combination fuel and vacuum pump, the vacuum
pump should be checked to see if the diaphragm is cracked. This
can be easily done by operating the windshield wiper and then
quickly accelerating the engine. If the windshield wiper stops
during acceleration, it indicates that the vacuum-pump diaphragm
is cracked. Oil can pass through the crack into the combustion
chamber. If the windshield wiper continues to operate at normal
speed during acceleration, the vacuum-pump diaphragm is not the
cause of excessive oil consumption. This test does not, of course,
apply to a car without a combination fuel and vacuum pump.

A second means by which oil can enter the combustion chamber
is through clearance caused by wear between the intake-valve
guides and stems. When clearance is excessive, oil will be sucked
into the combustion chamber on each intake stroke. The appearance
of the underside of an intake valve provides a clue to the condition
of its stem and the guide. If the underside of the intake valve has
excessive amounts of carbon, the valve guide and possibly the valve
stem are excessively worn. Part of the oil that passes around the
valve remains on the underside to form carbon. When this condi-

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When excessive oil consumption is found, it is usually necessary to install valve packing or a new valve guide. A new valve may also be required.

Probably the most common cause of excessive oil consumption is passage of oil to the combustion chamber between the piston rings and the cylinder walls. This results from worn, tapered, or out-of-round cylinder walls, or from worn or carboned piston rings. In addition, when the bearings are worn, excessive amounts of oil are thrown on the cylinder walls, so that the piston rings, unable to control all of it, allow too much oil to work up into the combustion chamber.

NOTE: A method of checking for worn bearings by using a bearing oil-leak detector is described in §217.

Another factor that must be considered in any analysis of oil consumption is engine speed. High speed produces high oil temperatures and thin oil. This combination causes more oil to be thrown on the cylinder walls. The piston rings, moving at high speed, cannot function so effectively, and more oil works up into the combustion chamber past the rings. In addition, the churning effect on the oil in the crankcase creates more oil vapor or mist at high speed, and more oil is lost through the crankcase ventilation system. Tests have shown that an engine will use several times more oil at 60 mph (miles per hour) than at 30 mph.

§195. Excessive fuel consumption

Excessive fuel consumption can be caused by almost anything in the car from underinflated tires or dragging brakes to a defective choke. When excessive fuel consumption is reported, the first step is to determine whether the trouble is in the fuel system, the engine, or elsewhere. A fuel-mileage tester can be used to measure actual fuel consumption accurately. This tester is simply a container holding a measured amount of gasoline. It is connected to the carburetor in place of the fuel pump (the carburetor float bowl must be empty to start with) and the car is operated until the fuel is exhausted. Miles per gallon can then be calculated.

The compression tester (§174) and the intake-manifold vacuum gauge (§175) will determine quite accurately whether the trouble is in the engine, fuel system, ignition system, or elsewhere.1

1 A rough test of mixture richness that does not require any testing instruments is to install a set of new or cleaned spark plugs of the correct heat range for the engine and to operate the car for 15 or 20 minutes; then stop the car, and remove...
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If the trouble lies in the fuel system, the fuel-pump pressure should be checked, since excessive fuel-pump pressure will cause too much gasoline to be delivered to the carburetor, resulting in an excessively rich air-fuel mixture. If the fuel-pump pressure is found to be within specifications, consider the following:

1. A “nervous” driver who pumps the accelerator pedal when idling and insists on being the first to get away when the stop light changes uses excessive amounts of gasoline, since each downward movement of the accelerator pedal causes the accelerator pump to discharge a flow of gasoline into the carburetor air horn.

2. Improper operation of a mechanical choke can cause the engine to run with the choke valve partly closed after warm-up and to use excessive amounts of fuel.

3. Short runs, between which the engine is allowed to cool, mean that the engine is usually operating cold or warming up, so that fuel consumption is high.

These three conditions (1, 2, and 3) are due not to any malfunctioning of the fuel system but to the type of operation. Changing the operating conditions is the only cure.

4. If excessive fuel consumption is not due to high fuel-pump pressure or to operating conditions, the trouble is likely to be in the carburetor, and could be any of the following:
   a. If the car is equipped with an automatic choke, the choke may not be opening rapidly enough during warm-up or may not fully open. This can be checked by removing the air cleaner and observing the choke operation during warm-up.
   b. A clogged air cleaner that does not admit sufficient air will act somewhat like a partly closed choke valve. The cleaner element should be cleaned or replaced.
   c. If the float level is high in the float bowl it will cause flooding and delivery of excessive fuel to the carburetor air horn. The needle valve may be stuck open or may

and examine the plugs. If they are coated with a black carbon deposit, the indication is that the mixture is too rich. See points a to g under 4. Black exhaust smoke is another indication of an excessively rich mixture; the mixture is too rich to burn fully, so the exhaust gas contains “soot,” or unburned fuel.

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not be seating fully. The float level should be checked and adjusted.

d. If the idle is set too rich or the idle speed too high, excessive fuel consumption will result. These should be checked and adjusted as necessary.

e. Where the accelerator-pump circuit has a check valve, failure of the check valve to close properly may allow fuel to feed through into the carburetor air horn. The carburetor will require disassembly for repair.

f. If the metering rod is stuck in the high-speed, full-throttle position or the economizer valve holds open, it will permit the high-speed, full-power circuit to function, supplying an excessively rich mixture. The carburetor will require disassembly for repair.

g. Worn jets, permitting the discharge of too much fuel, require replacement during carburetor rebuilding.

5. Faulty ignition can also cause excessive fuel consumption; the ignition system could cause engine miss and thus failure of the engine to utilize all the fuel. This sort of trouble would also be associated with loss of power, acceleration, or high-speed performance (§189). Conditions in the ignition system that might contribute to the trouble include a "weak" coil or condenser, incorrect timing, faulty advance mechanism action, dirty or worn plugs or contact points, or defective wiring.

6. Inferior engine action can produce excessive fuel consumption; for example, loss of engine compression from worn or stuck rings, worn or stuck valves, or a loose or burned cylinder-head gasket cause loss of power; more fuel must be burned to achieve the same speed. Refer to §174 for compression checking procedure.

7. Excessive fuel consumption can also result from conditions that make it hard for the engine to move the car along the road. Such factors as low tires, dragging brakes, and misalignment of wheels increase the rolling resistance of the car. The engine must use up more fuel to overcome this excessive rolling resistance.

§196. Engine noises Various types of engine noises may be found, some of which have little significance. Other noises may indicate
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serious engine trouble that will require prompt attention to prevent major damage to the engine. Characteristics of various noises and their causes are described below, along with tests that may be necessary to confirm a diagnosis.

A listening rod will be of help in locating the source of a noise. The rod acts somewhat like the stethoscope that a doctor uses to listen to a patient's heartbeat or breathing. When one end is placed at the ear and the other end at some particular part of the engine, noises from that part of the engine will be carried along the rod to the ear. A long screw driver or one of the engine stethoscopes now available can be used. When using the listening rod to locate the source of a noise, put the engine end at various places on the engine until the noise is the loudest. You can also use a piece of garden hose (about four feet long) to localize engine noises. Hold one end of the hose to your ear and move the other end of the hose around the engine until the noise is the loudest. By determining the approximate source of the noise, you can, for example, locate a broken and noisy ring in a particular cylinder or a main bearing knock.

Caution: Keep away from the moving fan belt and fan when using the listening rod.

1. Valve and tappet noise. This is a regular clicking noise that increases in intensity as engine speed increases. The cause is usually excessive valve clearance. A feeler gauge inserted between the valve stem and lifter or rocker arm will reduce clearance. If the noise also is reduced, then the cause is excessive clearance; clearance should be readjusted. If inserting the feeler gauge does not reduce noise, the noise is resulting from such conditions in the valve mechanism as weak springs, worn lifter faces, lifters loose in block, rough adjustment screw face, or rough cams, or else the noise is not from the valves at all. See other conditions listed below.

2. Spark knock. Spark knock, or rap, is a pinging or chattering sound most noticeable during acceleration or when the car is climbing a hill. Some spark knock is normal, but when it becomes excessive, it is due to any of several conditions such as use of fuel of excessive low-octane rating for the engine, carbon deposits in engine which increase compression ratio, advanced ignition timing, or conditions described in §193.
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3. Connecting-rod noises. Connecting-rod noises usually have a light knocking or pounding character. The sound is most noticeable when the engine is "floating" (not accelerating or decelerating). The sound becomes more noticeable as the accelerator is eased off with the car running at medium speed. To locate connecting-rod noise, short out spark plugs one at a time. The noise will be considerably reduced when the cylinder that is responsible is not delivering power. A worn bearing or crankpin, a misaligned connecting rod, inadequate oil, or excessive bearing clearances cause connecting-rod noise. Sections 240 and 241 describe the removal and servicing of the crankshaft. Section 224 discusses bearing service, while §§218 to 220 pertain to connecting-rod service.

Note: A method of checking for worn bearings by using a bearing oil-leak detector is described in §217.

4. Piston-pin noise. Piston-pin noise is somewhat similar to valve and tappet noise, but it has a metallic double-knock characteristic. In addition, it is usually most audible during idle with the spark advanced. However, on some engines, the noise becomes most audible at car speeds of around thirty miles per hour. A check can be made by running the engine at idle with the spark advanced and then shorting out spark plugs. Piston-pin noise will be reduced somewhat when a plug in a noisy cylinder is shorted out. Causes of this noise are a worn or loose piston pin, worn bushing, or lack of oil. Sections 221 and 227 describe how to test piston-pin fit as well as bushing replacement and reaming or honing of bushings.

5. Piston-ring noise. Piston-ring noise is also somewhat similar to valve and tappet noise since it is characterized by a clicking, snapping, or rattling noise. This noise, however, is most evident on acceleration. Low ring tension, broken rings, or worn rings or cylinder walls produce this noise. Since the noise can sometimes be confused with other engine noises, a test can be made as follows. Remove the spark plugs and add an ounce or two of heavy engine oil in each cylinder. Crank the engine for several revolutions to work the oil down past the rings. Then replace the plugs and start the engine. If the noise has been reduced, it is probable that the rings are at fault. Section 228 discusses installation of new rings.

6. Piston slap. Piston slap is characterized by a muffled, hollow, bell-like sound and is due to the rocking back and forth of the piston in the cylinder. If it occurs only with the engine cold, it should not be considered serious. When it occurs under all oper-
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ating conditions, further investigation is in order. It is caused by inadequate oil, worn cylinder walls or pistons, collapsed piston skirts, excessive piston clearances, or misaligned connecting rods. Fitting of pistons to cylinders is described in §226, while §§242 to 249 detail cylinder service.

7. Crankshaft knock. This noise is a heavy and dull metallic knock most noticeable when the engine is under a heavy load or accelerating, particularly when cold. When the noise is regular, it probably results from worn main bearings. When the noise is irregular and sharp, it is probably due to worn end-thrust bearings. This latter condition, when unusually bad, will cause the noise to be produced each time the clutch is released and engaged. Crankshaft and bearing service is discussed in §§232 to 241.

Note: A method of checking for worn bearings by using a bearing oil-leak detector is described in §217.

8. Miscellaneous noises. Other noises result from loosely mounted accessory parts, such as generator, cranking motor, horn, water pump, manifolds, flywheel, crankshaft pulley, oil pan, and so forth. In addition, other automotive components such as the clutch, transmission, and differential may develop various noises. These noises and their causes are discussed in other books in the McGraw-Hill Automotive Mechanics Series.

CHAPTER CHECKUP

The chapter you have just completed is probably one of the hardest in the book. At the same time, it is perhaps one of the most important. For, to be an engine expert, you need to know what troubles an engine might have, the causes of those troubles, and how to find the causes; that is, you need to be a good trouble-shooter. The fact that you have come this far in the book shows that you have made an earnest start toward becoming an engine expert. You have done well; by the time you have finished the remaining few chapters in the book you should have the background information you need about engines. The checkup below will help you determine how well the information you have been studying in this chapter has stuck with you. If any of the questions are hard to answer, reread the pages in the book that will give you the answer.

Correcting Troubles Lists

The purpose of this exercise is to help you spot related and unrelated troubles on a list. For example, in the list, Engine will not turn over; run-
down battery, worn rings, starting circuit open, engine jammed, cranking motor jammed, you can see that worn rings does not belong since it is the only condition that would not directly cause failure of the engine to turn over. Any of the other conditions in the list could prevent the engine from turning over.

In each of the lists, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. Engine turns over slowly but does not start; run-down battery, undersized battery cables, bad connections in starting circuit, defective cranking motor, cooling-system thermostat stuck.
2. Engine will not turn over; engine jammed, cranking motor or drive jammed, starting circuit open, battery run down, excessive carbon in engine.
3. Engine runs but one cylinder misses; defective spark plug, stuck valve, defective fuel pump, defective rings, defective distributor cap.
4. Engine turns over at normal speed but does not start; ignition system defective, engine defective, fan belt defective, fuel system defective.
5. Engine runs but different cylinders miss; clogged exhaust, defective rings, overheated engine, defective valve action, loss of compression, excessive vacuum in intake manifold, defective ignition.
6. Engine lacks power, acceleration, or high-speed performance when cold; stuck valves, manifold heat-control valve stuck, vapor lock, automatic choke stuck.
7. Engine lacks power, acceleration, or high-speed performance when hot or cold; defective valve action, ignition system defective, fuel system defective, loss of compression, excessive carbon in the engine, run-down battery.
8. Engine lacks power, acceleration, or high-speed performance when hot only; overheating of engine, defective choke, vapor lock, sticking manifold heat-control valve, incorrect idle adjustment.
9. Engine overheats; ignition timing late, loose fan belt, defective water pump, high altitude, clogged water jackets, defective radiator hose, defective fuel pump, defective thermostat, lack of water.
10. Engine stalls as it warms up; choke valve closed, manifold heat-control valve stuck, engine overheats, idling speed too low, defective head gasket.
11. Engine stalls after idling or slow-speed drive; defective fuel pump, overheating, high float level, overcharged battery.
12. Engine stalls after high-speed drive; carburetor antipercolator defective, vapor lock, run-down battery.
13. Engine backfires; spark plugs of wrong heat range, overheating of...
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engine, valves hot, carbon in engine, vapor lock, rich or lean mixture, ignition timing off.

14. Excessive oil consumption (blue exhaust smoke); burning oil in combustion chamber, clogged air cleaner, worn rings, worn valve guides, worn bearings.

15. Excessive fuel consumption (black exhaust smoke); clogged air cleaner, rich idle, worn carburetor jets, loss of engine compression, run-down battery, faulty ignition, defective valve action.

16. Light knock or pound with engine floating; worn connecting-rod bearing, spark knock, worn crankpin, misaligned rod, lack of oil.

17. Dull, heavy knock under load or acceleration; worn main bearings, loose piston pin, worn crankshaft end-thrust bearings.

18. Light double knock during idle; worn piston pin, lack of oil, broken rings, loose piston pin, worn piston-pin bushing.

19. Hollow, muffled, bell-like sound with engine cold; worn piston, collapsed piston skirt, worn cylinder walls, worn piston-pin bearings, lack of oil.

20. Chattering or rattling during acceleration; worn rings, worn cylinder walls, low ring tension, broken rings, misaligned rods.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. Engine will not turn over with
   a defective ignition coil
   a run-down battery
   a defective fuel pump
   valves that hang open

2. Engine will turn over slowly because of
   a defective water pump
   vapor lock
   undersized battery cables
   excessive fuel-pump pressure

3. Failure of an engine to start, even though it turns over at normal cranking speed, could be due to
   a run-down battery
   a defective cranking motor
   a sticking engine valve
   defective ignition

4. Missing in one cylinder is likely to result from
   a clogged exhaust
   an overheated engine
   vapor lock
   a defective spark plug

5. Irregular missing in different cylinders may result from
   a defective cranking motor
   a defective carburetor
   an open cranking circuit

6. Loss of engine power as engine warms up is most likely due to
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vapor lock excessive rolling resistance throttle valve not closing fully heavy oil

7. Engine will lose power (hot or cold) if it has incorrect idle adjustment automatic choke valve stuck open worn rings and cylinder walls.

8. An engine will overheat if the automatic choke sticks the fan belt breaks the fuel pump is defective the battery is run down.

9. An engine may stall as it warms up if ignition timing is off choke valve sticks closed battery is run down throttle valve does not open fully.

10. The most probable cause of an engine stalling after a period of idling or slow-speed driving is loss of compression a defective fuel pump sticking engine valves.

11. Stalling of an engine after a period of high-speed driving is apt to be due to vapor lock ignition timing worn carburetor jets.

12. Engine backfiring may result from spark plugs of wrong heat range vapor lock run-down battery worn piston rings.

13. A smoky blue exhaust is due to an excessive rich mixture burning of oil in combustion chamber a stuck choke valve incorrect valve adjustment.

14. A smoky black exhaust may be due to worn piston rings worn carburetor jets spark plugs of wrong heat range.

15. A light knock or pound with engine floating can result from worn main bearings worn connecting rod bearing worn rings.

16. A light double knock during idle can result from piston slap spark knock incorrect ignition timing loose or worn piston pin.

17. A rattling or chattering sound during acceleration may be due to worn main bearings loose valve and tappet adjustment worn or broken rings.

18. A hollow, muffled, and bell-like sound, with the engine cold, is apt to be due to worn or collapsed pistons worn main bearings loose oil pan sticking engine valves.

19. A dull, heavy knock under load or acceleration is likely due to worn rings worn main bearings worn piston pins worn pistons.

20. Loss of engine compression can result from worn rings or cylinder walls loose valve and tappet adjustment defective fan belt.

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Trouble-shoot Engine Complaints

The following questions are stumpers that you might actually encounter in the engine shop. As an engine expert you will come up against complaints of loss of power, high fuel consumption, knocking and so on, and you must know what to do to get at the cause of trouble. In the following questions, you are asked to write down the procedures you would follow if various troubles were reported to you. If you are not quite sure of a procedure, turn back to the pages in the chapter that will give you the information. Then write it down in your notebook. Do not copy, but write it in your own words. This will help you remember the procedures.

1. You are called out to check a car in which the engine will not turn over when the cranking motor switch is closed. You turn on the headlights and try to start. What are the five things that might happen to the lights? List the probable troubles under each.

2. What are the possible causes of trouble if the engine turns over slowly but does not start, and how would you locate the actual cause?

3. A car that will not start is pulled into your shop and you find, on testing it, that the engine turns over at normal speed but will not start. What are the ignition and fuel-system checks to be made?

4. An engine misses. What check can you make with a screwdriver to try to locate the missing cylinder?

5. You find that one particular cylinder is missing. What further checks do you make on this cylinder and what are the possible causes of trouble?

6. What are the possible causes of trouble if the engine miss is irregular and cannot be traced down to any one cylinder?

7. List the possible causes of trouble and how to locate them if an engine loses power as it warms up.

8. If an engine lacks power hot and cold, what are the possible causes of the trouble, and how would you diagnose the trouble?

9. If an engine lacks power only when cold but seems to run normally when hot, what could the trouble be and what would you do to make sure?

10. What would you look for if a car owner reported to you that his car overheated?

11. What are three basic conditions under which an engine will stall and what are the causes under each condition? How could you tell which is the trouble?

12. List possible causes of engine backfire and how to locate the actual cause.
13. In what three ways is engine oil lost?
14. List the causes of excessive oil consumption due to burning of oil in the combustion chamber.
15. What are some causes of excessive fuel consumption resulting from troubles in the fuel system?
16. Describe various types of car operation that will increase fuel consumption.
17. What are causes of excessive fuel consumption due to high rolling resistance?
18. List various engine noises and explain their causes.
19. List various causes of loss of compression.
20. Explain how to use the engine vacuum gauge and make a list of the various vacuum-gage readings along with their causes.

**Suggestions for Further Study**

Careful observation of checking or trouble-shooting procedures in the engine shop and examination of engine components after engine teardown will be of great value to you in linking cause and effect more closely. For instance, if you can examine the pistons, rings, and cylinder walls of an engine which has lost compression and is using too much oil, you will see why the engine has lost compression and why it has begun to use too much oil.

It will be a great asset to you in the engine shop to know the trouble-shooting procedures outlined in the chapter you have just completed. Thus you will want to study those procedures carefully and refer to the trouble-shooting chart over and over again. We previously suggested, at the beginning of the chapter, one way of helping yourself remember the procedures. This is to write them down on 3- by 5-inch cards, and carry these cards around with you. Then whenever you get a chance, as for instance when you are listening to music on the radio, eating your lunch, or getting ready for bed, you can take out one of these cards and read it over. Soon you will know the procedures thoroughly.

Be sure to discuss with expert automotive mechanics and your teacher the various methods of locating troubles in engines. Ask them about their experiences in locating troubles, how often they find that loss of compression is due to worn rings, whether they find much valve-guide wear, and so on.
13: Valve and valve-mechanism service

THIS CHAPTER is the first of three that discuss engine-servicing jobs; it covers valves, valve seats, valve guides, valve lifters, cylinder heads and camshafts. Note that §§197 and 198 on tools and cleanliness apply to all servicing jobs and not merely to the valve and valve-mechanism servicing jobs covered in this chapter. Before you start on this chapter, you may wish to review §§121 to 133, which discuss various aspects of valve construction and operation.

§197. Engine service Usually the correction to be made for any engine trouble is obvious once the cause of trouble has been determined. The previous two chapters, Chap. 11, "Engine-testing procedures and Tools," and Chap. 12, "Diagnosing Engine Troubles," explain how to test and trouble-shoot an engine to find causes of various engine troubles. This and following chapters describe in detail how to service valves, camshafts, crankshafts, pistons, bearings, cylinder walls, cylinder heads, and other engine components.

Special tools are required to perform many of the engine service jobs. Such special tools are described on the following pages where the service jobs are covered. In addition, numerous common hand tools are needed for engine service work. These common hand tools and how to use and take care of them are described in Chap. 16, "Shop Practice." It is suggested that you refer to that chapter in order to familiarize yourself with the different hand tools.

You will notice, in the discussions of the various engine-service jobs, that the time required to do each job is usually given. These figures have been taken from the manufacturer's flat-rate shop manuals and are included to give you some idea of the size of the job.

Note: Servicing of water pumps, oil pumps, and ignition distributors is covered in other books in the McGraw-Hill Automotive Mechanics Series. Water-pump and oil-pump service is described in
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Automotive Fuel, Lubricating, and Cooling Systems while ignition-distributor service is discussed in Automotive Electrical Equipment.

§198. Cleanliness

The major enemy of good service work is dirt. A trace of dirt or abrasive in a bearing, on cylinder walls, or in other working parts in the engine can ruin an otherwise good service job. Such dirt or abrasive can cause rapid wear and quick failure of engine parts. For instance, if a precision-insert main bearing is installed with dirt under it, the bearing shell will not fit snugly into the cylinder block or cap counterbore. The bearing will distort and high spots may develop. This condition would probably cause quick bearing failure, possibly in less than a thousand miles. Similarly if abrasive is left on cylinder walls after a honing job, pistons, rings, and other engine parts may wear rapidly and fail in a few thousand miles.

When you consider that engine parts are precision-machined to tolerances of less than one-thousandth of an inch, you can understand that pieces of grit or abrasive only a thousandth of an inch in diameter can cause real damage. Such fine pieces of abrasive are so small that you cannot normally see or feel them. You must, therefore, be very careful in engine work to remove all dirt and abrasive produced by any service job. You must keep all engine parts clean and must be doubly sure that they are clean as they go back into the engine.

Before a major engine-service job is performed, the block should be cleaned to remove dirt and grease so that they will not get into the engine when it is opened. If a steam-cleaning or similar process is used, electrical parts should be covered or removed so that moisture or cleaner will not get into them.

When reassembling an engine or installing engine parts, remember that dirty parts are almost sure to cause trouble in the engine. Parts should be cleaned as explained in the following sections dealing with the different engine components. Several cleaning methods and materials are in use. Some methods make use of hot water mixed with solvent in which the parts are soaked. Other methods include steam jets and vapor de-greasers.

Caution: As soon as a part is cleaned and dried, a light coating of oil should be applied to bright finished surfaces so that rust will not form. Be sure that parts are thoroughly clean and thoroughly

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dry. If you use an air hose to dry parts, you had better wear goggles. Remember that the air stream drives dirt particles at high velocity and that these particles could do serious damage to your eyes. Be careful where you point the hose. Don't point it at your fellow workers. Remember that they have eyes, too!

§199. Valve troubles The engine valves must open and close with definite timing in relation to the piston positions (§132). They must seat tightly against the valve seats and must open and close promptly without lagging. The clearance between the valve stems and valve guides must be correct. Failure of the valves to meet any of these requirements means valve and engine trouble.

For example, let us see what excessive clearance between the valve stem and valve guide might lead to. On every intake stroke, this excessive clearance will permit oil to be pulled past the intake-valve stem and opened valve into the combustion chamber where it will burn (Fig. 13-1). The carbon from the burning oil builds up in the combustion chamber where it can cause excessive compres-
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ion, preignition, clogged piston rings, and fouled spark plugs. The oil will tend to deposit on the valve and carbonize, thereby restricting valve action. Further, the excessive clearance may allow the valve to cock and not seat properly, and it will also probably reduce valve-stem cooling. Either of these will cause the valve to overheat and burn (this applies particularly to the exhaust valve). Naturally, burned valves will leak (from poor seating) and cause major engine power losses. And once a valve starts to burn, it burns away rapidly so that complete valve and engine failure soon follow. As you can see, with faulty valve conditions one thing can lead to another; wear of an apparently minor item like the valve guide can lead to many engine troubles.

We could trace the results of other faulty valve conditions in a like manner. What we want to emphasize is that valves must work properly and must be serviced properly if engine troubles are to be avoided. On the following pages we list and describe various valve troubles, their causes, and corrections.

§200 The valve-trouble chart The chart below lists various valve troubles, their possible causes, and corrections. Following articles supply fuller explanations of these troubles. The latter part of the chapter discusses valve service. When a Possible Cause and Correction in the chart below involves the fuel, cooling, or lubricating system, refer to Automotive Fuel, Lubricating, and Cooling Systems (another book in the McGraw-Hill Automotive Mechanics Series).

NOTE: The complaints and possible causes are not listed in the chart in the order of frequency of occurrence. That is, item 1 (or item a under Possible Cause) does not necessarily occur more frequently than item 2 (or item b).

VALVE-TROUBLE CHART

(See §§201 to 205 for detailed explanations of trouble causes and corrections listed below.)

<table>
<thead>
<tr>
<th>Complaint</th>
<th>Possible Cause</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Valve sticking (§201)</td>
<td>a. Deposits on valve stem</td>
<td>See item 5. Valve deposits, below</td>
</tr>
<tr>
<td></td>
<td>b. Worn valve guide</td>
<td>Replace</td>
</tr>
<tr>
<td></td>
<td>c. Warped valve stem</td>
<td>Service lubricating system; add oil</td>
</tr>
<tr>
<td></td>
<td>d. Insufficient oil</td>
<td></td>
</tr>
<tr>
<td>Complaint</td>
<td>Possible Cause</td>
<td>Check or Correction</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Valve burning</td>
<td>Cold-engine operation</td>
<td>Valves free up as engine warms up</td>
</tr>
<tr>
<td></td>
<td>Overheating valves</td>
<td>See item 2. Valve burning, below</td>
</tr>
<tr>
<td>2.</td>
<td>Valve sticking</td>
<td>See item 1. Valve sticking, above</td>
</tr>
<tr>
<td></td>
<td>Valve-tappet clearance too small</td>
<td>Readjust</td>
</tr>
<tr>
<td></td>
<td>Spring cocked or weak</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distorted seat</td>
<td>Check cooling system, head-bolt tightening</td>
</tr>
<tr>
<td></td>
<td>Overheated engine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lean air-fuel mixture</td>
<td>Service fuel system</td>
</tr>
<tr>
<td></td>
<td>Preignition</td>
<td>Clean carbon from engine; use cooler plugs</td>
</tr>
<tr>
<td></td>
<td>Detonation</td>
<td>Adjust ignition timing (§177); use higher-octane fuel</td>
</tr>
<tr>
<td></td>
<td>Seat leakage</td>
<td>Try interference angle</td>
</tr>
<tr>
<td></td>
<td>Overloaded engine</td>
<td>Reduce load or try heavy-duty valves</td>
</tr>
<tr>
<td></td>
<td>Valve-stem stretching from strong</td>
<td>Use weaker spring; see §190 for overheating causes</td>
</tr>
<tr>
<td></td>
<td>spring or overheating engine</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Valve overheating</td>
<td>See item 2. Valve burning, above</td>
</tr>
<tr>
<td></td>
<td>Detonation</td>
<td>Adjust ignition timing (§177); use higher-octane fuel; clean carbon from engine</td>
</tr>
<tr>
<td></td>
<td>Excessive tappet clearance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seat eccentric to stem</td>
<td>Service</td>
</tr>
<tr>
<td></td>
<td>Cocked spring or retainer</td>
<td>Service</td>
</tr>
</tbody>
</table>
§201

Complaint

Possible Cause

Check or Correction

f. Scratches on stem from improper cleaning

Avoid scratching stem when cleaning valves

4. Valve-face wear (§204)

a. Excessive tappet clearance

b. Dirt on face

c. Also consider causes listed above under 2. Voltage burning

5. Valve deposits (§205)

a. Gum in fuel (intake)

b. Rich mixture (intake)

c. Poor combustion (exhaust)

d. Worn valve guides

e. Dirty or wrong oil

Use proper fuel

Service fuel system

Service fuel, ignition system, or engine as necessary

Replace

Service lubricating system; replace oil

§201. Valve sticking

Valves will stick from gummy or carbon deposits on the valve stem (see §205). Worn valve guides, which pass excessive amounts of oil, speed up the formation of deposits since the oil carbonizes on the hot valve stem. If the valve stem warps it will stick in the valve guide. Warpage could result from overheating (§202), an eccentric seat (which throws pressure on one side of valve face), or from a cocked spring or retainer (which puts bending pressure on stem). Of course, insufficient oil would also cause valve sticking. Sometimes valves will stick when cold but work themselves free and function normally as the engine warms up.

NOTE: When valves and piston rings have become so clogged with deposits that they no longer operate properly, it is usually necessary to overhaul the engine. However, some authorities suggest the use of special compounds in the oil and fuel which help in freeing valves and rings. When parts are not too badly worn, and the major trouble seems to be from deposits, use of these compounds often postpones engine overhaul, at least for a while.

§202. Valve burning

Valve burning is usually an exhaust-valve problem. Any condition that causes the valve to stick so that it does not close tightly will cause valve burning. Not only does the poor seat prevent normal valve cooling through the valve seat, but it also
allows hot gases to blow by, further heating the valve. The valve is cooled through both the valve seat and the valve guide (§123), so poor seating or a worn guide can cause overheating. Also, if the water jackets or distributing tubes in the cooling system are clogged, local hot spots may develop around valve seats, producing valve overheating. These hot spots may cause seat distortion which then prevents normal seating and thus permit blow-by and valve burning. Seat distortion can also result from improper cylinder-head-bolt tightening. Other conditions that prevent normal seating include a weak or cocked valve spring and insufficient valve-tappet clearance. If the tappet clearance is too closely adjusted, the valve may be held open.

Any condition that causes the engine to labor hard or overheat will also overheat the valves. Section 190 discusses causes of engine overheating. If the engine must be operated under heavy load and this causes valve trouble, heavy-duty valves should be installed in the engine.

A lean air-fuel mixture may cause exhaust-valve burning since some combustion may still be going on (the lean mixture burns slowly) when the valve opens. If this is the cause, the fuel system should be serviced.

Preignition or detonation, both of which produce excessively high combustion pressures and temperatures, will have an adverse effect on valves as well as on other engine parts. They can be eliminated by cleaning out carbon, retiming the ignition (§177), or using higher-octane fuel.

In some persistent cases of seat leakage (especially where deposits on the valve seat and face prevent adequate sealing), the use of a so-called “interference angle” has proved helpful. The valve is

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Fig. 13-2. Interference angle between valve face and seat. The seat and interference angles have been exaggerated to show how sealing pressure is applied mostly at upper edge of seat.
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faced at an angle \( \frac{1}{4} \) to 1 degree flatter than the seat angle (Fig. 13-2). This gives greater pressure at the upper edge of the valve seat, which tends to cut through any deposits that have formed and thereby establish a good seal.

In some cases valve stems have been found to stretch due to a combination of heavy springs and overheating. Lighter springs should be used and the causes of overheating eliminated (§190).

§203. Valve breakage Any condition that causes the valve to overheat (§202) or to be subjected to heavy pounding (as from excessive tappet clearance or from detonation) may cause valves to break. Excessive tappet clearance permits heavy impact seating. If the seat is eccentric to the stem or if the valve spring or retainer is cocked, then the valve will be subjected to side movement or pressure every time it seats. Ultimately, this may cause it to fatigue and break. If the stem has been scratched during cleaning, the scratch may serve as a starting point for a crack and a break in the stem.

§204. Valve-face wear In addition to the conditions discussed in §202 (Valve burning), excessive tappet clearance or dirt on the valve face or seat could cause valve-face wear. Excessive tappet clearance causes heavy impact seating that is wearing on the valve and may cause valve breakage (§203). Dirt may cause valve-face wear if the engine operates in dusty conditions or if the carburetor air cleaner is not functioning properly. The dust enters the engine with the air-fuel mixture and some of it deposits on the valve seat. The dust will also cause bearing, cylinder wall, and piston and ring wear.

§205. Valve deposits If the fuel has excessive amounts of gum in it, some of this gum may deposit on the intake valve as the air-fuel mixture passes the valve on the way to the engine cylinder. Carbon deposits may form from an excessively rich mixture or from oil passing a worn valve guide (intake valve). Improper combustion, due to a rich mixture, defective ignition system, loss of compression in the engine, a cold engine, and so forth, will result in carbon deposits on the exhaust valves. Dirty or improper oil will cause deposits to form on the valves.

§206. Valve service We have already described methods of checking engine and valve actions with a compression tester (§174) and [350]
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a vacuum gauge (§175), and have listed and discussed various valve troubles and their corrections. The remainder of this chapter describes the valve-servicing procedures in detail.

In servicing valves, a number of components must be considered. These include the valves, valve seats and guides, valve springs and retainers, rocker-arm mechanisms (in overhead-valve engines), valve tappets, camshaft, camshaft drive, and bearings.

The service jobs on valves include adjusting valve-tappet clearances (also called adjusting valve lash), grinding valves and valve seats, installing new seat inserts on engines so equipped, cleaning or replacing valve guides, removing and checking the camshaft, servicing camshaft bearings, and timing the valves. A complete valve-service job, including grinding valves and seats, checking springs, cleaning guides, and tuning the engine, requires from about 5 hours for a six-cylinder overhead-valve engine to about 8 hours for an eight-cylinder L-head engine. Replacing seat inserts requires an additional 1/2 hour each. Replacing the camshaft requires about 8 hours; approximately 4 more hours are required to replace camshaft bearings. These operations will now be considered.

§207. Valve-tappet clearance

The procedure of checking and adjusting the clearance between the valve stem and the rocker arm (L head) or valve lifter (L head) varies with different engines. Following are typical procedures on different types and models of engine.

Note: Where a pressure-type radiator cap is used (§158), it should be removed during the valve-adjusting process, to prevent excessive engine temperatures.

1. L-head engine. To measure valve-tappet clearances on L-head engines, remove the valve-cover plates on the side of the engine block to expose the valve-tappet mechanisms. The clearance between the valve stem and the adjusting screw in the valve lifter is measured with a feeler gauge of the correct thickness. Two methods are used. One is to take the measurement with the engine warmed up and idling. The second method is to measure the clearance when the engine is warm and not running; the crankshaft is turned over until the valve lifter is on the low point of the cam, and the clearance is then checked. The first method is usually recommended. If the clearance is not in accordance with the specifications [351]
for the engine, adjustment must be made. Some tappet-adjusting screws are self-locking, while others have a locking nut that locks the screw in the valve lifter after the adjustment is completed. On the second type, two wrenches must be used to loosen the locking nut. Then, on both types, one wrench is placed on the flat section of the valve lifter to prevent it from turning while a second wrench is used to turn the adjusting screw (Fig. 13-3). The adjusting screw should be turned in or out as necessary so that the feeler gauge can be moved between the screw and the valve stem with some drag when the valve is closed. When a locking nut is used, it should be tightened after the adjustment is made and the clearance again checked. One manufacturer of an engine using self-locking adjusting screws recommends that the force required to turn the screw be measured by hooking a spring gauge to the outer-end of the adjusting-screw wrench. This determines whether the self-locking feature of the adjusting screw is in sufficiently good condition to hold the screw in position. On this design any defect requires replacement of the valve lifter and screw as an assembly. When the valve-cover plates are reinstalled, new gaskets should be used.

2. I-head engine. On the overhead-valve engine the valve cover must be removed and the clearance between the valve stem and the rocker arm measured with the engine warmed up and running at fast idle. Clearance is measured with a feeler gauge as already described. Adjustment is made by loosening the locking nut and turning the adjusting screw in the rocker arm (Fig. 13-4), or on the stud-supported rocker arms, by turning the stud nut (Fig. 13-5).

3. F-head engine. On the F-head engine (Fig. 7-48) a combined L-head and I-head adjusting procedure is called for. The in-block
Fig. 13-4. Adjustment of valve-tappet clearance (or valve lash) on overhead-valve engine.

Fig. 13-5. Adjusting valve-tappet clearance on engine with rocker arms independently mounted on ball studs. Backing stud nut out increases clearance. (Chevrolet Motor Division of General Motors Corporation)
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valves are checked and adjusted as in an L-head engine. The in­
head valves are checked and adjusted as in an I-head engine. Valves
of the free type (Fig. 7-44) have the clearance check made be­
tween the tip cup on the valve stem and the adjusting screw in the
valve lifter (and not between the valve stem and screw).

4. Ford engines. Some Ford engines are what might be termed
standard L head, others are I head; adjustment on these is basically
the same as already described in previous paragraphs. On the type
of Ford engine using a valve design such as shown in Fig. 13-10 or
13-11 the only provision for adjustment is to grind off the valve stem
to increase clearance or to grind the valve to reduce clearance.
Clearance is checked between the lifter and valve stem with a “go,
no-go,” or “stepped,” feeler gauge (Fig. 16-38). The gauge should
be inserted between the lifter and the stem with the engine stopped
at closed-valve position and with the valve lifter on the low part of
the cam. If the “go” part of the gauge will not enter, the clearance
is too low and the end of the valve stem must be ground off. If the
“no-go” part of the gauge enters between the lifter and the valve
stem, the clearance is excessive and refacing of the valve or the
valve seat is required. Clearances must then be rechecked and the
valve stem ground if necessary.

5. Hydraulic valve lifters. Engines equipped with hydraulic valve
lifters normally require no valve-tappet-clearance adjustment. How­
ever, on some engine models there is provision for initial adjust­
ment when valve work has been done. In such case, the adjustment
is made with the lifter on the low part of the cam. The adjusting
stud in the rocker arm should then be turned until all play of the
push rod between the lifter and the ball on the stud is just removed.
Finally, the stud should be turned down exactly two turns and
locked in position with the lock nut.

§208. Valve removal For such services as valve or valve-seat grind­
ing, valve-seat insert replacement, valve-guide cleaning or replace­
ment, and so forth, the cylinder head and the valves must be
removed from the engine. Section 210 covers removal and replace­
ment of cylinder heads, while §211 covers cleaning of carbon from
the head or the block after the head is removed. Extreme care must
be used to avoid interchanging the valves; each valve must be re­
placed in the cylinder-valve port from which it was removed. A
valve rack in which valves (with their valve springs, retainers, and locks) can be placed in proper order is recommended (Fig. 13-14). In addition, free-type valves (Fig. 7-44), which have a tip cup on the end of the stem, have very close fits between the valve parts; this makes it necessary to keep the valve parts (valve, spring, tip cup, retainer, lock) together as sets. The tip cup or lock from one valve, for example, must not be installed on another valve. Different tools and removal procedures must be used for different engines.

1. L-head engines. Because of the interference of the manifolds, it is common practice to remove the manifolds from the cylinder block before attempting to remove valves in many late L-head engines. A valve-spring compressor or lifter (Figs. 13-6 and 13-7) can then be used to compress the valve spring so that the valve-retainer lock or keeper can be removed from the valve stem. Various
types of retainer locks are shown in Fig. 7-37. Extreme care must be exercised to prevent the lock from falling down into the crankcase, where it might become jammed into moving parts and cause serious damage. Any openings through which the locks could fall into the crankcase should be temporarily closed with clean cloths. Valve-spring-retainer lock receivers that will receive the lock when it is released are available. Some manufacturers recommend the use of a special magnet (Fig. 13-8) to hold the lock when it is released so
that it will not fall into the crankcase. Several types of valve-spring lifters (Fig. 13-7) that can be used on many cars without removal of manifolds are available.

After the valve-spring retainer is removed, the valve may be lifted out and the spring assembly taken from the valve-spring compartment.

2. Ford engines. On many Ford engines a somewhat different valve, valve guide, and retainer arrangement is used (Figs. 13-9 to 13-11). On the earlier types the valve guide is split and the lower end of the valve stem is enlarged so as to hold the spring retainer and lock in place. No separate lock or keeper is used on this design. On later types the valve guide is one piece and the valve has a straight stem with an undercut section for holding the valve-spring retainer locks in position. In either case, the valve guide, spring, valve, and spring retainer are removed as a unit from the engine and separated after they are out.

Before the valve guide can be removed, the valve-guide retainer must be removed by either of two methods. In one method, a bar-type lifter is inserted through the valve springs and behind the flange at the lower end of the valve guide (Fig. 13-9). By prying against the flange, the guide is pulled down sufficiently to permit removal of the valve-guide retainer. In the second method, a valve-guide-retainer driver is hooked into the valve-guide retainer (Fig. 13-10).
13-12). By driving against the driver as shown, the retainer can be withdrawn. Light hammer blows must be used to avoid tearing the lip off the retainer. New retainers will be required when this latter method is used. The guide and valve assembly can be pulled out through the valve port after the retainer is removed. A special puller (Fig. 13-13) may be required if the valve guide is stuck in place, or "frozen." When the screw handle is turned, the guide-puller jaw presses against the lower end of the guide, forcing it up to the position indicated by the dotted line. A quantity of penetrating oil placed around the guide may aid in loosening it. If the guide is badly stuck, give the oil some time to work before using the tool [358]

Fig. 13-11. (a) Sectional and (b) disassembled views of valve mechanism using one-piece valve guide. The disassembled view shows a seal not shown in the sectional view. (Ford Motor Company)
to loosen the guide. The valve and guide assembly is disassembled by compressing the spring in a special fixture so that the spring retainer and the split guide may be removed from the valve stem.

3. Overhead-valve engine. On the overhead-valve engine the cylinder-head assembly, with valves, and the rocker-arm assembly must be removed from the engine before the valves can be removed from the head (§210). A special cylinder-head holding fixture, such as that shown in Fig. 13-14, is desirable. This fixture not only provides places for all valves, keys, springs, and spring cap so that they can be kept in order, but also has a valve-spring compressor to compress the springs, thus facilitating removal of the valves (Fig. 13-15).

4. Testing valve springs. The valve springs, after removal, should be tested on a valve-spring-tension tester to make sure that their tension is within the proper limits (Fig. 13-16). In addition, they

Fig. 13-12. Using a valve-guide-retainer driver to remove valve-guide retainer in Ford engine. (K-D Manufacturing Company)

Fig. 13-13. Using guide puller to remove valve and guide assembly from Ford engine. (K-D Manufacturing Company)
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FIG. 13-14. Fixture for holding cylinder head of overhead-valve engine while valve work is being done. Note that the fixture also has a rack to hold the valves and valve springs so that they will not become mixed. (Kent-Moore Organization, Inc.)

FIG. 13-15. Using the fixture shown in Fig. 13-14 to compress a valve spring and remove a valve-spring retainer and lock. (Chevrolet Motor Division of General Motors Corporation)
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should be lined up on a flat surface, side by side, so that warped, cocked, short, or crooked springs can be detected. Weak or otherwise defective springs should be replaced, since they are apt to cause poor valve action and poor engine performance.

Fig. 13-16. Using a valve-spring-tension tester to measure valve-spring tension. (Chevrolet Motor Division of General Motors Corporation)

§ 209. Valve reassembly

In general, valve reassembly is the reverse of disassembly. Procedures of checking and servicing valves, valve seats, and valve guides are covered in following articles. Note that many valves use stem oil seals (as for instance in Fig. 13-17 which shows the valve-assembly sequence for an overhead-valve V-8 engine). On engines equipped with free valves (Fig. 7-44) make sure that the tip cups and retainer locks are thoroughly clean and reinstalled on the same valve stems from which they were removed. Worn sides of the locks should contact the tip cups. If the contact faces of the locks are badly worn, new locks and tip cups should be installed.

After installation of free valves, their freeness can be checked by trying to rotate them when they are in the wide-open position. To do this, turn engine until valve is wide open, and then note whether the valve can be rotated with little effort. If the valve cannot be
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turned easily, it will be necessary to grind a few thousandths of an inch from the bottom of the valve stem. There should be a clearance of less than 0.004 inch between the bottom of the valve stem and the tip cup (see Fig. 7-44) with the valve open. Clearance may be checked by mounting a dial indicator on the block so that the up-and-down movement of the valve can be measured as it is moved by hand. If the clearance is too great, it may be reduced by grinding a few thousandths off the upper edge of the tip cup. This should be done by laying a piece of fine emery cloth on a flat surface, and then moving the tip cup back and forth in a figure 8 pattern. Be careful not to grind off too much.

§210. Removing and replacing cylinder heads and manifolds

The procedures of removing and replacing cylinder heads and manifolds vary with different engines. On some cars the manifolds must be removed before the head can be taken off. On other cars the manifolds do not require removal when the head is taken off. Removal and replacement procedures follow.

1. Removing cylinder heads. Before the cylinder head can be removed, the radiator and the block must be drained, and the thermostat housing and the thermostat must be taken off the head. In addition, spark-plug wires, spark plugs, ignition coil, oil filter, and...
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tributor, temperature gauge, and other parts attached to the head must be removed. On I-head engines the push-rod cover, valve rocker-arm cover, valve rocker-arm assembly, and the push rods must also be removed. Rocker-arm assembly is removed from the head by taking off bolts or nuts holding it in place. On many I-head engines the manifolds must be taken off before the cylinder head will come off. On other I-head engines sufficient room can be obtained simply by detaching the manifolds and pushing them to one side. On L-head engines manifolds do not need to be removed for cylinder head removal.

Caution: If the carburetor is not removed, it should be covered with cloths for protection against dirt and dust.

After the above preliminary work, the cylinder head may be removed by taking off the head bolts or nuts. If the head sticks, pry bars can be used to loosen it. (Use care to avoid damaging head or block with pry bar.) After the cylinder head is off it should be cleaned of carbon and gasket particles (§211) and then inspected as explained below.

2. Disassembly of rocker-arm assembly. The rocker-arm assembly can be disassembled by loosening the pilot screw in the bracket that locks the shaft, removing the cotter pin and sliding brackets, rocker arms and springs from the shaft. On some engines the shaft is doweled to the bracket instead of being locked with a screw; on these handle the bracket and shaft as a unit. Rocker arms with worn bushings can be rebushed. Rocker-arm valve ends that are pitted or worn can be refaced on the valve-refacing machine by use of a special attachment. On reassembly of the rocker-arm assembly be sure that all springs and arms are restored to the shaft in their original positions. Also make sure that the oil holes in the shaft are on the underside so that they will feed oil to the rocker-arm bushings.

3. Inspecting cylinder heads. Cylinder heads should be inspected for cracks, warpage, or rough gasket surfaces. One method of checking for cracks is to moisten the combustion-chamber surface with water, tap the cylinder head with a hammer, wipe the surface, and then tap the cylinder head again. Cracks would be indicated by a line of water reappearing along the crack. Some mechanics prefer to use kerosene instead of water because it has a greater ability to...
penetrate and show up cracks. Warpage is detectable with a long straightedge held against the sealing surface of the head.

4. Replacing cylinder heads. Before a cylinder head is replaced, the gasket surfaces on both the head and the block should be carefully cleaned, and any roughness removed with a fine-cut mill file. A new gasket should be used when the head is replaced, since the old one may be damaged or flattened. Lacquered-type gaskets should be handled carefully, so that the lacquer will not be scratched or chipped. When the block has stud bolts, the gasket should be put into position on the block right side up. Gasket sealer should be used if specified by the manufacturer. If block does not have bolts, two pilot pins should be screwed into two bolt holes to assure alignment of the gasket and the head. The cylinder head may then be put into position, lowered on the gasket, and bolts or nuts run on, finger-tight. Bolts can then be substituted for the pilot pins.

**Caution:** All bolt holes in the block should be cleaned out. If they are not, the bolts may bottom against the foreign materials so that the head is not tight on the block.

![Fig. 13-18. Sequence chart for tightening intake-manifold attaching bolts on a V-8 engine. (Chevrolet Motor Division of General Motors Corporation)](image)

Use a torque wrench to tighten the bolts or nuts the proper amount and in the proper sequence, to avoid head and block distortion and possible breaking of bolts. The sequence chart for the engine being serviced should be studied before any attempt is made to tighten the bolts or nuts. Usually the center bolts are tightened first and then the bolts on either side. The adjacent bolts are next tightened alternately on one side and then the other. A sequence chart for one engine is shown in Fig. 13-18 while Fig. 13-19 illus-
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trates one type of torque wrench in use. Figure 16-15 shows other types. Each nut or bolt should be tightened in several steps; that is, the complete circuit of all bolts should be made several times, with the bolts being drawn up little by little until finally, on the last circuit, they are tightened to the correct tension. Then the engine should be operated until it warms up and the bolts be given a final tightening. On aluminum heads they should also be rechecked after the engine has been turned off and has cooled.

![A torque wrench being used to tighten cylinder-head bolts. The amount of torque being imposed on the bolt registers on the dial. This assures the application of the proper torque so that the bolt is correctly tightened. (Oldsmobile Division of General Motors Corporation)](image)

**NOTE:** Removal of broken cylinder-block bolts or studs is covered in §268.

5. **Removing and replacing manifolds.** When manifolds are removed, the carburetor must be taken off and the vacuum line and exhaust pipe disconnected. Bolts or stud nuts holding the manifold to the block or the head can then be removed so that the manifolds will come off.

**Caution:** The carburetor must be handled with care to avoid damaging it or spilling any gasoline that might remain in the float bowl.

New gaskets should be used when the manifolds are replaced. All traces of the old gasket material should be removed from the block.
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or the head and manifolds. When bolts or nuts are tightened, a torque wrench should be used so that they will be drawn up to the correct tension.

CHECK YOUR PROGRESS

Progress Quiz 17

Here is your chance to check up on the progress you have made since starting Chap. 13. The questions below will help you review the material you have just covered, and at the same time will help you fix the more essential points firmly in your mind. If any of the questions stump you, reread the pages in the book that will give you the answer.

Correcting Trouble Lists

The purpose of this exercise is to help you spot related and unrelated troubles on a list. For example, in the list Excessive oil consumption; worn valve guides, worn piston rings, worn bearings, worn fuel pump, you can see that worn fuel pump does not belong since it is the only condition listed that would not be directly related to excessive oil consumption. Any of the other conditions could cause excessive oil consumption.

In each of the lists below, you will find one item that does not belong. Write down each list in your notebook, but do not write down the item that does not belong.

1. Valve sticking; deposits on valve stem, worn valve guide, warped valve stem, insufficient oil, excessive tappet clearance, overheating valves.
2. Valve burning; insufficient tappet clearance, spring cocked, distorted seat, lean mixture, preignition, detonation, seat leakage, excessive tappet clearance, valve-stem stretched, overloaded engine.
3. Valve breakage; overheating valve, detonation, excessive tappet clearance, idle too high, seat eccentric to stem, cocked spring, scratches on stem.
4. Valve-face wear; excessive tappet clearance, dirt on face, interference angle, conditions causing valve burning.
5. Valve deposits; gum in fuel, rich mixture, poor combustion, heavy valve spring, worn valve guides, dirty oil.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

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1. When the valve is faced at an angle flatter than the seat angle, the difference is called the interference angle seat angle flat angle face angle

2. On L-head engines valve-tappet clearance is measured between the adjusting screw in the valve lifter and the rocker arm valve stem valve retainer

3. On overhead-valve engines clearance is measured between the valve stem and rocker arm valve retainer adjusting screw in lifter adjusting screw

4. To adjust clearance in the L-head engine, an adjusting screw is turned in the rocker arm push rod valve lifter valve stem

5. To adjust clearance in the overhead-valve engine, an adjusting screw is turned in the rocker arm push rod valve lifter valve stem

6. On Ford engines that do not have an adjusting screw in the valve train, clearance is increased by grinding the valve face valve lifter valve stem valve retainer

7. On Ford engines that do not have an adjusting screw in the valve train, clearance is reduced by grinding the valve valve lifter valve stem

8. On the Ford engine, to remove the valve-guide and valve assembly, you must first remove the valve retainer guide retainer spring lock

9. The type of engine that requires no valve-tappet-clearance adjustment uses free valves hydraulic valve lifters F-head valves I-head valves

10. If the clearance between the tip cup and the valve stem on the free valve is insufficient, correction can be made by grinding the tip cup valve stem valve retainer valve lock

§211. Cleaning carbon from head and block

Accumulations of carbon should be scraped from the combustion-chamber surfaces of both the head and the block. To remove carbon from the cylinder head, place it upside down on the bench or in head-holding fixture, and use a carbon scraper to take off heavy accumulations of carbon. On I heads with valves still in place take carbon off the valve surfaces as well. Do not scrape on flat finished surfaces of the cylinder head, since this might scratch the surfaces and prevent normal sealing. Particles of gasket and gasket cement should be scraped off with a flat scraper. To finish the carbon-removing job, a carbon-removing brush driven by an electric drill may be used. All traces of dirt and dust should then be blown away with compressed air.

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To remove carbon from an engine block, cover all cylinders with cloths except the one being worked on (Fig. 13-20). Crank the engine until the piston of the cylinder to be cleaned is at TDC (top dead center) and (on L-head engines) both valves of the cylinder are closed. If the carburetor has not been removed, cover it with cloths. Then use a carbon scraper to remove carbon from the block surfaces, piston, and valves (L-head engine) of the exposed cylinder. Put a carbon-removing brush into an electric drill and complete the job. Then use compressed air to blow all dust from the work.

Be sure that bolt holes are cleaned out, because dirt in the bolt holes may cause the bolts to bottom so that they cannot be tightened to provide a good seal of the head to the block. Bottoming of the bolts due to dirt in the bolt holes may also cause the bolts to be twisted off before they are tightened to the specified tension.

Caution: Goggles should be worn when a carbon brush or compressed air is used, to prevent particles of dust from being blown into the eyes.

Be very careful to avoid getting dirt or dust into open valve ports or into cylinders where the piston is not at TDC. Do not scrape flat finished surfaces with the carbon scraper, but use a flat scraper to remove traces of gasket or gasket cement.

[368]
§212. Servicing valves  The first step in servicing valves after they have been removed from the engine is to clean them of carbon. The best method of doing this is to use a wire buffing wheel or brush. Valve stems should be cleaned of all trace of varnish or gum with a fine grade of abrasive cloth. This may be done by chucking the valve in an electric drill or a lathe and rotating it while holding a strip of abrasive cloth wrapped partly around the stem. The valve may be clamped instead in the soft jaws of a vise and a strip of abrasive cloth wrapped around the stem and pulled back and forth. Do not cut metal from the valve stem since this would reduce the stem diameter and cause excessive clearance between the stem and valve guide. During the cleaning process examine each valve carefully to determine whether it can be serviced and used again or whether a new valve will be required.

Caution: When using the wire buffing wheel, always wear goggles to protect your eyes from the particles of wire that fly off the buffing wheel.

When making this detailed cleaning and inspection of the valves, be careful not to mix them up. Each valve must be returned to the valve port from which it was removed. Take one valve at a time from the rack, clean and examine it, and, if you find it good enough to reuse, replace it. If a new valve is needed, discard the old valve and put a new valve into the rack in its place.

If the valve stems are worn or the seating faces badly cracked, pitted, or burned, new valves should be used. Slight pits, burns, or irregularities in the valve face can be removed as explained in the following paragraphs. There are two basic methods of performing this service: by lapping the valve and the valve seat together in one operation, or by refacing the valve and grinding the valve seat separately. The latter method has come into universal favor in recent years.

1. Lapping valves. The valve may be lapped by replacing it in the valve seat after the stem and the valve guide have been cleaned and put into condition. A light spring is placed under the valve between the valve head and the guide. Grinding compound is placed on the seating edge of the valve, and the valve is oscillated on the

\[\text{The chuck is a device with movable jaws that can be clamped on a part to be held by turning a collar.}\]
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valve seat. This laps the valve and the valve seat simultaneously. The valve may be oscillated by a screw driver twirled back and forth in the palms of the hands, by a brace and bit, or by a regular valve-lapping tool operated electrically or by hand. This method is no longer widely used and is not recommended.

2. Refacing or grinding valves. The use of a valve-refacing machine (Fig. 13-21) duplicates the procedure employed by the car manufacturers in finishing valves and is the recommended method of servicing valves. The valve stem is clamped in a chuck and the seating face of the valve is brought into contact with a grinding wheel. The chuck is set at the proper angle to give the correct angle to the valve-seating face. Thus, when the valve is rotated against the spinning grinding wheel, it is properly refaced.

Note: The angle of the face should just match the angle of the seat, or else there should be an interference angle of ½ to 1 degree (see Fig. 13-2). In no case should the valve-face and seat angles give a negative interference angle; that is, they should not be ground in such a way that they meet on their lower edges (instead...
of their upper edges as with a positive interference angle). This condition would probably permit valve leakage within a short time.

At the start of the operation, the first cut should be a light one. If this cut removes metal from only a third or a half of the face, possibly the valve is not clamped in the chuck squarely, or else the valve stem is dirty or bent. If the stem is bent, the valve should be discarded. If the cut is reasonably even around the circumference of the valve, then the valve-refacing operation should proceed. Only enough metal should be removed to true up the surface and remove pits. If too much metal is removed, the valve head will be ground down until its outer edge is sharp, or margin is lost (see Fig. 7-30). If this happens, the valve should be discarded since such a valve

![Fig. 13-22. Appearance of a new and a worn valve-stem tip. Note that the tip rounds off as it wears.](image)

will run too hot in the engine, so that it would probably burn or warp.

Do not take heavy cuts on the valve face since this is apt to heat the valve head and cause it to warp so that an irregular face will result. Heavy cuts will also make it necessary to dress the grinding wheel of the refacing machine more often. New valves that have been substituted for defective ones should also be refaced lightly. This assures that all valves will have uniform face angles.

**Note:** When using the valve-refacing machine, be sure to follow the machine manufacturer’s recommendations on how to operate it. The grinding wheel must be dressed frequently with the diamond-tipped dressing tool. As the diamond is moved across the rotating face of the wheel, it cleans and aligns the grinding face. This assures smooth, even grinding of the valves.

3. Valve-stem-tip refacing. If the tip ends of the valve stems are rough or worn unevenly, they should be ground lightly with the special attachment on the valve-refacing machine. Figure 13-22 shows the appearance of new and of worn valve-stem tips. Note that the sharp edges of the chamfer tend to round off. In regrinding the
stem tips, the original chamfer shape should be restored by grinding the tip flat.

§213. Valve seats. We have already noted that it is extremely important for the valve to seat firmly and to seal all the way around the valve seat (§202). If the valve does not seat properly, so that leakage occurs, then blow-by, valve burning, and rapid valve failure will result. For effective sealing, the valve guide must be concentric with the seat, the valve stem must be concentric with the valve face, and the seat itself must be concentric with the valve guide, valve stem, and face. Further, the face angle of the valve must match the seat angle (or else there must be a slight interference angle as shown in Fig. 13-2). The following paragraphs describe seat servicing and checking methods.

Valve seats are of two types: the integral type, which is actually the cylinder block or cylinder head, and the insert type, which consists of a ring of special metal inserted into a counterbore in the cylinder block (Fig. 7-35). Valve seats are serviced by grinding machines or by reaming cutters that grind or cut the valve seats, thereby smoothing them and removing roughness or pits. Valve-seat inserts, being of harder metal, cannot be cut and must be ground.

1. Replacing valve-seat inserts. When a valve-seat insert is badly worn or burned or has been ground down on previous occasions so that insufficient metal remains to permit another grind, it must be replaced. The old valve-seat insert can be pulled with a special puller. If a puller is not available, the insert should be punch-marked on two opposite sides and an electric drill used to drill holes almost through the insert. A chisel and a hammer can then be used to break the insert into two halves so that it can be taken out. Care must be used to avoid damaging the counterbore. If the new insert fits too loosely, the counterbore must be rebored oversize and an oversize insert installed. The new insert should be chilled in dry ice for 15 minutes before it is put into place. This shrinks the insert so that it will fit into place. It should be driven into place with a special driver, and the valve seat then ground.

2. Reaming valve seats. Except for valve-seat inserts, valve seats can be reamed with special valve-seat cutters (Fig. 13-23). Although this method of servicing valve seats is still in use, grinding
of valve seats (see next paragraph) is the more widely recommended and preferred method. As a first step, the valve guide must be cleaned and checked to make sure that it is in good condition (§214), since the cutter pilots in the guide. Then the cutter arbor is inserted into the guide and the rough seat reamer is installed and rotated against the seat face until roughness is removed. Next, the finish reamer is used. No more than the minimum necessary metal must be removed. As a final step in the operation, the upper and lower cutting reamers are used to cut away the upper and lower cutting edges of the seat, thereby narrowing the seat to the proper width (Fig. 13-24). Finally, the seat and the seating of the valve should be checked as explained at the end of this section.

3. Grinding valve seats. Two general types of valve-seat grinding equipment are in use, one of which is a concentric grinder, the other an eccentric grinder. In the concentric valve-seat grinder a grinding stone of the proper shape and angularity is rotated in the valve seat (Fig. 13-25). Since the stone is kept concentric with the valve seat by means of a pilot installed in the valve guide (Fig. 13-26), the valve guide must be clean and in good condition (§214). In the unit shown in Fig. 13-25 the stone is automatically lifted off the valve seat about once every revolution, to permit the stone to clear itself of grit and dust by centrifugal action.
FIG. 13-24. (a) Diagram and (b) sectional view of valve seat showing angles to which seat and upper and lower cuts must be ground on one application. Dimensions and angles vary with different engines. (Chrysler Sales Division of Chrysler Corporation)

FIG. 13-25. Concentric valve-seat grinder of type using the patented Vibro-centric principle. The stone is rotated at high speed and, about once every revolution, it is automatically lifted off the valve seat so that it can throw off loosened grit and grindings. (Black and Decker Manufacturing Company)

FIG. 13-26. Pilot on which grinding stone rotates. The pilot keeps the stone concentric with the valve seat. (Black and Decker Manufacturing Company)
The eccentric valve-seat grinder makes use of an eccentric grinding mechanism in which the grinding wheel is offset from the center of the valve seat, so that it makes only line contact with the valve seat. As the grinding wheel spins, it rotates slowly on an eccentric shaft. This permits the line contact along which grinding is taking place to progress evenly around the entire valve seat. Figure 13-27 illustrates an eccentric valve-seat grinder in place in a cylinder block. Before it is installed, the valve guide must be properly cleaned (§214), since the grinder pilots in the valve guide. Regardless of the grinding method or mechanism used, the
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FIG. 13-28. Use of masking tape (A) to cover cylinders of L-head engine during valve-seat grinding. The masking tape prevents abrasive or grinding dust from getting into the cylinders where it could cause serious trouble.

abrasive stone must be dressed frequently with the diamond-tipped dressing tool to assure even, uniform grinding of the valve seats. Also, after the seats are ground, upper and lower cutting stones should be used to narrow the valve seats to the proper width (Fig. 13-24).

Caution: Unless the engine has been completely torn down so that the block can be cleaned after valve service, extreme care must be taken to prevent cuttings or abrasive from the stone from getting into the cylinders. To prevent this on L-head engines, the cylinders should be protected with cloths or masking tape (Fig. 13-28).

4. Checking valve seat for concentricity with valve guide. After the valve seat has been ground or reamed, it may be checked for concentricity with the valve guide by use of a valve-seat dial gauge, as shown in Fig. 13-29. The gauge is mounted in the valve guide and is rotated so that the indicator finger sweeps round the valve
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seat and indicates, on the dial, any eccentricity. The valve guide must be cleaned and in good condition (§214) before this test is made.

5. Lapping valve seats. Although valve lapping is no longer recommended as a valve and valve-seat servicing operation, some manufacturers recommend that the fit between the valve and the valve seat be perfected by lapping after the two are serviced as above. To lap-in valves, put a small amount of lapping compound on the valve face and then insert the valve into position with a small spring under it. Next, use a valve lapper to force the valve down on the seat, and turn the valve back and forth on the seat (Fig. 13-30). Then release the pressure so that the spring pushes the valve up, turn the valve a few degrees to a new position, and repeat. Continue until the valve and the seat are smooth. Wipe off compound with a cloth moistened with cleaning solvent. Be sure to remove all the compound.

6. Testing valve and seat. Contact between the valve face and the seat may be tested by marking lines with a soft pencil about \( \frac{1}{8} \)
inch apart around the entire valve face. Then the valve should be put into place and, with light pressure, rotated one-half turn to the left and then one-half turn to the right. If this removes the pencil marks, the seating is good. The seating may also be checked with prussian blue. Coat the valve face lightly with prussian blue, put the valve into the seat, and turn it with light pressure about a quarter revolution. If the prussian blue transfers evenly to the seat, the seat can be considered to be concentric with the valve guide. All prussian blue should then be washed from the seat and the valve. The valve seat should then be coated with prussian blue. If the blue again transfers evenly, this time to the valve when it is turned in the seat, the seating can be considered to be normal.

§ 214. Valve guides. Two services may be performed on valve guides, cleaning and replacement. A wire brush or an adjustable-blade cleaner (Fig. 13-31) may be used to clean the valve guide.

![Fig. 13-31. Valve-guide cleaner of the adjustable-blade type. (Kent-Moore Organization, Inc.)](image)

To remove old and worn guides and install new ones, special guide-removing and replacing tools are required as explained in the following paragraphs.

1. Testing valve guide for wear. Before a valve guide is tested for wear, it should be cleaned with a valve-guide cleaner and wiped with a strip of cloth dampened with cleaning solvent. The cloth can be pulled through by hooking it to the end of a wire stuck through the guide.

One method of testing for valve-guide wear on L-head engines makes use of a dial indicator. With the valve in place, the camshaft is turned until the cam raises the valve off its seat. The dial indicator is then installed on the block with the indicating button touching the edge of the valve head (Fig. 13-32). With this arrange-
ment the valve can be moved sideways in the guide, and the amount of movement will give an indication of guide wear.

A second method of checking guide wear (on both L-head and I-head engines) is to insert a tapered pilot into the guide until it is tight, pencil-mark the pilot at the top of the guide, and then remove it. Measure the pilot diameter half an inch below the pencil mark with a micrometer. This gives the guide diameter (except on guides that have a counterbore at the top) which can then be compared with the diameter of the valve stem.

Neither of the above two methods gives a really accurate measurement of valve-guide eccentricity and bellmouthing. The guide is apt to wear oval-shaped, with the upper and lower ends flaring out, or bell mouthing as shown in Fig. 13-33, left. A tapered pilot or plug gauge would not detect these types of wear, but the small-hole gauge will. To use this gauge, adjust the split ball until it is a light drag fit at the point being checked. Then measure the split ball with a micrometer (Fig. 13-33, right). By checking the guide at various points, the amount of oval-shaped and bell mouthing wear can be accurately determined.

Excessive wear of any type in the valve guide will cause excessive clearance. This will in turn produce excessive oil consumption. Oil will be pulled through the excessive clearance and past the
FIG. 13-33. A small-hole gauge is the most accurate device to check for valve-guide wear. The gauge is adjusted so that the split ball is a drag fit in the guide (left), and then the split ball can be measured with a micrometer as shown (right).

FIG. 13-34. The valve guide is removed from the cylinder block with a special puller. 1, screw; 2, nut; 3, spacer; 4, nut; 5, bearing.
intake valves on each intake stroke. This leads to many types of troubles as explained in §199. In addition, if the guide is worn oval or bell-mouthed, the valve will probably wobble as it moves up and down. This will be an added factor that will make valve seating still worse and increase valve and valve-seat wear. Whenever excessive wear is found, new guides (and new valves if valve stems are worn) should be installed. However, in some cases, installation of valve packing around the valve stem will help reduce the high oil consumption.

Fig. 13-35. The valve guide is installed in the cylinder block with a special replacer. 1, screw; 2, nut; 5, spacer; 6, recessed nut; 7, sleeve; 8, collar.

2. Removing valve guide. If inspection of the guide discloses that it is worn, cracked, or burned, it should be replaced. A guide puller is required to pull the valve guide (Fig. 13-34). The guide puller exerts pressure on the guide end when it is operated, forcing the guide out. On many L-head engines the guides can be driven down into the valve-spring compartment and removed from there instead of being pulled as shown in Fig. 13-34. On overhead-valve engines the valve guide can be pressed out of the head with an arbor press.

3. Installing valve guides. New valve guides should be installed with a valve-guide driver or a valve-guide replacer (Fig. 13-35).
On overhead-valve heads valve guides can also be installed with an arbor press. In any case, the valve guides must be installed to the proper depth in the block or the head. After installation a guide reamer should be used to ream the guide to size. Usually this is done in two steps, the first being a rough ream and the second, the final finishing ream. Figure 13-36 illustrates both the depth of assembly of valve guides in an overhead-valve engine and also the reaming dimensions of the guides.

Note: After new guides are installed and reamed, the concentricity of the guide to the valve seat must be established. Concentricity should be checked as explained in §213. If the seat is not concentric with the valve guide, the seat must be ground (§213).

§ 215 Camshaft Occasionally the camshaft must be removed from the engine. The bearing journals are larger at the front, becoming progressively smaller toward the back of the engine. Once the camshaft is started moving, it will slip endwise out of the engine.

Before the camshaft can be removed, the radiator must be off, the dynamic balancer or pulley must be removed from the crankshaft, and the gear or timing-chain cover must be detached. Then the camshaft-thrust plate attaching screws (on engines so equipped) should be removed so that the thrust plate is free. Next the cam-
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shaft sprocket and chain (on engines with timing chain) should be removed. The sprocket is usually bolted to a hub on the camshaft. The distributor or the oil pump (whichever has the drive gear on its shaft) must also be removed so that the gear will not interfere with camshaft removal. See §240 for procedure of removing the oil pump. With all these parts out of the way or detached, the camshaft is free to move forward. Before it is moved, however, the valves and lifters must be raised and blocked up. Otherwise, as the camshaft moved forward, the lifters would drop off the backs of the cams and would jam. Figures 13-37 and 13-38 illustrate how to block up valves and lifters on an L-head engine. First, the valves are raised and V-shaped wood blocks are inserted between the valves and seats. The lifters can then be raised and clamped in the up position with ordinary spring-type clothespins. The camshaft is then free and ready to be pulled out. Care must be used to keep cams and journals from being scratched or from their hitting and damaging the bearings. To prevent such damage, the rear of the camshaft should be supported as the camshaft is pulled out (Fig. 13-39).

1. Checking camshaft. The camshaft must be checked in two ways: for bearing journal or cam wear and for alignment. Align-
Fig. 13-38. Using spring-type clothespins to hold valve lifters up so that they will clear the camshaft bearings and cams as camshaft is removed. (Studebaker-Packard Corporation)

Fig. 13-39. Supporting rear of camshaft as it is pulled from engine block. The engine shown here is in different position from that shown in previous two illustrations; it is upside down.

ment may be checked by placing the camshaft in V blocks and using a dial indicator to check run-out of the journals when the shaft is turned (Fig. 13-40). A bent shaft can often be straightened in a heavy press. Journals should be checked with a micrometer and their dimensions compared to the bearing dimensions. The bearing
dimensions can be checked with a telescope gauge. If there is excessive clearance, the bearings should be replaced.

2. Replacing camshaft bearings. If the camshaft bearings are worn or have excessive clearance, they should be replaced. On some engines, all old bearings are removed at the same time by use of a special bearing remover. The remover bar is inserted through the bearings, with puller sleeves being installed on the bar at each bearing. Then, when the remover handle is turned, all bearings are pulled at once. By a similar action, new bearings are installed. When the new bearings are put in, the oil holes in the bearings must align with the oil holes in the block. Also, new bearings should be staked into place if the original bearings were staked. On some engines which do not use precision-insert camshaft bearings, line reaming of the bearings is required after they are installed. This calls for a special reaming tool.

3. Timing the valves. The relationship between the camshaft and the crankshaft determines valve timing, that is, the opening and closing of the valves in relation to the piston positions in the cylinder. The meshing crankshaft and camshaft timing gears or sprockets and chain are marked to assure proper relationship when the parts are reinstalled on the engine. Figures 7-27 and 7-28 show typical markings. Of course, the front end of the engine must be practically torn down in order to remove the timing cover so that the markings can be seen. Since this is a big job, many engines have a simpler means of checking the valve timing that does not require taking a look at the gears or sprockets.

The means used in many engines include a marking on the engine flywheel or vibration damper. This marking is usually near the
ignition-timing markings. When this marking is visible or registering with the pointer, a certain designated valve should be just opening or should have opened a specified amount. Valve action can be observed by removing the valve cover. On L-head engines you can tell when a valve is about to open by grasping the valve lifter and moving it up and down while the crankshaft is slowly turned. At the instant after all clearance is taken up, the valve will start to open. On overhead valves, the same thing can be done with the rocker arm. Just after all clearance has been taken up, so that the rocker arm can no longer be moved, the valves will start to open. To measure the amount of opening (as required in some valve-timing procedures) a dial indicator can be used.

Where the flywheel or vibration damper is not marked, piston position can be measured with a special gauge (through spark-plug hole) so that its relationship to the valves can be accurately determined.

NOTE: Be sure to refer to the appropriate manufacturer's manual for details of valve timing, since the procedures and specifications vary somewhat from engine to engine.

4. Timing gear and chain checks. Gear run-out can be checked by mounting a dial indicator on the block, with the indicating finger resting on the side of the gear. Then, when the gear is rotated, the amount of run-out will be indicated. Gear backlash can be checked with a narrow feeler gauge inserted between the meshing teeth. Excessive run-out or backlash, which mean worn gears, require gear replacement. On timing chains excessive slack indicates a worn chain; the chain and possibly the sprockets (if they are worn excessively) should be replaced.

§216. Valve lifters There are two types of valve lifters, the plain-sleeve type and the hydraulic type. The procedures of removing and servicing the two types are quite different.

1. Plain-sleeve valve lifter. Plain-sleeve valve lifters are usually removed from the camshaft side of the block; this necessitates removal of the camshaft first as explained in §215. With the camshaft out, the wires or clips holding the lifters up can be released so that the lifters can be removed. Be sure to keep the lifters in proper order so that each may be returned to the bore from which it was removed.
If the lifter-screw face is worn or pitted, it may be refaced in the valve refacing machine (Fig. 13-21). On many engines oversize valve lifters may be installed in case the lifter bores in the block have become worn. Before the oversize lifters are installed, the lifter bores must be reamed oversize with a special reamer (Fig. 13-41).

2. Hydraulic valve lifter. Some engine manufacturers recommend testing of the "leak-down" rate as a means of checking hydraulic-valve-lifter action. This test is made by inserting a feeler gauge between the rocker arm and valve stem and noting the time it takes for the valve lifter to leak enough oil to permit the valve to seat. As the valve seats, the feeler gauge becomes loose and this signals the end of the test. If leak-down time is too short, the valve lifter is defective.

To remove hydraulic valve lifters of the type shown in Fig. 7-50 from an engine, the push-rod cover and rocker-arm assembly must first be removed. The push rods and valve lifters can then be
Valve lifters can be lifted from the bores with a piece of stiff wire slightly hooked on the end; hook the wire end in the oil hole in the push-rod seat.

**NOTE:** Where only two or three lifters are to be removed, it is possible on some engines to slide the rocker arm over (after compressing the valve spring) and take out the push rod. Thus the rocker-arm assembly does not need to be removed.

![Fig. 13-42. Using special valve-lifter remover tool to removed hydraulic valve lifter from cylinder block. The tool has special jaws that fit the lifter so that the lifter body is not scratched. (Cadillac Motor Car Division of General Motors Corporation)](image)

On some engines the valve lifter protrudes above the lifter bore in the block and a special removing tool can therefore be used to take the lifter out (Fig. 13-42).

On the type of valve lifter shown in Fig. 7-53 the tappet or body of the lifter is left in the lifter bore, and the plunger unit assembly is removed. This is done by first compressing the valve spring and moving the rocker arm to one side, and then inserting a special tool over the push rod and the unit assembly so that they can be withdrawn (Fig. 13-43).

3. **Servicing hydraulic valve lifters.** The lifter should be disassembled and all parts cleaned in solvent. If any part is defective,
the lifter should be replaced. On reassembly, fill the lifter with clean, light engine oil.

Work on only one lifter at a time, in order to avoid mixing parts between different lifters. Make sure that each lifter goes back into the lifter bore in the block from which it was removed.

Caution: You must use extreme care to do a clean job when working on hydraulic valve lifters. Small traces of dirt or foreign matter will cause the lifter to malfunction. Make sure your hands, tools, and bench are clean. Lay lifter parts on clean cloths or paper as you clean them.

CHECK YOUR PROGRESS

Progress Quiz 18

Once again you can check your progress in your study of automotive engines. The following quiz covers the second half of Chap. 13 and will

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help you review the material you have just studied. If any of the ques-
tions stump you, reread the pages you have just read to get the answer.

Completing the Sentences

The sentences below are incomplete. After each sentence there are sev-
eral words or phrases, only one of which will correctly complete the sen-
tence. Write down each sentence in your notebook, selecting the proper
word or phrase to complete it correctly.

1. If the cylinder-block bolt holes are not cleaned out, the head bolts
   may bottom in the bolt holes and prevent head-to-block sealing
   normal valve action adequate oil-ring action loss
   of compression
2. Two methods of servicing valve faces are replacing and lapping
   lapping and grinding replacing and refacing
3. Oscillating the valve on the valve seat is called valve replacing
   valve lapping valve grinding valve interference
   grinding
4. If a valve is ground down so much that its outer edge is sharp (that
   is, its margin is lost), it will run too hot run too high
   run too cool
5. The difference between the valve-face angle and the valve-seat angle
   is called the differential angle angular difference
   interference angle
6. The tip end of the valve stem should be rounded curved
   flat convex concave
7. Valve seats may be serviced by either reaming or cutting
   cleaning or grinding reaming or grinding
8. The two types of valve-seat grinding equipment are concentric
   and eccentric centrifugal and concentric valve-guide
   piloted and eccentric
9. Valve guides are apt to wear round or oval-shaped out-
of-round or oval-shaped oval-shaped and bellmouthed
10. On many engines valve timing can be checked by means of a marking
    on the valve guide or valve cover valve lifter or engine
    flywheel engine flywheel or vibration damper

CHAPTER CHECKUP

Note: Since the following is a chapter review test, you should review
the chapter before taking the test.

You are now well into the second half of the book, the part of the book
that is designed to give you practical guidance in actual work on automo-
tive engines. Nearly all servicing procedures on modern engines are dis-
Valve and Valve-mechanism Service

cussed on these pages. You should, of course, remember the essentials of these various procedures so that when you are in the shop, you will have a good idea of what to do and why you should do it. The checkup below will give you a chance to test yourself on how well you remember these procedures. In the "Service Procedures" part of the checkup, you are asked to write the procedures in your notebook. The act of writing them down will help you remember the procedures, and, in addition, you are filling your notebook with valuable information to which you can easily refer. Don’t copy from the book; use your own words.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. Among other things, excessive clearance between the valve stems and guides is apt to cause excessive compression spark knock tappet noise excessive oil consumption

2. With the proper tools a complete valve-servicing job on an eight-cylinder L-head engine, including grinding valves and seats, checking springs, and cleaning guides, should require about 4 hours 6 hours 8 hours

3. When you measure valve-tappet clearance on an L-head engine, you measure the clearance between the rocker arm and valve stem rocker arm and push rod valve stem and tappet-adjustment screw valve stem and seat

4. When you measure valve-tappet clearance on an overhead-valve engine, you measure the clearance between the rocker arm and valve stem rocker arm and push rod valve stem and tappet-adjustment screw valve stem and seat

5. Engines equipped with hydraulic valve lifters normally require valve-tappet adjustment no valve-tappet adjustment adjusting screw adjustment

6. Before you can remove a valve from an L-head engine, the retainer lock must be removed after the retainer is removed valve spring is compressed valve guide is removed

7. The valve guide, spring, valve, and spring retainer are removed as a unit in L-head engines 1-head engines many Ford engines F-head engines

8. Before a valve seat is ground, the valve guide must be replaced reamed adjusted cleaned

9. If you find that the camshaft bearings are excessively worn, you will
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have to replace them rebore them replace cam-
shaft grind camshaft journals

10. After a valve seat has been smoothed and trued, upper and lower
cutting reamers or stones must be used to widen valve seat
narrow valve seat produce interference angle

Service Procedures

In the following, you should write down in your notebook the pro­
cedures asked for. Do not copy from the book, but try to write in your
own words, just as you would explain it to another person. Give a step­by-step story. This will help you remember the procedures later when
you go into the shop.

1. Explain how to check and adjust valve-tappet clearance on L-head
engines; overhead-valve engines; Ford engines.
2. Explain how to remove the valves from an L-head engine; from an
overhead-valve engine; from a Ford engine.
3. Explain how valves are lapped.
4. Explain how to grind valves.
5. Explain how to ream or grind a valve seat.
6. Explain how to remove and replace valve guides in L-head and over­
head valve engines.
7. Explain how to remove and check a camshaft.
8. Explain how to remove and replace an L-head cylinder head.
9. Explain how to remove and replace an overhead-valve cylinder head.
10. Make a list of the various valve troubles, their causes, and their cor­
rections.

SUGGESTIONS FOR FURTHER STUDY

When you are in the engine service shop, keep your eyes and ears
open so that you can learn more about how various engine jobs are done.
Study the operating manuals supplied by the service-equipment manu­
facturer so that you can learn how to operate valve-refacing machines,
seat grinders, and so on. Also study carefully the shop manuals issued
by automobile manufacturers. These manuals supply a great deal of
specific information on how to do various service jobs on the engines they
manufacture. Keep a notebook and jot down every important fact that
comes to you during your time in the shop or when you are reading any
of the various manuals and books. You will find that this helps you to re­
member these facts. At the same time, the notebook becomes an increas­
ingly valuable reference for you.

[392]
14: Connecting-rod, piston, and ring service

THIS CHAPTER continues the discussion of engine service and covers the servicing of connecting rods, connecting-rod bearings, pistons, piston rings, piston pins, and piston-pin bushings. The information in §§197 and 198 on tools and cleanliness applies to the services discussed in this chapter as well. It is extremely important to keep engine parts as clean as possible during service operations on them, and to make sure that the parts are absolutely clean when they are replaced in the engine. An otherwise good engine-servicing job can be completely ruined by dirt or abrasive carelessly left in the engine or on engine parts.

§217. Bearing oil-leak detector Before engine teardown and removal of the connecting rod and crankshaft bearings, it is sometimes desirable to give these bearings a preliminary check, in place, to see if they are excessively worn. As has already been mentioned, a worn bearing will have excessive clearance which will pass too much oil. This excess of oil will cause high oil consumption (§194), possible oil starvation of certain engine parts, and ultimate engine failure. Bearings will be noisy (§196), and bearing failure will probably take place in a short time.

The bearing oil-leak detector (Fig. 14-1) supplies oil under pressure to the bearings. With the oil pan removed (§218), leakage of oil at the bearings can be seen. The leakage appears as drops or streams of oil. If the bearing clearances are excessive, the oil will leak out with excessive rapidity. On the other hand, if no leakage occurs at a bearing, then either the clearance is too small, or the oil line to the bearing is stopped up. With normal conditions, leakage should be between 20 and 150 drops a minute.

The manufacturer of the oil-leak detector shown in Fig. 14-1 specifies that SAE 30 oil be used (the detector holds 5 quarts of...
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oil), and that the detector be connected to a 25 psi (pounds per square inch) air-pressure source. The oil hose from the detector is connected into the pressure side of the engine lubricating system. It can be connected in various places. The line from the engine block to the oil filter, for example, can be disconnected and the detector line connected in its place. Or else one of the pipe plugs closing off the drilled oil holes or lines in the cylinder block can be removed so that the detector line can be connected. Then, when air pressure is applied to the detector, the oil will be forced through the oil lines to the bearings.

![Diagram of engine bearing oil leak detector](image)

**FIG. 14-1.** Engine bearing oil leak detector to check main and connecting-rod bearings for wear. (Federal-Mogul Corporation)

**NOTE:** When oil-passage holes in the crankshaft and bearings index, considerable oil will be forced through the bearing, giving the appearance of worn bearings. In such case, the crankshaft must be rotated somewhat to move oil holes out of register.

§218. **Preparing to remove connecting rods** When service is required on pistons, rings, connecting rods, cylinder walls, crankshaft, or associated parts, the rods and pistons must be removed from the engine. Removing, servicing, and replacing connecting rods requires from 5 to 8 hours, according to the type of engine. About 3 additional hours are required to install new piston rings, with
more time needed for such services as piston-pin or bushing replacement. Piston and rod assemblies can be taken out from the top of the cylinder block or, on some engines, from the crankcase end. The first step in piston and rod removal, where removal is to be from the top of the engine, is to take off the cylinder head and examine the cylinder for wear. If wear has taken place, there will probably be a ridge at the top of the cylinder that marks the upper limit of the top-ring travel. If this ridge is not removed, the piston or rings could be damaged as they were forced out the top of the cylinder. The rings, jamming behind the ridge, might break or could cause the piston-groove lands to be broken (Fig. 14-2). A ridge-removing tool, such as shown in Fig. 14-3, should be used. This and other service operations on piston and rod assemblies are discussed in the following paragraphs.

1. **Removing ridge.** If examination of cylinders discloses ridges at the tops, use a ridge remover to remove them. With piston of cylinder 1 near BDC (bottom dead center), stuff cloths into the cylinder to protect piston and rings from metal cuttings. Then cover all other cylinders, valves, and openings with cloths. Adjust cutters
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on the ridge remover to take correct depth of cut, install the ridge remover in the cylinder, and turn the cutters by the means provided to remove the ridge. Do not take off any more material than is necessary to remove the ridge. Take the cloth from the cylinder. Do not allow any cuttings to drop into the cylinder. Wipe the cylinder walls clean. Repeat for other cylinders where necessary.

Fig. 14-3. Ridge-removing tool in place in top of cylinder. Cutters remove the ridge as the tool is turned in the cylinder. (Studebaker-Packard Corporation)

2. Removing oil pan. Before the connecting rods can be detached from the crankshaft, the oil pan must come off. To remove the oil pan, first take out drain plug, and drain oil from engine. On many cars the steering idler or other steering linkage must be detached before the oil pan can be removed. In such case, carefully note the manner in which the linkage is attached and also the number and location of shims (where used) so that the linkage can be correctly reattached after the oil pan is replaced. On Fords oil-pan removal can be simplified by removing the engine mounting bolts and raising the engine slightly off its mounting. Exhaust pipe and oil-level tube must be disconnected, brake return spring detached,
and cranking motor removed, to remove oil pan. With these parts off, remove bolts or nuts holding pan to block. To prevent pan from dropping, steady it before taking out the last two bolts. If the pan sticks, pry it loose with a screw driver, but be careful to avoid bending the pan. If the pan strikes the crankshaft so that it will not come free, turn the crankshaft over a few degrees so that the counterweights move out of the way.

Before replacing the pan, it should be cleaned out thoroughly, as should the oil screen and the oil pump. Gasket material and cement should be scraped from the pan and block. New gasket cement should be applied and a new gasket (or gaskets) laid in place on the gasket surface of the pan. Bolt holes in gasket and pan must align. Then, when pan is replaced, bolts or nuts should be tightened to proper tension.

§219. Removing and replacing piston and rod assemblies

1. Removal. With head and oil pan off, crank the engine so that the piston of cylinder 1 is near bottom. Examine rod and rod cap for identifying marks, and, if none can be seen, mark them with metal numbering dies. This assures against mixing the parts and returning them to the wrong cylinders. The marking should be done before the assembly is removed, to avoid distorting rod or cap. (The piston should also have an identifying mark.) Then remove the rod nuts and cap with a wrench, and slide rod and piston assembly up into the cylinder away from the crankshaft.

   NOTE: Some engine manufacturers specify the use of guide sleeves placed over the rod bolts before the rods are pushed away from the crankshaft. The sleeves prevent the bolt threads from scratching the crankshaft-bearing surfaces (Fig. 14-4).

   After all piston and rod assemblies have been detached, they may be removed from the tops of the cylinders. It will be necessary to turn the crankshaft as you go from one cylinder to the next, to detach rods.

   2. Separating rods and pistons. As the piston and rod assemblies are removed from the engine, they should be laid out in order on a rack or bench. Then, when the assemblies are taken apart, this same order should be maintained so that the various parts will not become mixed. The rod and piston are separated by removing the piston pin. If the pin is of the free-floating type, it can be slipped out after
the snap rings in both ends of the piston bushings are removed. On other types loosen the locking bolt in the rod or piston, or press the pin out in an arbor press. Never clamp the piston in an ordinary vise since this could distort and possibly ruin it. Use a special piston vise (Fig. 14-20).

3. Connecting-rod checks. Several checks of the connecting rod should be made, as explained in the following sections. These include checking rod alignment and the condition and fit of the piston-pin bushing and rod bearing. In addition, the drilled oil holes in the connecting rod should be inspected to make sure that they are open.

4. Reinstalling piston and rod assemblies. After the rods, pistons, and rings have been reassembled, they should be reinstalled in the engine. It is extremely important to make sure that parts which are used again are rematched (piston pins put back in same rods and pistons from which they were taken) and that the assemblies go back into the same cylinders from which they were removed. Rings should be positioned so that gaps are uniformly spaced around the piston (except on pistons where rings are pinned). A piston-ring compressor should be used to compress the piston rings so that they will slip easily into the cylinders (Figs. 14-33). The compressor clamps around the rings, compressing them into their grooves so that they will not catch on the edge of the cylinder but will slide easily into the cylinder bore.

Before putting the piston-ring compressor into place, the piston-ring and rod assembly should be dipped in heavy oil or in castor
oil to provide initial lubrication. Castor oil is considered better than heavy oil since it has greater film strength and since gasoline and lubricating oil will not wash it out during the break-in period of engine operation. Thus the rings, piston, piston pin, and piston-pin bushings will be adequately lubricated during initial operation.

Use bolt guide sleeves, if so specified, to bring the rod down over the crankpin, and attach the rod to the crankpin with the rod cap and nuts. After tightening the rod nuts lightly, tap the bearing cap on its crown lightly with a brass hammer to help center the bearing. Then use a torque wrench to draw down the nuts to the specified tension.

**Note:** Bearing clearance should be checked as explained in §224.

§220. **Checking connecting-rod alignment** If the rod is out of alignment, it will cause uneven bearing loading and heavy pressure at certain spots on the piston. Figure 14-5 shows, in exaggerated view, a bent rod. Note that the bearing load will be greatest at points A and B. The bearing will probably fail at these points; it will flake or burn out in the areas of greatest load. The heavy loading spots on the piston (at C and D) will wear heavily and will probably score the piston and cylinder wall.

A rough check for rod alignment can be made on the engine by detaching the oil pan and watching the rod movement while the engine is slowly cranked. If the piston end of the rod can be seen to move back and forth on the piston pin, the rod is out of line.
The rod should be centered on the piston pin between the piston-pin bosses. If it moves in, or if it is tight, against one of the bosses, it is bent.

To check alignment of the rods after they are out of the engine, the piston pins can be reinstalled and the fixture shown in Fig. 14-6 used. To use the fixture, the rod is mounted on the special arbor in the fixture and the rod cap is replaced. Then the V block is placed over the piston pin and moved in against the faceplate. If the rod bearing and piston pin are not in perfect alignment, the V block will not fit squarely against the faceplate. This same type of fixture can be used to check alignment of the rod and piston assembly before the rings are installed on the piston (Fig. 14-32).
Connecting-rod, Piston, and Ring Service

If a rod is found to be out of line, the crankpin should be checked for taper (§241). A tapered crankpin causes the rod to be subjected to uneven loading which tends to bend it.

Bent rods must be either straightened or replaced. To straighten a rod, a straightening bar must be used. The bar is inserted in the piston-pin bushing and force exerted in the proper direction to align the rod. Actually, the rod should be bent a little past the straight position and then back to straight again. This relieves stresses set up in the rod by the bending process.

Note: Some engine manufacturers call for replacement of bent connecting rods. The reason is this: It is their experience that the type of rod they use may, if bent, take on a permanent set. The rod can be temporarily straightened with a straightening bar, but it may soon drift back to its permanent-set, or bent, condition.

§221. Piston-pin bushings On the type of connecting rod with a piston-pin bushing, the fit of the piston pin to the bushing should be checked. If the fit is correct, the pin will not drop through the bushing of its own weight but will, when held vertical, require a light push to force it through. If the fit is too loose, the bushing should either be reamed or honed for an oversize pin or else replaced. On some engines the specifications call for a new rod if the bushing is so worn that it cannot be satisfactorily reamed or honed for an oversize pin. On other engines the worn bushings can be replaced in the rods and the new bushings reamed or honed to fit the present pins (if they are in good condition) or new standard-sized pins. Pins that are worn, pitted, or otherwise defective should be discarded. To replace bushings, press out the old bushings with an arbor press. If there are burrs on the edges of the bushing bore in the rod, they should be removed with a hand scraper or a tapered burring reamer. Then press in new bushing with the arbor press. Next, a tapered mandrel can be used to expand the edges of the bushing and thereby swage them firmly in the rod. Make sure that the oil holes in the bushing and the connecting rod align. Ream or hone new bushings to size.

Some connecting rods have two piston-pin bushings, separated a fraction of an inch to form an oil groove. On these each bushing must be swaged, or expanded, into place with a special burnishing tool (Fig. 14-7), so that it will not work out of position. To do this,
install one of the bushings so that its outer edge is flush with the edge of the bore in the rod. Put rod in arbor press as shown (Fig. 14-7) with bushing down. Then push the burnisher through. Install second bushing, turn rod over, pass burnisher through previously burnished bushing and then through the second bushing. After bushings are burnished, they should be reamed or honed to size.

To ream a set of bushings, proceed slowly on the first connecting rod. Use expansion reamer and expand the reamer by easy stages, taking off only a little metal each time. After each reaming operation, try the pin fit. This procedure guards against overreaming. After the first rod is reamed, the others may be quickly reamed by reducing the reamer diameter about 0.0005 inch and then rough-reaming the rest of the rods, one after another. Then the reamer may be expanded to take the final cut. At this stage, it would be well to check the pin diameters with a micrometer so that any slight variation can be taken care of. Thus if one pin is slightly larger than the others, the bushing into which it is to fit can be reamed slightly larger to provide a good fit. This process assures proper matching of pins and bushings.

To hone, or grind, a set of bushings, you follow approximately the same procedure as when reaming bushings; that is, you proceed slowly with the first rod, taking off a little metal at a time until the bushing is within about 0.0005 inch of the right size. Then the bushing can be finish-ground. Figure 14-8 shows a clamp used to hold the connecting rod and the method of holding the rod and clamp during honing. The bushing should be moved from one end of the stone to the other and not held on one part of the stone. However, the bushing should not be moved past the end of the
Connecting-rod, Piston, and Ring Service

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Since this would wear the edges of the bushing bell-shaped. When starting the honing operation, first expand the hone until the honing stone bites and begins to take off metal. Then expand the hone further to within 0.0005 inch of the finished size. Complete rough honing, then change hone and finish-hone to size. When honing a set of rod bushings, rough-hone them all and then, when finish-honing, check pin diameters with a micrometer so that any slight variation can be taken care of in honing to secure a good fit.

Fig. 14-8. Connecting rod in clamp, and method of holding rod and clamp while honing (grinding) the piston-pin bushing.

NOTE: If oversize pins are used, then the piston bearings must be reamed or honed oversize (§227).

§222. Inspection of connecting-rod bearings

Sections 102 to 109 describe engine bearings in some detail. Connecting rods use two types of bearings at the big end, the precision-insert type and the direct-bonded type. The precision-insert type consists of a shell, usually of steel, to which the bearing material is bonded. In the direct-bonded type the bearing material is bonded directly to the bearing cap and connecting rod. Precision-insert bearings can be serviced by replacement of the bearing shell only. On the direct-bonded type, however, a defective bearing calls for replacement of the connecting rod and cap.

When a bearing is defective, it must, of course, be replaced. However, an analysis of the bearing failure should also be made so that the cause of the failure can be determined and eliminated. Some bearing failures may result from excessive clearance, others from a tapered or out-of-round crankpin or a bent rod. Dirty oil, lack of oil, improper installation of the bearing shell will also cause bearing failure. Often the type of bearing failure clearly indicates the cause. Figure 14-9 illustrates various kinds of bearing failures while §223 discusses the causes of these failures.
§223 Analysis of bearing failures

As mentioned in the previous paragraph, a bearing will fail for a number of reasons. Types of failure and their causes are detailed below.

1. Bearing failure due to lack of oil (A in Fig. 14-9). If the oil supply to a bearing fails for any reason, the protective oil film is lost. Actual metal-to-metal contact takes place, the bearing overheats, and the bearing metal then melts or is wiped out of the bearing shell. Further operation after this has happened usually results in welds forming between the rotating journal and the bearing shells. There is a good chance that the engine will "throw a rod"; that is, the rod will "freeze"; to the crankpin and break, and parts of the rod will go through the engine block. Several conditions could cause loss of the oil supply to the bearing. If other bearings have excessive clearance, they may pass all the oil from the pump, thus starving one bearing, which fails. In addition, oil lines may be clogged, the oil pump or pressure regulator may be defective, or there may be insufficient or the wrong kind of oil in the crankcase. Any of these could oil-starve bearings and cause them to fail.

2. Fatigue failure of bearing (B in Fig. 14-9). Repeated application of loads on a bearing will ultimately fatigue the bearing metal so that it starts to crack and flake out. Craters, or pockets, form in the bearing where metal has been lost. As more and more of the metal is lost in this manner, the remainder is worked harder and fatigues at an accelerated rate. Ultimately complete bearing failure occurs.

Under normal operating conditions, fatigue failure of bearings is not a problem. However, there are certain operating conditions that hasten fatigue greatly. For instance, if crankpins or journals are worn out of round, bearings will be overstressed with every crankshaft revolution and will be short-lived. Unusual operating conditions will produce unusual wear patterns on connecting-rod bearings. For example, if the engine is idled or operated at low speed a good deal of the time, the center part of the upper connecting-rod-bearing half will carry most of the load and will "fatigue out," with the lower half remaining in nearly perfect condition. On the other hand, if the engine is operated at maximum torque with wide-open throttle (that is, if the engine is "lugged"), then most or all of the upper connecting-rod-bearing half will fatigue out. If the lower bearing half fatigues, chances are that the
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A. Lack of oil.

B. Fatigue failure.

C. Scratched by dirt in the oil.

D. Tapered journal.

E. Radii ride.

F. Improper seating.

Fig. 14-9. Types of engine-bearing failure. Appearance of bearing usually indicates cause of failure. (Ford Motor Company)
engine has been operated at high speeds. Refer to §§107 to 109 to see how the bearings are loaded under those different conditions.

3. Bearing scratched by dirt in the oil (C in Fig. 14-9). The property of embeddability (§105) enables a bearing to protect itself by allowing dirt particles to embed so that they will not gouge out the bearing metal or scratch the rotating journal. However, when many particles are present (oil is dirty), the bearing will become overloaded with dirt. And if dirt particles are too large to embed completely, they will be carried around (or roll around) with the rotating journal and will gouge out scratches on the bearing. In either case, loss of bearing surface and shortened bearing life result. Figure 14-10 shows, in exaggerated view, what happens when a particle becomes embedded in the bearing metal. The metal is pushed up around the particle, reducing oil clearance in that area. Usually the metal can flow outward from the high spot and fairly normal oil clearance will be restored. However, if too much dirt becomes embedded, then bearing failure will soon follow.

4. Bearing failure due to tapered journal (D in Fig. 14-9). If the journal is tapered, one side of the bearing will carry all or most of the load. The bearing metal will be overheated and will melt or be wiped from the bearing shell on the overloaded side. Short bearing life can be expected with a tapered journal.

Note: Bearing failure from a tapered journal should not be confused with bearing failure caused by a bent connecting rod (Fig. [406])
14-5). With a tapered journal, both bearing halves will fail on the same side, while with a bent rod, failure will be on opposite sides (A and B in Fig. 14-5).

5. Bearing failure from radii ride (E in Fig. 14-9). If the radius on the journal, where the journal curves up to the crank cheeks, is not cut away sufficiently, the edge of the bearing will ride on the radius, causing cramping of the bearing, possible poor seating, rapid fatigue, and early failure. This sort of difficulty would be most apt to arise after a crankshaft-grind and bearing-replacement job where the radii were not relieved sufficiently when the crankpins or journals were ground.

6. Bearing failure from improper seating (F in Fig. 14-9). If the bearing is not properly seated in the counterbore, there will be high spots in the bearing where oil clearances will be too low. Figure 14-11 shows, in exaggerated view, what happens when particles of dirt are left between the bearing shell and the counterbore. Not only is the bearing shell raised in the area so that oil clearance is reduced (as at X), but air spaces exist as well which prevent normal cooling of the bearing. The combination can lead directly to quick bearing failure.

7. Bearing failure from ridging. Crankpin ridging, or "camming," may cause failure of a partial-oil-groove-type replacement bearing installed without previously removing the ridge. The ridge forms on the crankpin as a result of uneven wear rates between the part of the crankpin in contact with the partial oil groove and the part that runs on the solid bearing. The original bearing wears to conform to this change of contour. When, however, a new bearing is installed, the center zone (at the ridge) will be overloaded and will soon fail. A ridge so slight that it can scarcely be detected (except with a carefully used micrometer) may be sufficient to cause this sort of failure. Failures of this sort have actually been reported in engines having ridges of less than 0.001 inch.

§224. Checking connecting-rod-bearing fit

The method of checking connecting-rod-bearing fit varies with the type of bearing (direct-bonded or precision-insert). Procedures for the two types of bearing are described below. These procedures can be used with the crankshaft in or out of the engine. When the crankshaft is out of the engine, it should be supported by clamping one end in the...
soft jaws of a vise with a V support at the other end. The crankshaft must be in a horizontal position; the connecting rod must be attached to its proper crankpin, and it must be facing in the right direction (and not turned 180 degrees).

Crankpins should always be checked for taper or eccentricity with a micrometer before new bearings are installed. New bearings installed around out-of-round or tapered crankpins will not last long. See §225, 1 for checking procedure.

![Diagram of connecting rod bearing with micrometer and bar stock](image)

**Fig. 14-12. Using micrometer and finished bar stock to measure thickness of bearing and thereby determine amount of wear.**

1. **Precision-insert bearings.** Fit of the bearing to the crankpin may be checked in any of three ways, with Plastigage, feeler stock, or micrometer and telescope gauge. In addition, the amount of bearing wear can be checked with a micrometer and a piece of finished round bar stock (Fig. 14-12).

a. **Plastigage.** Plastigage is a plastic material that comes in strips and is soft enough to be flattened with pressure. When used to check bearing clearances, a strip of the material is put into the bearing cap; the cap is installed, tightened, and then removed. The amount that the Plastigage strip is flattened indicates the clearance. If it flattens only a little, clearance is large. But if it is flattened a great deal, the clearance is small.

Before the Plastigage is used, the cap bearing and crankpin should be wiped clean of oil and the crankshaft turned so that the
crankpin is about 30 degrees back of bottom dead center. Then a strip of Plastigage should be placed lengthwise in the center of the bearing cap (Fig. 14-13), and the cap should be replaced. After the nuts are tightened to the proper tension, the nuts and cap should be removed so that the amount of flattening of the Plastigage can be measured with the special scale supplied with the Plastigage (Fig. 14-13). If the amount of flattening indicates excessive bearing clearance, new bearings should be installed (§225).

**Caution:** Do not move the rod on the crankpin while the cap nuts are tight. This would further flatten the Plastigage and throw off the clearance measurement.

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**b. Feeler stock.** When feeler stock is used, a strip of it is placed lengthwise in the center of the bearing cap and lubricated with light engine oil. Then the cap is installed, the cap nuts tightened lightly, and the ease with which the rod may be moved endwise on the crankpin is noted. If the rod moves too easily, the clearance is excessive. Tighten the cap nuts a little more and recheck clearance. Continue this procedure until the nuts have been drawn down to the specified tightness or until the rod tightens up on the crankpin. If the rod tightens up, the clearance is less than the thickness of the feeler stock. If the rod does not tighten up, the
clearance is greater than the thickness of the feeler stock. In such case, additional thicknesses of feeler stock should be placed in the cap on top of the first piece of feeler stock (repeating the checking procedure with each additional thickness) until the actual bearing clearance is determined. Excessive clearance requires bearing replacement (§225).

c. Micrometer and telescope gauge. The crankpin diameter can be checked with a micrometer and the bearing bore checked (cap in place) with a telescope gauge and micrometer (or an inside micrometer). The two diameters can then be compared to deter-
When the rod bearings are of the type that use shims for adjustment, fit is checked by using a micrometer and telescope gauge (see 1 c, above) or by attempting to snap the rod back and forth on the crankpin with one hand (Fig. 14-14). With the clearance above the minimum, the rod should snap back and forth with the pressure of one hand. To check the clearance, remove the bearing cap and take off one shim from each side of the cap. Be sure that only one pair of shims is removed. Then replace the bearing cap and tighten nuts to the specified tension. If the rod still moves back and forth, remove another pair of shims and retest. Continue to remove shims until the rod will not move endwise on the crankshaft. Then add one shim to each side of the cap, replace and tighten the cap, and retest. Adjustment should now be correct.

**NOTE:** If a bearing is worn, pitted, scored, chipped, or otherwise damaged, the complete rod and cap should be replaced as a unit. Manufacturers of engines using this direct-babbitted type of bearing state that rods rebabbitted by ordinary methods may not provide normal service. Only rods babbed by the special techniques and machinery used at the factory should be installed on their engines.

§225. **Installing new precision connecting-rod bearings** New connecting-rod bearings are required in case the old ones have become defective (§223) or have worn so much that clearances are excessive. They are also required if the crankpins have worn out of round or tapered so much that they must be reground undersized. In this case, new undersize bearings are required. In addition, it is often the practice of engine rebuilders to replace the bearings in an engine when it is torn down regardless of whether or not the old bearings are in bad condition. Their reasoning is that it costs little more to put in the new bearings at the time that the engine is torn down. But if the engine had to be torn down especially for bearing installation, then the cost would be high. They believe it is cheap insurance against failure always to install new bearings during an engine rebuilding job.

1. **Checking the crankpins.** Regardless of whether the old bearings or new ones are to be installed, it is of great importance to check the crankpins with a micrometer to make sure that they are not excessively tapered or out of round. If crankpins are out of
round or tapered more than 0.0015 inch, the crankshaft must be replaced, or the crankpins reground (§241). Bearings working against out-of-roundness or taper of more than 0.0015 inch will not last long. And when bearings go, chances are the entire engine will be severely damaged. Measurements should be taken in various places along the crankpin to check for taper. The diameter should also be checked in various places all the way around the crankpin to determine the amount of eccentricity (or out-of-roundness).

2. Taper shim bearing adjuster. If the crankpins are not excessively out of round or tapered, yet there is excessive clearance, the best remedy is to install new bearing shells. Sometimes, however, the new bearings will not reduce clearances to specified limits. This calls for crankpin grinding and installation of new undersize bearings. There is, however, a compromise repair that can be made.

In case the value of the car does not warrant the more expensive but correct (from the engineering standpoint) crankpin-regrind and new-bearing job. This compromise involves the use of taper shim bearing adjusters (Fig. 14-15) under the bearing shells. These adjusters come in different thicknesses. The correct thickness must be selected for each bearing to give the proper oil clearance at that bearing. Note that the adjuster is tapered from the center to half thickness at the ends. The adjuster shown, for example, is 0.002 inch thick at the center \((C)\) but only 0.001 inch thick at the ends \((A \text{ and } B)\). Tapering is necessary so that the correction of clearance will be the same at the ends as at the center of the bearing shell. That is \(A + B = C\).

Note: This is not a "recommended" repair procedure, but a relatively inexpensive way to get some added mileage out of an old car. It should not be used in a late-model car since the small saving achieved is not worth the risk of subsequent bearing and engine failure.
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3. Installing new bearings. When new bearings are to be installed, make sure that your hands, the workbench, tools, and all engine parts are clean. Keep the new bearings wrapped up until you are ready to install them. Then handle them carefully, wiping each with a fresh piece of cleaning tissue (such as Kleenex) just before installing it. Be very sure that the bores in the cap and rod are clean and not excessively out of round. Then put the bearing shells in place. If they have locking tangs, make sure tangs enter the notches provided in the rod and cap. Note comments about bearing spread and crush, below. Check clearance after installation (§224).

Caution: Do not attempt to correct clearance by filing bearing cap. This destroys original relationship between cap and rod and will lead to early bearing failure.

4. Bearing spread. Bearing shells are usually manufactured with "spread," that is, with the shell diameter somewhat greater than the diameter of the rod cap or rod bore into which the shell will fit (Fig. 14-16). Then, when the shell is installed into the cap or rod, it will snap into place and will hold its seat during subsequent assembling operations.

5. Bearing crush. In order to make sure that the bearing shell will "snug down" into its bore in the rod cap or rod when the cap is installed, the bearings have crush (Fig. 14-17); that is, they are

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Some manufacturers recommend a check of bore symmetry with the bearing shells out. Cap should be attached with nuts drawn up to specified tension. Then a telescope gauge and micrometer or a special out-of-roundness gauge can be used to check the bore.
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manufactured to have some additional height over a full half. This additional height must be crushed down when the cap is installed. Crushing down the additional amount forces the shells into the bores in the cap and rod, assuring firm seating and snug contact with the bores.

Caution: Never file off the edges of the bearing shells in an attempt to remove crush. When you select the proper bearings for an engine (as recommended by the engine manufacturer) you will find that they have the correct crush. Precision-insert bearings must not be tampered with in any way in an attempt to make them “fit better.” This will usually lead only to rapid bearing failure.

CHECK YOUR PROGRESS

Progress Quiz 19

You are now deep in the part of the book that deals with engine service, and these periodic progress checks are more important to you than ever. The proof of your training is your ability to handle engine service; this part of the book is designed to give you the facts you need to be successful in engine-service work. Check yourself on how well you are remembering those facts by answering the questions below.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. With the bearing oil-leak detector in use, a bearing in normal condition should leak about 2 to 15 drops a minute 20 to 150 drops a second 20 to 150 drops a minute

2. One of the major reasons for removing the ridge from the top of the cylinder before taking out the piston is to keep from damaging piston pin breaking piston rings scratching cylinder wall breaking connecting rod

3. If piston-pin bushings have become worn so that they must be reamed or honed, then it will be satisfactory to use original piston pins new undersize piston pins new oversize piston pins

4. When honing piston-pin bushings, you should first rough-hone to

\[ \text{within } 0.0005 \text{ inch } 0.005 \text{ inch } 0.05 \text{ inch } \text{ of finished size} \]
5. The special tool specified by some manufacturers to swage, or expand, piston-pin bushings into place is called a burnisher, expander, expanding hone, reamer.

6. The material which flattens varying amounts to indicate the amount of bearing clearance is called feeler stock, shim stock.

7. Badly worn bearings of the direct-bonded type are serviced in the field by installing tapered shim adjusters, replacing connecting rod, replacing bearing shells.

8. Where clearance is excessive, but crankpin is not excessively tapered or out of round, a compromise repair can sometimes be made by installing a taper shim bearing adjuster, feeler stock, shim stock, a shell bearing adjuster.

9. The amount that the bearing-shell diameter is greater than the diameter of the bore into which it is placed is called the bearing crush, bearing spread, bearing diameter, bearing bore.

10. The additional height over a full half that the bearing shell has is called bearing crush, bearing spread, bearing diameter, bearing bore.

Unscrambling Causes of Bearing Failure

Listed to the left, below, are various types of bearing failure. Listed to the right, below, but not in the same order, are the causes of the failures. To unscramble the lists, take each type of bearing failure on the left in turn, and find the cause in the list to the right. Put the two together and write the result in your notebook. For example, the first bearing failure listed is "scratches in bearing metal." When you look down the list to the right, you come to "dirt in oil," which will cause this sort of bearing trouble. So you put the two together to get "scratches in bearing metal—dirt in oil."

- scratches in bearing metal
- bearing metal wiped out uniformly
- bearing metal wiped out on one side
- bearing metal wiped out at center
- bright spots on bearing metal
- craters flaked out
- bearing failure at edge
- tapered crankpin
- fatigue
- dirt under shell
- radius ride
- lack of oil
- dirt in oil
- crankpin ridged

§226. Pistons

Pistons are removed from the engine by taking out the piston and the connecting-rod assembly as a unit, as already described (§§218 and 219). If the assembly is removed from the
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top of the engine block, any ridge must first be removed with a ridge-removing tool (§218) in order to avoid damage to the piston or the rings. After the piston pin has been removed and the piston and rod separated, the piston rings should be removed. A special ring tool can be used for this operation (Fig. 14-18). The ring tool usually employed has two small claws that catch under the ends of the ring at the ring gap. When pressure is applied to the tool handle, the ends of the ring are forced apart so that the ring is sprung enough to pass over the piston head.

1. Piston cleaning. After the rings have been removed, the piston should be cleaned inside and out before further examination is made to determine whether it can be reinstalled in the engine.

Even if the old piston is in good enough condition to be reinstalled, a new piston may be required if the cylinder into which the piston is to be reassembled is so worn that it must be bored to a larger diameter. Oversize pistons are available for installation in refinished cylinders. In some cases, where cylinder diameters have not been increased too greatly, the old pistons may be resized to increase their diameters and thus improve the fit. Piston resizing is discussed on a following page.

When pistons are cleaned, a carbon scraper should be used to scrape the carbon from the head and from the inside of the piston. However, the piston skirts, or sides, should not be scraped since this might scratch the finish and thereby cause rapid cylinder-wall and piston wear. The ring grooves should be cleaned out with a groove clean-out tool as shown in Fig. 14-19. This device pulls a cleaning tool through the groove to remove accumulated carbon. Care must
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be used to prevent removal of material from the ring lands of the piston since this might cause an excessively loose ring fit. The oil holes in the oil-ring grooves should be cleaned out so that oil can drain through them properly. A drill is handy to use for this operation if the holes are badly carboned. The drill should just fit the holes but should not remove metal from the piston.

A piston vise (Fig. 14-20) should always be used whenever it is necessary to hold the piston firmly. An ordinary vise is not satisfactory; it may not only damage the piston finish but also distort the piston so much that it will be ruined.

Fig. 14-19. Groove clean-out tool in use on piston-ring grooves.

2. Piston fit. The size of the piston should be measured with a micrometer (Fig. 14-21) after it has been cleaned. The measurements should be taken at various places in order to determine whether the piston has worn excessively or has "collapsed." Piston measurements should be compared with cylinder measurements (taken as explained in §244) to determine whether or not correct clearances exist. The engine manufacturer's shop manual should be consulted for details of measurements and allowable clearances as well as for maximum allowable piston and cylinder-wall taper.

Many engines use cam-ground pistons (Figs. 7-22 and 7-23).

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A piston that has "collapsed" has suffered an excessive reduction in diameter at the lower end of the piston skirt. The piston is tapered.
Cam-ground pistons are not round when cold but are slightly elliptical in shape. On this type of piston, the measurements for taper are usually taken at the larger diameter or in a direction perpendicular to the piston-pin holes. Measurements should be taken close to the top and to the bottom of the piston.
The fit of the piston to the cylinder must be very accurately determined. This fit can be measured with a piece of feeler stock of the proper thickness. Some engine manufacturers recommend the use of a spring scale in checking piston-to-cylinder fit. The piston is inserted in the cylinder upside down with the feeler stock (lightly oiled) placed at right angles to and 90 degrees from the piston-pin holes. The fit is thus measured at the point of greatest piston diameter. When a scale is used, the amount of force required to pull the feeler stock out is measured (Fig. 14-22). As an example, on the Oldsmobile six-cylinder engine, a ribbon of feeler stock ½ inch wide by 12 inches long by 0.0015 inch thick should be withdrawn from between the piston and cylinder wall with a pull of between 7 and 20 pounds. The feeler stock should be placed at a point 90 degrees from the piston-pin holes. If the feeler stock pulls out too easily, the fit is too loose. If it pulls out too hard, the fit is too tight.

If the piston is too loose in the cylinder, a new piston or piston resizing is necessary to reestablish the close fit required. As pre-
viously mentioned, if the cylinder is so worn that it must be re-bored or honed (see §§245 to 249), then new pistons probably will be required. If, however, the increase in cylinder size is not too great, the piston can be resized (made larger in diameter) so that it will fit the enlarged cylinder. The actual amount that a piston can be increased in diameter varies with the type of resizing tool used as well as the type of piston and piston material. Furthermore, not all engineers agree on the amount of resizing that a piston can safely take and still provide normal service in the engine. In any event, no resizing method in use today could increase piston diam-

Fig. 14-23. Simple type of piston resizer. Pressure between inner and outer roller wheels squeezes metal and expands skirt. (Sealed Power Corporation)

eter enough for it to fit a 0.060 inch oversize cylinder. But the actual top limit, or maximum piston-diameter increase, will probably vary with local conditions and experience in different parts of the country.

One simple type of piston resizing tool is shown in Fig. 14-23. This tool has inner and outer roller wheels that roll under pressure on the piston skirt as the tool is moved back and forth. This squeezes the metal and expands the skirt. Another type of piston resizing tool, called the Nutlizer, is shown in Fig. 14-24. This tool has a knurling wheel (which looks like a small gear) which is rolled, under pressure, on the piston skirt. The skirt is expanded by this action and at the same time an interrupted surface is left
Fig. 14-24. The Nurlizer, a piston-resizing tool which uses a knurling wheel. (a) Piston in Nurlizer. (b) End view (top of piston cut off) to show effect of knurling wheel. (Perfect Circle Company)

Fig. 14-25. Piston-skirt expander. (Ramsey Accessories Manufacturing Corporation)

(similar to the surface found on the edge of a silver coin). Tests have shown that this interrupted surface resists scuffing and scoring, thereby improving the piston life.

In addition to the piston resizing tools, there are piston expanders that serve a similar purpose (Fig. 14-25). These are spring devices that are installed permanently in the piston and exert spring pres-
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sure on the piston skirt so that the skirt increases slightly in diameter.

New pistons are supplied either finished or semifinished. The finished pistons are ready for installation and are available in a number of sizes. When these are used, the cylinder must be finished to fit the piston (§§245 to 248). Semifinished pistons are oversize and must be finished down to size to fit the cylinder. When the pistons are cam-ground, special cam-grinding equipment must be used to finish the pistons to size. However, finished pistons have a special finish and should not be turned down or finished undersized. This would remove the finish, thereby producing rapid piston wear after installation.

§227. Fitting piston pins If the piston-pin bushings are worn, they should be reamed or honed oversized (Fig. 14-26) and oversize pins installed. The pins should be replaced if they are worn or

Fig. 14-26. Piston-pin bushings being honed. (Sunnen Products Company) [422]
pitted. The reaming and honing procedures are very similar to those used to ream or hone piston-pin bushings in connecting rods (§221). Where the pin is of the type that floats, or turns, in the piston-pin bushing, the fit is correct if the pin will pass through with light thumb pressure when both piston and pin are at room temperature.

Fig. 14-27. Using special hydraulic cylinder to assure correct pressure on piston pin as it is forced into piston-pin bosses. On the engine piston shown, specifications call for a pressure of between 200 and 350 pounds. (Pontiac Motor Division of General Motors Corporation)

Fig. 14-28. Using pilot tool to help install piston pin in piston and connecting rod. On the engine piston illustrated, specifications call for heating the piston to 180°F and then installing the pin as shown. (Studebaker-Packard Corporation)
Fitting piston rings

Piston rings must be fitted to the cylinder and to the ring groove in the piston. As a first step, the ring should be pushed down into the cylinder with a piston, and the ring gap (or space between ends of the ring) checked with a feeler gauge (Fig. 14-29). If the ring gap is too small, the ends of the ring should be filed with a fine-cut file. The file should be clamped into a vise and the ring worked back and forth on the file (with the ring ends on the two sides of the file). Use care to avoid distorting the ring.

Caution: If the cylinder is worn tapered, the diameter at the lower limit of ring travel (in the assembled engine) will be smaller than

Fig. 14-29. Ring gap being measured with ring in cylinder. 1, feeler gauge; 2, piston ring. (Plymouth Division of Chrysler Corporation)
the diameter at the top (Fig. 15-14). In this type of cylinder the ring must be fitted to the diameter at the lower limit of ring travel. If fitted to the upper part of the cylinder, the ring gap will not be great enough as the ring is moved down to its lower limit of travel. This means that the ring ends will come together and the ring will be broken or the cylinder walls scuffed. In tapered cylinders file

![Image](image_url)

Fig. 14-30. Checking fit of ring in ring groove. (Chevrolet Motor Division of General Motors Corporation)

Fig. 14-31. Piston-ring clearance being tested with gauge. (Chevrolet Motor Division of General Motors Corporation)
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the ring gap so that the ring fits the cylinder at the point of minimum diameter, or the lower limit of ring travel.

After the ring gap has been corrected, the outside surface of the ring should be inserted into the proper ring groove in the piston and the ring rolled around in the groove to make sure that the ring has a free fit around the entire piston circumference (Fig. 14-30). An excessively tight fit probably means that the ring groove is dirty, and it should be cleaned (Fig. 14-19). After the rings are installed in the ring groove (using the ring tool as shown in Fig. 14-18), fit should again be tested. This test is made by inserting a feeler gauge between the ring and the side of the groove (Fig. 14-31).

§229. Rod and piston alignment  After assembly of the connecting rod to the piston, but before installation of the rings in the piston

Fig. 14-32. Checking connecting-rod and piston alignment with alignment-checking tool. (Chevrolet Motor Division of General Motors Corporation) [426]
grooves, the rod and piston alignment should be checked on the rod-alignment tool (Fig. 14-6) as shown in Fig. 14-32. If the V block does not line up with the faceplate as the piston is moved to various positions, the connecting rod is twisted. It is often possible to straighten out a misaligned connecting rod (see §220).

§230. Installing piston in cylinder To install the piston in the cylinder after the piston, rings, and rod are reassembled, it is necessary to compress the rings in their grooves so that they will enter the cylinder. A piston-ring compressor (Fig. 14-33) may be used for this operation. The compressor clamps around the rings, compressing them into their grooves so that the piston and ring assembly can be pushed into the cylinder. See §219, 4 for replacement procedure on rod and piston assemblies.

§231. Piston rings If an engine is torn down for major overhaul after reasonably long mileage, it is probable that the piston rings will require replacement. Sometimes, however, it may be found that new rings have been only recently installed on the engine, and they will need only to be freed in the ring grooves and cleaned up. Special compounds that can be introduced into the intake manifold and engine oil to free piston rings without tearing down the engine have already been mentioned (§201).

In the examination of piston rings to determine whether they will require replacement, several conditions may be found. Rings that show irregular light and black areas are warped or worn and should be discarded. If the cylinder sides of the rings are scored, they should be replaced. If the rings seem to lack tension, that is, require
but little pressure to compress them until the ring gap is closed, the ring should not be used again. As a rule, it is considered best practice to install new rings during engine overhaul. This avoids the possibility of trouble due to worn rings.

The proper selection of new rings depends upon the condition of the cylinder walls and whether the cylinder walls are to be reconditioned. Section 244 describes the procedure of checking the cylinder walls for wear and taper. If they are only slightly out of round or have only a slight taper (consult manufacturer's manual for the maximum allowable out-of-round or taper), new standard-type rings can be installed. Where the walls have some taper, and it is not considered enough to warrant the extra expense of a rebore or hone job (see §§245 to 249), special compression and oil-control rings should be used. The more taper the cylinder walls have, the more difficult it is for the rings to follow the changing contour and diameter to provide proper sealing and oil control. Expanders

[Fig. 14-34. Disassembled view of one type of replacement piston rings. Number 1 is the top compression ring; 2 is the second compression ring, which includes an expander ring; 3 is the upper oil-control ring; while 4 is the lower oil-control ring. The latter is of a three-part construction; it consists of an upper and lower rail with an expanding spring. (Plymouth Division of Chrysler Corporation)]
under one or more of the compression rings and special lightweight, spring-loaded oil-control rings help provide satisfactory operation with tapered walls. Figure 7-17 illustrates a set of replacement rings of this combination, while Fig. 14-34 shows an exploded view of the rings. Such rings are often called severe or drastic rings because of the higher ring pressures used; this means that the rings can work under more severe operating conditions (or against greater taper).

Servicemen and engineers are not all agreed about the amount of taper that severe rings will handle. Some enginemen are more conservative than others, and would prefer to rebore or hone cylinders with considerable taper, rather than to use drastic rings. At least one replacement-ring manufacturer says that his replacement rings are designed to give satisfactory compression sealing and oil control in cylinders with as much as 0.015-inch taper (that is, 0.015 inch larger in diameter at the top than at the bottom of ring travel). But all agree that even the most drastic rings will not perform satisfactorily if taper is excessively high.

NOTE: It may or may not be necessary to hone the cylinder walls lightly before ring installation to "break the glaze" as explained in §247. Cylinder walls take on a hard, smooth glaze after the engine has been in use for a while. It is the practice of some engine servicemen to knock off this glaze by running a hone up and down in the cylinder a few times before putting in the new rings. However, at least one ring manufacturer says that this does not need to be done on cast-iron cylinder walls, provided the walls are not wavy or scuffed. The glaze is a good anti-scuff material and will not unduly retard wear-in of new rings if the walls are reasonably concentric and in relatively good condition.

CHECK YOUR PROGRESS

Progress Quiz 20

Here is your own personal checkup quiz on the latter half of Chap. 14. Answering the questions below will tell you how well you have retained the material you have just read. If any of the questions cause you trouble, you should reread the section that will give you the answer.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sen-
1. A piston that has collapsed has lost diameter at the head bosses skirt.

2. The fit of the piston to the cylinder is measured at the piston skirt point of minimum diameter piston head.

3. No piston-resizing method in use today could increase piston diameter enough for it to fit a cylinder that is oversize 0.006 inch 0.006 inch 0.060 inch.

4. The piston resizer that uses a knurling wheel to leave an interrupted surface on the piston skirt is called a coiner gear wheel Nurlizer scuffer.

5. The first step in installing new piston rings is to check the ring gap on the piston in the cylinder on the bench in a vise.

6. When oversize pistons of the finished type are to be installed on an engine, the correct piston clearance is attained by refinishing the cylinder refinishing the piston installing piston expander knurling the piston.

7. One of the major factors in determining whether drastic rings will be required on an engine is the amount of piston taper cylinder taper cylinder-wall thickness.

8. At least one ring manufacturer states that his replacement rings will work satisfactorily in cylinders that have a taper of as much as 0.0015 inch 0.015 inch 0.150 inch.

9. Rings for use in tapered cylinders are called tension, or heavy, rings hard, or tension, rings severe, or drastic, rings.

10. It is often the practice to use a hone in the cylinders before installing new rings to reduce the friction break the glaze scuff the walls.

CHAPTER CHECKUP

Note: Since the following is a chapter review test, you should review the chapter before taking the test.

You have made excellent progress in the engine-servicing section of the book and have now completed a good part of the section. The material you are now studying is really the heart of the subject since it deals with the various service jobs that are required to correct different engine troubles. It is important for you to remember the details of these various service jobs. The checkup below will give you the chance to test yourself and find out how well you remember the way these service jobs are done.
Connecting-rod, Piston, and Ring Service

Completing the Sentence

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write down each sentence in your notebook, selecting the proper word or phrase to complete it correctly.

1. Items that must be removed before the pistons can be taken out of the engine are **rings, piston pin, and head** head, oil pan, and ridge (if present) head, block, and oil pan
2. One group of parts removed from the engine as an assembly includes the piston, pin, rings, and rod piston, rod cap, rings, and valve head, rod, valves, and lifters
3. A ring compressor should be used when reinstalling the piston and rod assembly in the engine to compress the piston rings so that they will not catch on rod enter cylinder mate with piston pin
4. When checking connecting rods, items to be considered include ring fit, bushings, pins, and alignment bushings, bearings, pins, and rings bushings, bearings, oil hole, and alignment
5. Two methods of checking clearance of a precision-insert bearing are by using Plastigage and taper shim Plastigage and adjuster Plastigage and feeler stock
6. Two characteristics of precision bearings that help to install them properly are spread and crush bore and spread pitch and crush bore and pitch
7. The direct-bonded type of connecting-rod bearing can be adjusted by filing the shells filing the caps removing or installing shims
8. Severe, or drastic, rings are for use in tampered cylinders with tapered pistons with collapsed pistons in tapered cylinders
9. In fitting rings to tapered cylinders, ring gap is measured with the ring located at point of maximum diameter top of cylinder bottom of cylinder point of minimum diameter
10. If the cylinder is in good condition, but the piston clearance is excessive, piston fit can be improved by honing cylinder installing new rings Nurlizing piston

Service Procedures

In the following, you should write down in your notebook the procedures asked for. Do not copy them from the book, but try to write them in
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Your own words. Give a step-by-step account. This will help you remember the procedures when you go into the engine shop.

1. Explain how to remove a piston and rod assembly from an engine.
2. List various connecting-rod-bearing troubles and their causes.
3. Explain how to install and ream, or hone, a set of piston-pin bushings in the connecting rods.
4. Explain how to check the fit of a precision-insert bearing with Plastigage and with feeler stock.
5. List the steps in replacing a precision-insert rod bearing.
6. Explain how to check piston fit in a cylinder.
7. Explain how to fit piston rings.
8. List important points of selecting new rings for a job.

SUGGESTIONS FOR FURTHER STUDY

Always keep your eyes and ears open while you are in the engine shop. Notice how the different jobs are done, and pay particular attention to the methods of testing, removing, servicing, and replacing engine parts. Always examine all the defective parts you can find, and notice particularly exactly why the parts are defective. If you are not sure, ask someone why the part was discarded. Soon you will learn to spot defects quickly and easily. Study the operating manuals of the different service equipment. For instance, the honing-equipment manufacturer supplies an operating manual that explains what his machine will do and how to operate it. You will find such manuals of great interest. Keep a notebook and jot down every important fact that you learn while you are in the shop or while you are studying the different manuals. Jotting down these facts will help you remember them. Also, it will increase the value of the notebook to you.
15: Crankshaft and cylinder service

THIS CHAPTER continues the discussion of engine service and describes crankshaft removal, service, and replacement, and main-bearing and cylinder service. The information in §§197 and 198 on tools and cleanliness apply to the services discussed in this chapter as well. It is of the utmost importance to keep engine parts clean during service operations on them and to make sure the parts are absolutely clean when they are restored to the engine. Many otherwise perfect engine-service jobs have been ruined by dirt or abrasive carelessly left in the engine or on engine parts.

§232. Crankshaft service Main bearings of the precision-insert type can be replaced without crankshaft removal (§237). Thus it is necessary to remove the crankshaft from the engine only if it is worn or damaged, or during a major engine overhaul. However, with bearings of the type that require finishing after installation, the crankshaft must be removed so that the new bearings can be installed and then line-bored (§239). Replacing precision-insert main bearings without removing the crankshaft requires about 5 hours. To remove the crankshaft and install, fit, and adjust main bearing requires approximately 19 hours on six-cylinder engines and as many as 22 hours on eight-cylinder engines.

§233. Checking crankshaft and bearings in place Crankshaft journals and crankpins, as well as main bearings, can be given a preliminary check without removal of the crankshaft. The procedure of checking crankpins (after detachment of connecting rods) has already been discussed. You can get a good idea of the condition of the bearings by using the bearing oil-leak detector (described in §217); this device supplies oil under pressure to the bearings. Excessive leakage of oil from any bearing indicates that the bearing

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has excessive clearance and is probably worn. The discussion of connecting-rod bearing failures (§223) also applies to main bearings. Checking main-bearing fit is described in §236. The following section describes the procedure of checking crankshaft journals with the crankshaft in the engine, while §241 describes the checking and servicing of the crankshaft after it is off the engine.

§234. Checking crankshaft journals on engine

There are two ways to measure crankshaft journals without removing the crankshaft from the engine. One requires a special crankshaft gauge, the other a special micrometer. Regardless of the method, it is of great importance to take several measurements along the journal to check for taper. Also, rotate the crankshaft by quarter or eighth turns so that additional measurements can be taken to check for out-of-round wear. Note whether the journals are ridged, tapered, or out of round (see §223 for explanations of what a ridged, out-of-round, or tapered journal will do to a bearing). A crankshaft with journals tapered or out of round by more than 0.003 inch should have a journal-regrind job. As a matter of fact, a taper or eccentricity of 0.0015 inch is considered excessive by many authorities who point out that any appreciable out-of-roundness or taper will shorten bearing life. Measurements are made after removing the oil pan and bearing caps. It is not necessary to detach the connecting rods from the crankshaft. However, the spark plugs should be removed so that the crankshaft can be turned easily; this relieves cylinder compression. Oil-pan removal has already been discussed (§218).

1. Removing bearing caps. Bearing caps should all be marked so that they can be replaced on the same journals from which they were removed. As a first step in cap removal, loosen the nuts or bolts. The nuts or bolts are sometimes locked in place by lock wires that must be cut or by lock-washer tangs that must be bent out of the way before the nuts or bolts can be loosened. Oil lines, where present, must be disconnected.

   Note: New tang lock washers or lock wires must be used on reassembly.

   If the bearing caps stick, they must be worked loose carefully to avoid distorting them. In some engines bearing-cap pullers can be used. The puller bolt is screwed into the oil-coupling bolt hole. In other engines a screw driver or a pry bar can be used to pry the
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cap loose. Also, a brass hammer can be used to tap the cap lightly on one side and then on the other so that it is worked loose.

**Caution:** The caps must be removed with care. Heavy prying or hammering will distort the cap, bend the dowels, or damage the dowel holes. In such case, the bearing may not fit when the cap is replaced, with the result that bearing failure would soon occur.

Do not take off all bearing caps at one time unless the crankshaft is to come out. Take them off one at a time to check journals and bearing fit as explained below.

2. **Measuring journal with special crankshaft gauge.** The special gauge (Fig. 15-1) can be used to measure crankshaft-journal diameter. To use the gauge, first make sure that the crankshaft journal and the gauge pads and plunger are thoroughly clean. Then turn the plunger in by turning the thumbscrew. Push the gauge up against the shaft journal and rock it slightly to make sure that the pads are seated tightly on the shaft. Hold the gauge firmly against the journal, and loosen the thumbscrew so that the plunger moves up against the journal (Fig. 15-2). Turn the thumbscrew back and
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forth several times and then tighten it. If this is done properly, the plunger will be held in the position at which it and the two pads touch the journal simultaneously. Use a micrometer to measure accurately between the plunger (D in Fig. 15-2) and the button (C in Fig. 15-2). Multiply the reading by two to get the actual diameter of the journal.¹

![Fig. 15-3. Installing a new main upper bearing with a special “roll-out” tool inserted into the crankshaft oil hole. 1, special tool; 2, main bearing. (Plymouth Division of Chrysler Corporation)](image)

3. Measuring journal with special micrometer. To use the special micrometer on the crankshaft journal, the bearing must be removed. If the bearing is of the precision-insert type, the upper shell can be removed by the use of a special “roll-out” tool as shown in Fig. 15-3. The roll-out tool is inserted into the oil hole in the crankshaft.

¹ If you are interested in the geometry of the gauge, note the following, and refer to Fig. 15-2.

\[2AO = OC\] (In 30-degree right triangle, hypotenuse \(OC\) is twice side opposite 30-degree angle)

\[2OD = OC = OD + DC\]

\[OD = DC\]

Since \(DC\) is therefore equal to the radius of the journal, \(2DC\) equals the diameter of the journal.

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Then the crankshaft is rotated, and the tool is carried around with it to force the bearing shell out of the bore in the cylinder block. Be sure to turn the crankshaft so that the lock, or tang, on the shell (where present) is raised up out of the notch in the cylinder block.

With the bearing shell removed, the special micrometer can be used as shown in Fig. 15-4 to measure journal diameter.

![Figure 15-4: Crankshaft-journal diameter being measured with special micrometer.](image)

**Note:** The illustration (Fig. 15-3) actually shows an upper shell being installed. However, the principle is the same whether the shell is being removed or installed.

§235. **Checking main or crankshaft bearings** Sections 102 to 109 describe engine bearings in some detail. Main bearings are of two types, precision-insert and semifinished. Precision-insert bearings can be serviced (if journals are in good condition) by replacement of the bearing shells. It is not absolutely necessary to remove the crankshaft for this operation, although authorities caution that replacing bearing shells without removing the crankshaft is not the
best policy. They point out that you are, in a way, working blind when doing this and cannot be sure that the counterbore in the cylinder block is perfectly clean and that the shell is seating tightly in the counterbore. However, when replacing the semifitted type of main bearing, the crankshaft must come out; these bearings must be line-bored after installation.

Main bearings should be replaced if they are worn, burned, scored, rough, pitted, flaked, cracked, or otherwise damaged. The information on bearing failures in §223 also applies to main bearings. It is extremely important to check the crankshaft journals before installing new bearings (see §234). New bearings will fail rapidly if they are installed around journals that are out of round, rough, or tapered to any extent. A crankshaft with out-of-round, rough, or tapered journals should be removed from the engine so that the journals can be ground undersized. Then, new undersize bearings must be installed.

The procedure of checking bearing fit is discussed in the following section.

NOTE: If one main bearing requires replacement, then all main bearings should be replaced, even if the others appear to be in good condition. If only one main bearing were replaced, crankshaft alignment might be lost and this would overload certain bearings, causing them to fail rapidly.

§236. Checking main-bearing fit

Bearing fit (or oil clearance) should always be checked when new bearings are installed. Of course, bearing fit should also be checked at other times when the condition of the bearings is being determined. When the bearing caps are off, the journals should be measured so that wear, out-of-roundness, or taper can be detected.

1. Precision-insert type. Bearing clearance can be checked either with feeler stock or with Plastigage. Plastigage is a plastic material that is flattened by pressure. When used to check clearances, the amount of flattening indicates the amount of clearance, as explained below.

a. With feeler stock. When feeler stock is used to check main-bearing clearances, a piece of stock of the correct size and thickness

1 A compromise repair can be made when journals and bearings are in good condition but have too much clearance, by using taper shim bearing adjusters as explained in §225.
should be placed in the bearing cap after it is removed (Fig. 15-5). The feeler stock should be lightly coated with oil. The bearing cap should then be replaced and tightened. Note the ease with which the crankshaft can be turned. If it drags noticeably, bearing clearance is less than the thickness of the feeler stock. If it does not, an additional thickness of feeler stock can be placed on top of the first and the ease of crankshaft movement again checked. Clearance normally should be about 0.002 inch (see engine manufacturer's shop manual for exact specifications).

b. With Plastigage. When Plastigage is used to check bearing clearance, the journal and the bearing should be wiped clean of oil. A strip of the Plastigage is placed lengthwise in the center of the bearing cap (Fig. 14-13), and the cap is installed and tightened into place. When the cap is removed, the amount of flattening of the strip can be noted and measured with a special scale (Fig. 14-13). The flattened strip should not be removed from the cap or
the journal to measure the width, but it should be measured in place, as shown. Not only does the amount of flattening measure bearing clearance, but also uneven flattening would indicate a tapered or worn crankshaft journal or bearing.

**Caution:** The crankshaft must not be turned with the Plastigage in place.

2. **Semifitted (shim-adjusted) main-bearing type.** On the shim-adjustment type of main bearing all bearing caps should be loosened enough to permit the crankshaft to turn freely. The rear main-bearing cap should then be taken off and one shim removed from each side of the cap. The cap should then be replaced and the cap bolts tightened. The crankshaft should be rotated to note any tendency for it to drag. If it does not drag, additional shims (in pairs) should be removed until a drag is noted. Then one shim should be replaced on each side of the bearing cap. If the crankshaft now turns freely when the cap bolts are tightened, that bearing has been correctly adjusted. Next loosen bolts on the bearing that has been adjusted and adjust the adjacent main bearing. Continue to adjust main bearings until all are adjusted. Finally, with all bearing caps [440]
tight, note any tendency for the crankshaft to drag. If it drags, recheck and readjust the bearings.

3. Checking crankshaft end play. Crankshaft end play will become excessive if the end-thrust bearings are worn. This produces a noticeable sharp, irregular knock. If the wear is considerable, the knock will occur every time the clutch is released and applied; this action causes sudden endwise movement of the crankshaft. End play should be only a few thousandths of an inch (see engine manufacturer’s shop manuals for exact specification) and is measured by forcing the crankshaft endwise as far as it will go with a pry bar and then measuring the clearance at the end-thrust bearing with a feeler gauge (Fig. 15-6).

§237. Replacing precision-insert main bearings

Precision-insert main bearings may be replaced without removing the crankshaft from the engine. One bearing should be worked on at a time, with all other bearing caps loose to facilitate the replacement operation. With the bearing cap off, insert a bearing-removing (or "roll-out") tool into the oil hole in the crankshaft journal (Fig. 15-3). Then rotate the crankshaft so that the bearing shell rotates with it and is turned out of its bore. Be sure to rotate the crankshaft in the proper direction so that the lock, or tang, in the bearing is raised out of the notch in the cylinder block. With the shell out the special micrometer (Fig. 15-4) or the special gauge (Fig. 15-1) should be used to measure the journal. Measurements should be taken from one end to the other of the journal to check for taper. In addition, the crankshaft should be rotated by quarter or eighth turns so that the journal can be checked for out-of-round wear. Excessive taper or wear requires removal of the crankshaft for journal grinding; new undersize bearings should then be installed.

To install a new bearing, first coat the upper shell with engine oil and make sure the bore in the cylinder block is clean. Do not file the edges of the shell if they protrude slightly above the block surface, since they will crush down to provide proper fit. Use the tool as shown in Fig. 15-3 to slide the bearing shell into place. After the upper shell is in place, a new lower shell is put into the bearing cap and the cap installed on the block. The nuts or bolts should be drawn up to the proper tension with a torque wrench. Tap the crown of the bearing cap lightly with a brass hammer several times.
while tightening the bolts or nuts; this helps the bearing to align properly. After all bearing caps are in place, bearing fit should be checked as outlined in the previous article.

While removing and replacing the upper bearing shell of a rear main bearing, hold the oil seal in place in the cylinder block to prevent it from moving out of position.

**Caution:** Remember what we said in the first paragraph of §235 about replacing bearing shells without removing the crankshaft. Some authorities, as we mentioned, do not advocate this. They say that you are working blind and may not get the upper bearing shell properly seated in the bore. Thus if you do the job this way, you must be very clean and very careful; bearing shells must seat snugly in the bore.

As mentioned above, bearing fit should be checked after all bearing caps have been replaced. If excessive bearing clearances are found after new bearings are installed, it means that the journals are worn, and this requires removal of the crankshaft for journal grinding. (Measuring the journals as explained in §234 should have disclosed the worn condition before new bearings were installed.) Bearings are available in several undersizes. The journals should be ground down enough to remove the imperfections; then an additional amount should be ground off so that the journals will fit the next undersize bearings.

On all but a very few engines precision-insert bearings are installed without shims. Unless the engine manufacturer’s shop manual specifically states that shims must be used with the precision-insert bearings in their engine, they must not be installed. Similarly, bearing caps must not be filed in an attempt to improve bearing fit.

§238. Replacing main-bearing oil seal

An oil seal is required at the rear main bearing to prevent oil leakage at that point (Fig. 15-7). When main-bearing service is being performed, or whenever leakage is noted at the rear main bearing, the oil seal must be replaced.

The procedure of replacement varies with different constructions. On some engines using a split-type oil seal the crankshaft must be removed and a special oil-seal compressor or installer used to insert the new seal in the cylinder-block bearing. The seal should
then be trimmed flush with the block as shown in Fig. 15-8. The oil seal in the cap can be replaced by removing the cap, installing the oil seal, and trimming it flush. On other engines (the type shown in Fig. 15-7, for example) it is not necessary to remove the crankshaft, since removal of the flywheel will permit access to the upper oil-seal retainer. Retainer cap screws can then be removed along with the retainer for oil-seal replacement. Some engines use a one-piece rubber-type oil seal which can be pulled from around the crankshaft with a pair of pliers, and a new oil seal then worked into place. It should be coated with cup grease (except on the ends, since this would prevent the ends from meeting tightly) and one end of the seal should be forced up into the slot on one side until it is at the top of the bearing. Then the other end can be forced up into the slot on the opposite side, so that the ends meet at the top of the bearing.

Fig. 15-7. Crankshaft rear-main-bearing oil seal. 1, oil seal; 2, left cap gasket; 3, right cap gasket; 4, oil seal. (Plymouth Division of Chrysler Corporation)
§239, Replacing semifitted bearings In replacing bearings that require machining after installation, the crankshaft must be removed (§240) so that the new bearings can be machined to size. A special boring machine is required for this operation (Fig. 15-9).

In addition to machining the bearing diameters, the end-thrust-bearing faces must be machined or “faced” to provide the correct amount of crankshaft end play. An attachment on the boring machine permits facing of the end-thrust bearings (Fig. 15-10).

After the machining operation is completed and the engine cleaned, the main bearings must be adjusted. To do this, replace the crankshaft and install the main-bearing caps with several shims of 0.002-inch stock (or shim packs) on both sides of each cap. Make sure that the crankshaft turns freely. Then, starting with the rear bearing and working on one bearing at a time, take one shim from each side of a bearing cap, replace and fasten down the cap, and test the crankshaft for freeness of rotation. Continue to remove shims in pairs from a bearing until a slight drag is felt as the crankshaft is rotated. Then replace one shim on each side, replace and bolt down the cap, and test again. If the crankshaft rotates freely,
§240. Removing and replacing crankshaft  Before the crankshaft is removed, several other engine parts must be off the engine. The oil pan must be detached, the timing gear or timing-chain cover must be removed and the gear or sprocket taken off the crankshaft. These operations have already been described on previous pages.

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loosen cap bolts and adjust the next main bearing in the same manner until all have been adjusted. Then tighten all cap bolts and see if the shaft turns freely. If it does, bearing clearances are properly adjusted. If it does not, loosen all cap bolts and recheck each bearing separately.

Fig. 15-9. Main-bearing boring machine installed on engine: 1, 2, 3, 4, and 5 are the supporting clamps, bolts, and bearings; 6 is the boring bar; 7, 8, and 9 comprise the feed-screw arrangement; 10 is the turning handle, and the items marked 11 are the boring-bar cutters. (Chevrolet Motor Division of General Motors Corporation)
Interfering oil lines and usually the oil pump as well must be removed (see below). Oil lines are usually attached with coupling nuts. These should be carefully loosened with two wrenches in order to avoid twisting and damaging the tube.

**Note:** During a complete engine overhaul, the cylinder head and the rod and piston assemblies are removed. At other times, if only the crankshaft is being removed, it may not be considered necessary to remove the rod and piston assemblies. In such case, it would be necessary only to take off the rod caps and push the pistons and rods up into the cylinders so that they are out of the way. Be sure to replace the rod caps on the same rods from which they were removed.

![Fig. 15-10. Facing end-thrust bearing with facing cutters. (Chevrolet Motor Division of General Motors Corporation)](image)

1. **Removing oil pump.** Oil pumps that are mounted in the crankcase usually will interfere with crankshaft removal and must therefore, be taken out before the crankshaft can be removed. The procedure of oil-pump removal varies somewhat with different engines. Usually the pump is easily removed by disconnecting oil lines and taking out the lock screws, bolts, or nuts holding the pump in place. Note that on some oil pumps the drive gear is on the pump shaft [446]
and that this gear also drives the ignition distributor. If only the oil pump is being removed, great care is necessary to avoid disturbing the ignition timing. The distributor and camshaft should not be moved at all with the oil pump off. And then, when the oil pump is replaced, its drive shaft should realign correctly with the distributor shaft tang. Of course, with a major overhaul in prospect, so that both the distributor and crankshaft are off the block, this caution is not necessary, since retiming of the ignition will be required when the engine is reassembled.

2. Removing bearing caps and crankshaft. The procedure of removing bearing caps has already been described (§234). As the bearing caps are loosened and removed, the crankshaft will come free, provided all other components have been detached as already noted. In some cases, the flywheel must be removed separately from the crankshaft before the bearing caps are removed.

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§241. Checking and servicing crankshaft After the crankshaft has been removed from the engine, it should be carefully inspected and tested for alignment and for journal and crankpin wear and roughness. Alignment can be checked with the setup shown in Fig. 15-11. The crankshaft is supported in V blocks and slowly rotated, with the finger of the dial indicator resting on one of the journals. Any out-of-alignment will cause movement of the dial-indicator needle. If the crankshaft is out of line, it can usually be straightened in a heavy press. To avoid scratching the journals that are supporting
the crankshaft in the V blocks, make sure that the V blocks are clean and smooth. Oil them lightly.

**Caution:** Do not leave a crankshaft supported only at the ends as shown in Fig. 15-11. After a period of time the crankshaft may begin to sag from its own weight and will get out of alignment. Prevent this by supporting the crankshaft on wood blocks of equal thickness placed under each journal, or set the crankshaft on end.

In normal operation greatly varying loads and thrusts are imposed on the crankshaft main journals and crankpins and this may cause the journals and crankpins to wear tapered or out of round. In addition, where bearings of the partial-oil-groove type are used, the crankpin or journal may ridge, or cam, as already explained (§223, 7). A micrometer or crankshaft gauge should be used to check both journals and crankpins carefully for any of these types of wear (§234). At the same time, the bearing surfaces should be inspected for roughness. Roughness or excessive taper or out-of-roundness requires journal or crankpin grinding and subsequent installation of undersize bearings. Many authorities consider a taper or eccentricity of more than 0.0015 inch as excessive. Journals and crankpins must be ground to fit the next undersize bearings available.

**Note:** It is possible to “metalize” the journals and crankpins and then regrind them to the original size. As a first step, the journals and crankpins are rough-turned in a lathe. The metalizing process uses a high-temperature flame to spray liquid metal onto the prepared surfaces. This metal adheres and can be subsequently machined.

1. **Finishing journals and crankpins.** A special crankshaft grinder or lathe is required to service journals and crankpins. The bearing surfaces must be finished to extreme smoothness. Since the grinding wheel is apt to leave a certain amount of “fuzz” on the reground surfaces, the journals and crankpins should be final-finished with fine crocus (or emery) cloth. Put the crankshaft in V blocks (Fig. 15-11), cover the journals and crankpins with engine oil, and wrap a long strip of crocus cloth halfway around the journal. Take the ends of the strip in your two hands and pull the strip back and forth, working uniformly all the way around each journal and crank-
pin in turn. This finishing operation smooths off any trace of roughness left by the grinding wheel. As a final test, after wiping off the oil, rub a copper penny across the bearing surface. If it leaves traces of copper on the steel, there is still roughness that should be removed.

**Caution:** Be sure to relieve (or grind back) the journal and crankpin radii (where they curve up to the crank cheeks) adequately. This will prevent bearing failure from radii ride as discussed in §223, 5.

2. **Cleaning crankshaft.** After grinding journals or crankpins, or at any time that the crankshaft has been removed from the engine, it should be thoroughly cleaned in a suitable solvent. At the same time a small, rifle-type brush should be used to clean out all oil passages in the crankshaft (Fig. 15-12). Remember, any trace of abrasive left in the oil passages will work out onto bearing surfaces later and may cause bearing failure after short mileage. Reoil the bearing surfaces immediately after cleaning the crankshaft to prevent rusting.

**Note:** The special grinder shown in Fig. 15-13 can be used for grinding crankpins while the crankshaft is still in the engine. With this device, a rear-wheel drive attachment is installed, and the car is placed in gear so that the crankshaft rotates. The grinder wheel follows the crankpin around as it rotates, grinding evenly across the crankpin. The only objection to this procedure reported from the field is that there may be some difficulty in cleaning up the crankpins after grinding, and that there

![Fig. 15-12. Using a small brush to clean out oil passages in the crankshaft. (Federal Mogul Corporation)](image-url)
is no way of being absolutely sure that all abrasive has been re­
moved from oil passages in the crankshaft. The grinder shown in
Fig. 15-13 can be used to grind main journals as well as crank­
pins after the crankshaft has been removed from the engine.

FIG. 15-13. Crankshaft-journal grinding machine for grinding rod journals with­
out removing crankshaft from engine. (Sunnen Products Company)

CHECK YOUR PROGRESS

Progress Quiz 21

You are nearing the end of your studies of the Automotive Engines
book. If you have remembered the essentials of what you have read in
the book, you have become well acquainted with how automobile en­
gines are constructed, how they operate, what can go wrong with en­
gines, and how troubles may be eliminated. Regardless of what your
plans are for your future in the automobile business, you will find such
information valuable. These progress quizzes give you a good chance
to check up on your memory. Try the one below, which covers the past
few pages.

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Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. Crankshaft main journals can be checked on the engine by either of two special measuring devices, a micrometer or a dial indicator crankshaft gauge or a dial indicator micrometer or a crankshaft gauge

2. Crankshaft journals should be reground if they are tapered or out of round by more than 0.0003 inch 0.003 inch 0.030 inch 0.300 inch

3. If one main bearing requires replacement, you should replace adjacent main bearings all main bearings camshaft bearings rod bearings

4. If the Plastigage flattens more at one end than at the other when it is used to check main-bearing clearance, it means that the bearing cap is loose bearing shell is loose in bore journal is tapered shaft is bent

5. Excessive end-thrust-bearing wear will cause excessive crankshaft end play crankshaft deflection crankshaft torsional vibration

6. Before installing new main bearings, you should always check crankshaft journals check connecting-rod journals grind crankshaft journals replace crankshaft

7. After installing new main bearings, you should always check crankshaft journals check bearing fit check bore eccentricity shim-adjust bearings

8. Main-bearing clearances can be checked with either shims or dial indicator feeler stock or micrometer micrometer or Plastigage feeler stock or Plastigage

9. The crankshaft should not be supported by V blocks at its two end journals for any length of time, since this could cause the journals to scratch journals to rust crankshaft to sag

10. After grinding and final-finishing journals, they can be checked for smoothness by rubbing them with emery cloth crocus cloth a copper penny a silver dime

§242. Cylinder wear  The repeated up-and-down movement of the piston and rings in the cylinder, the high temperatures and pressures of combustion, the washing action of the gasoline entering the
cylinder—all these tend to cause cylinder-wall wear. At the start of
the power stroke when pressures are the highest, the compression
rings are forced with the greatest pressure against the cylinder wall.
It is at this point, also, that temperatures are highest and the oil
film is therefore least effective in protecting the cylinder-walls. In
consideration of all these factors, it is obvious that the cylinder-wall
area at the top of the cylinder will wear the most. As the piston

![Diagram of cylinder wear](image1)

![Diagram of piston movement](image2)

Fig. 15-14. Taper wear of engine cyl­
der. Maximum wear is at top, just
under ring ridge. Honing the cylinder
usually requires removal of less ma­
terial than boring, as indicated. (Sunnen Products Company)

Fig. 15-15. Side thrust C as piston
and connecting rod reach position
shown on power stroke. A repre­
sents the total pressure on the
piston head. B represents the com­
ponent of that pressure that is trans­
mittted through the connecting rod.

moves downward on the power stroke, the combustion pressure
and temperature decrease. Ring pressure and cylinder-wall wear
will also decrease. As a result of all this the cylinder walls will wear
irregularly, wearing most at the top where pressures and tempera­
tures are highest. The cylinder therefore wears tapered (Fig.
15-14), with a large ridge at the top and a smaller ridge at the
bottom marking the limits of ring travel.

In addition to taper wear, the cylinder tends to wear oval-shaped
because the piston tends to push sideways against the cylinder wall
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as it moves up and down in the cylinder. These side thrusts of the piston are due to the tilting of the connecting rod. For example, on the power stroke, in the piston position shown in Fig. 15-15 the total push on the piston is as shown at A. Most of this push is carried downward through the connecting rod as at B. But a small component of the total push (C) thrusts the piston sideways against the cylinder wall. Although this sideward force does tend to cause wear, it is actually not a major factor in cylinder wear because it is, after all, relatively small.

It is easy to be fooled by "oval wear," because cylinders have different shapes at different temperatures. When you remove the cylinder head of a cold engine and carefully measure cylinders for eccentricity, you are quite likely to find that they are indeed oval. What happens, however, when you put the head back on and run the engine? First, in replacing the head and drawing the bolts or nuts down tight you are introducing certain stresses in the block. This alters the shape of the cylinders. Then, when the engine is started and the block warms up, the expansion of the metal alters the cylinder shape still further. In many cases these changes in cylinder shape reduce the out-of-roundness; that is, putting on the head and warming the block reduces the eccentricity of the cylinders. Here is how this condition comes about. When the block is first manufactured, the bores are all machined to be perfectly round when cold. But installing the head and warming the new block (by running the engine) causes the cylinders to be distorted out of round. However, as the engine operates, the piston-ring action tends to wear the cylinders round. In other words, the cylinders wear round when hot. After that, when the block cools and the head is removed, the stresses are changed so that the cylinders distort out of round. But replacing the head and warming the block reduces this distortion; the cylinders become more nearly round.

Another type of wear results from the washing action of entering gasoline. This wear is most apt to occur on the cylinder wall opposite the intake valve. At times the air-fuel mixture is not perfectly blended and small droplets of gasoline, still unvaporized, enter the cylinder. These droplets of gasoline strike the cylinder wall and tend to wash away the protective film of lubricating oil. With reduced protection, some additional wear takes place. A closed choke, which excessively enriches the air-fuel mixture, hastens this sort of wear.

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wear because quantities of unvaporized gasoline are apt to enter the cylinder as long as the closed choke causes the carburetor to supply a rich mixture.

§243. Cylinder service There are certain limits to which cylinders may wear tapered or out of round before they will require refinishing. As mentioned in §231, special drastic replacement rings will control compression and oil in cylinders with some taper and out-of-round wear. But when wear goes beyond a certain point, even the severest rings cannot hold compression and control oil; loss of compression, high oil consumption, poor performance, and heavy carbon accumulations in the cylinders will result. In such case, the only way to get the engine back into good operating condition is to refinish the cylinders and fit new pistons (or resized pistons) and new rings to them.

Refinishing cylinders requires from 12 to 20 hours (according to the type of engine). This includes fitting and installing new pistons, rings, piston pins, and connecting rods. When new bearings are fitted, about 10 additional hours are required. Grinding valves would require several more hours. These various times are mentioned since an engine that requires cylinder refinishing is usually in need of a general overhaul and these other services would also be required.

§244. Checking cylinder walls As a first step in checking cylinder walls, wipe them clean and examine them carefully for scored places and spotty wear (which shows up as dark, unpolished spots on the walls). Holding a light at the opposite end of the cylinder from the eye will help in the examination. If scores or spots are found, the cylinder walls should be refinished; even drastic rings will not give satisfactory performance on such walls.

Next, measure the cylinders for taper and oval wear. This can be done with an inside micrometer, a telescope gauge and an outside micrometer, or with a special dial indicator. The dial indicator is shown in use in Fig. 15-16. As it is moved up and down in the cylinder and turned from one position to another, any irregularities will cause the needle to move. This will indicate how many thousandths of an inch the cylinder is out of round or tapered.

The permissible taper or out-of-roundness varies somewhat with different engines. Engine manufacturers issue recommendations
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based on experience with their own engines. In addition, engine servicemen and rebuilders have had considerable experience in maximum limits beyond which drastic rings will not work satisfactorily (see §231). If the irregularities exceed recommendations, the cylinders will have to be honed or rebored.

§245. Refinishing cylinders

If the decision to refinish the cylinders has been reached, then, as a first step, the block should be cleaned to remove all sludge from the oiled areas of the block. The water jackets should then be cleaned to remove all traces of lime, rust, and other accumulations (see §251).

There are two methods of refinishing cylinders. One method makes use of a boring machine with a revolving cutting tool. The other method, used where cylinders wear is not too great, employs a hone or set of grinding stones. Before deciding which method is to be used, the cylinders must be checked as outlined in the previous article to determine the amount of wear and taper. If taper and out-of-roundness are not too great, only honing will be required. But if the wear is too great to be taken care of by honing, the cylinders will have to be rebored. Figure 15-14 gives you some indication of what it means in terms of removed material to hone or rebore a cylinder. Note that when a cylinder is rebored, much more material is removed.

§246. Honing cylinders

If the taper or eccentricity is not excessive, only honing of the cylinders will be required. Figure 15-17 shows a cylinder hone in place, ready for the honing operation. The hone should be rotated in the cylinder until the cylinder is cleaned up.
If the honing is started with coarse stones, sufficient material should be left so that the final smoothing operation will not remove too much material from the cylinder walls. Final honed size should be such that the cylinder will take a standard or oversize set of rings and also a standard, an oversize, or a resized piston. In other words,

the cylinder, piston, and rings must match. Some honing equipment includes a vacuum device (Fig. 15-18) for dry honing. The dust that is raised during dry honing is pulled out by the vacuum device (as shown by the arrows). Other operators prefer to wet hone and use a lubricant (such as No. 10 oil). In this case, clean rags or paper, moistened with water, should be stuffed into the bottom of the cylinders so that the oil and abrasive don't run down into the crankcase.
Caution: After honing cylinders, be sure to clean them up as outlined in §249.

§247. Cracking glaze for new rings Some engine servicemen make it a rule to “break” or “crack” the glaze on cylinder walls with a hone when installing new rings, even though wear is not great enough to warrant honing or boring the cylinders. The idea behind this is to remove the smooth glaze that has formed and thus give the new rings a chance to seat quickly. However, at least one ring manufacturer suggests that this is not required on cast-iron cylinder walls, provided the walls are not wavy or scuffed. However, if the walls are of hard steel or hardened cast iron, the glaze should be broken with a hone. This requires only a few strokes, down and up, of the hone, with the hone moved rapidly enough to obtain a cross-hatch pattern on the cylinder wall with the lines at about sixty degrees to each other where they cross. Clean the cylinders thoroughly after honing (§249).

§248. Boring cylinders If the wear is too great to be taken care of by honing, the cylinders must be bored with a boring machine (Fig. 15-19). The size to which the cylinders should be rebored is determined by the amount of material that needs to be removed from the walls. In addition, the type of piston (finished or semifinished) to be installed must be considered. If semifinished pistons are to be installed, then only sufficient material need be removed to clean up the bores. The pistons are then finished to fit the cylinders. However, if new finished pistons are to be installed, the bore will have to be finished to the proper size to take the correct oversize piston (with matching new rings). In this case, the cylinder that is worn most in the engine should be bored first to make sure that it will clean up to the size that will take the next larger size of oversize piston. For example, suppose your measurements indicated that the bore should clean up if rebored 0.020 inch oversize to take the standard 0.020-inch-oversize piston supplied for the engine. However, you find in reboring that it does not clean up at this size but must be finished to 0.025 inch oversize to take the standard 0.025-inch-oversize pistons. If you had already refinished other cylinders before you discovered this, you would have to go back and refinish them again to the larger size so that all new pistons would be of uniform size.
Before the boring bar is mounted on the cylinder block, the top of the cylinder block must be cleaned, and all studs must be removed. Studs can be taken out with a stud remover or by locking two nuts on the stud and turning the lower nut with an end wrench. Carbon deposits, gasket cement, rust, and so on, must be removed.
from the top of the block. Burrs or high spots around bolt or stud holes should be filed off with a fine-cut file. The surface of the block must be as clean, level, and smooth as possible since any irregularity will cause the boring machine to mount crooked; it would therefore bore the cylinder off line.

As has already been mentioned, the boring machine should be mounted at the cylinder that is most worn, since that cylinder should be bored first. The methods of mounting the boring machine, of setting the cutting tool, and of operating the machine vary with different machines. Consult the instruction manual supplied with the machine before attempting to operate it. Figure 15-20 shows the centering fingers used in one machine to center the boring bar in the cylinder, while Fig. 15-21 shows the cutting tool in this machine in place and cutting.

When boring a cylinder, the first cut should be a roughing cut, followed by a finishing cut. The roughing cut should be to within 0.002 inch of the final size. Some manufacturers recommend the use of a hone to finish the job after the finishing cut. In such case, the finishing cut on the boring operation should be to within about 0.0005 inch of finished size. The hone will then take off the last 0.0005 inch. Fine finishing stones should be used in the hone for this operation. The cylinders should be cleaned carefully after the boring and honing job is done (§249).

Caution: If the main-bearing caps are off, they should be re­placed, and the cap bolts or nuts should be drawn up to specified tension, before cylinders are bored. If this is not done, the bores may be distorted out of line when the caps are installed. With the caps on, any distortion of the block will be held during the boring operation.

§249. Cleaning cylinders It is extremely important that cylinders be thoroughly cleaned after the boring or honing operation. Even slight traces of grit or dust left on the cylinder walls will probably cause rapid ring wear and early engine failure. Some engine manufacturers recommend wiping down the cylinder walls with very fine crocus cloth as a first step in cleaning. This loosens embedded grit and also knocks off "fuzz" left by the honing stones or cutting tool. Then use a swab and light engine oil or hot soapy water to wash down the walls. A small cotton string mop makes a good swab. Some enginemen like to use oil to clean up the cylinders; others
like soapy water. Whichever you use, make sure that the job is done thoroughly. For instance, when swabbing down with oil, scrub the walls with the oily swab, and then use a clean cloth to wipe off the oil. Do this several times or until the cloth will remain absolutely clean when rubbed on the walls.

Be sure to clean out all oil passages in the block, as well as stud and bolt holes.

Note: Gasoline or kerosene will not remove all the grit from the cylinder walls; they should not be used to clean up the walls after boring or honing.

§250. Replacing cylinder sleeves

On engines equipped with cylinder sleeves, the sleeves usually can be removed and replaced at room temperature. A special sleeve puller is required. The puller makes use of a screw which, when turned, applies pressure on the lower edge of the sleeve so that it is forced out of the block. The sleeve replacer uses the same principle. There is usually a counterbore in the block into which a flange at the top of the sleeve fits. The counterbore must be clean and square so that the flange fits snugly into it when the sleeve is replaced. If dry ice (frozen carbon dioxide) is available, the assembly job can be made easier by putting the sleeve into the dry ice for about fifteen minutes before installing it. This cools and shrinks the sleeve so that it slips into place more easily.

Cracked blocks, scored cylinders, cylinders worn so badly that they must be bored to an excessively large oversize—all these can often be repaired by the installation of cylinder sleeves (Fig. 15-22). As a first step, the cylinder must be bored out with a boring machine to take the cylinder sleeve. Then the sleeve should be installed and bored to the proper size.

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Before installing the new sleeve, it should be coated on the outside with a mixture of glycerin and red lead. This helps it slip into place and also provides a seal after installation. Heating the block to operating temperature and cooling the sleeve with dry ice will facilitate installation.

§251. Cylinder-block cleaning  Before a honing or boring operation, or at any time that the engine is torn down, the block should be cleaned. This means that the oiled sections should be cleaned of sludge and the water-jacket sections cleaned of lime, rust, and other deposits. To remove sludge, the various engine parts should be washed with a good solvent and a brush. Steam cleaning the block and other parts will help dispose of the sludge. The cooling system can be flushed out without tearing down the engine. A cleaning compound should be used (directions on the cleaner container should be followed), and then water under pressure should be forced through the engine water jackets to wash out loosened scale and rust. The cooling-system thermostat must be removed when the engine block is flushed out.

§252. Replacing expansion plugs  If an expansion plug must be removed from the block (because of water leakage past the plug, for example), it can be drilled in the center and then pried out with a punch or small pry bar. To install a new plug, scrape out all rust from the recess, coat the base and sides of the recess with red lead, and place the new plug in the recess, curved (convex) side out. Tap the center of the plug with a hammer to make sure that the plug is seated. Then use a flat-ended drift or punch to drive against the plug. This flattens and expands the plug so that it fits the recess tightly.

CHECK YOUR PROGRESS

Progress Quiz 22

Here is your personal checkup on cylinder service, the material we have been covering in the past few pages. See how well you remember the essential points by trying the quiz below.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the
Automotive Engines

sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. Taper wear in the cylinder is greatest at the top of cylinder center of cylinder bottom of cylinder

2. A wear spot may appear on the cylinder wall opposite the intake valve due to high-speed operation heavy compression-ring pressure washing by gasoline droplets

3. Cylinders that are oval when cold are apt to be more oval when hot less oval when hot about the same when hot

4. One of the major factors causing cylinder-wall wear is the pressure of the piston on the walls compression rings on the walls combustion gases on the walls

5. Two methods of finishing cylinder walls are grinding and honing reaming and boring roughing and finishing

6. When considerable material must be removed to clean up a cylinder bore, the cylinder should be bored honed ground reamed glazed

7. When cracking the glaze, you should use a hammer wrench hone bore

8. When boring cylinders, the main-bearing caps should be off attached lightly attached with normal bolt tension attached with heavy bolt tension

9. After cylinders are bored or honed, they should be cleaned with either light oil or soapy water light oil or gasoline gasoline or kerosene

10. Cracked blocks, scored cylinders, and badly worn cylinders can sometimes be repaired by reboring cylinders rehoning cylinders installing cylinder sleeves

CHAPTER CHECKUP

Note: Since the following is a chapter review test, you should review the chapter before taking the test.

You have made wonderful progress in your studies of the Automotive Engines book. You are now nearly at the end of the book, and have only the chapter on shop practice and tools to study. If you have been able to remember most of what you have studied in the book, you are well equipped with the fundamentals of engine theory, operation, construction, and servicing. Even if you haven’t been able to remember all the essential points, you have those points written down in your notebook. You can skim through your notebook from time to time and refresh your memory. Of course, you can also turn back through the book and review...
Crankshaft and Cylinder Service

the important points if they get hazy in your mind. See how well you remember what you have just studied in the chapter by taking the checkup test below.

Completing the Sentences

The sentences below are incomplete. After each sentence there are several words or phrases, only one of which will correctly complete the sentence. Write each sentence down in your notebook, selecting the proper word or phrase to complete it correctly.

1. Crankshaft main journals should be checked for **high spots and stretch taper, ridges, out-of-roundness connecting-rod-bearing fit**
2. Authorities point out that any appreciable taper or out-of-roundness of the crankshaft main journals will **cause rapid journal wear excessively reduce oil consumption shorten main-bearing life**
3. Crankshaft main-journal alignment can be checked with crankshaft **in engine off engine supported in V blocks**
4. Crankshaft main-journal taper or out-of-roundness can be checked with crankshaft **on or off engine off engine only on engine only**
5. Precision-insert main bearings can be installed with the crankshaft **on or off the engine; however, authorities agree that there is less chance for trouble if they are installed with crankshaft on engine with crankshaft partly removed from engine with crankshaft off engine**
6. Of the three methods used to check main-bearing fit, the one that is most apt to show up main-journal taper is the **feeler-stock method Plastigage method shim-stock method**
7. When machining semifitted main bearings, not only must they be bored, but also the correct amount of crankshaft end play must be established by **installing shims filing bearing caps facing end-thrust bearing**
8. Engine cylinder bores are apt to wear **tapered and oval out of round and oval flat and oval tapered and flat**
9. When you examine a cylinder bore to decide what sort of service it requires, the more taper it has, the more likely it is that you will decide that the cylinder must be **reamed bored honed glaze-cracked**
10. Cylinders may be honed **wet or dry to 0.300 inch oversize to remove 0.070 inch taper**
Automotive Engines

Service Procedures

In the following, you are asked to write down in your notebook the servicing procedures described in this chapter. Do not copy the procedures from the book but try to write them in your own words. Give a step-by-step account of how to do the service job asked for. This will help you remember the procedure later when you go into the engine shop.

1. Explain how to remove and replace a crankshaft.
2. List the special points to be watched when removing main-bearing caps.
3. Explain how to check a crankshaft for journal and crankpin wear.
4. Explain how to check (with feeler stock and with Plastigage) and replace precision-insert main bearings.
5. Explain what causes cylinders to wear tapered.
6. Explain how to check cylinder walls with a dial indicator.
7. Explain how to hone cylinder walls.
8. Explain how to bore a cylinder.
9. Explain how to clean cylinder walls after boring or honing.
10. Explain how to remove and replace expansion plugs.

Suggestions for Further Study

Keep your eyes and ears open when you are in the engine shop. You will be able to pick up much valuable information if you are alert. Notice how different jobs are done and particularly how testing and repair equipment is used. Study the operating manuals supplied by the manufacturers of the servicing equipment. For instance, the cylinder hone and cylinder reborer manufacturers both supply operating manuals that will prove of interest to you. Jot down in your notebook important facts that you get out of these manuals as well as information you pick up in the service shop. Jotting down these various facts will help you to remember them and will also preserve the information for you in permanent form.

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THE PURPOSE of this chapter is to supply information on how to use tools and how to behave in the shop. If tools are used properly, and if you are reasonably careful in your shopwork, you will be as safe from harm as in your own home. But tools in poor condition, tools carelessly used, thoughtless or careless actions will probably result in poor work and may lead to a serious accident.

§ 253. Taking care of yourself in the shop  Work quietly and give your work your undivided attention. You should never indulge in horseplay or create an unnecessary disturbance. Such actions might distract someone and cause him to get hurt. Keep your tools and equipment under control. Don't scatter them about or lay them on operating machinery or equipment. Keep them out of aisles and working spaces where someone could trip over them. Use special care to keep jack handles and creepers out of the way; tripping over these is one of the most common causes of accidents in the automobile shop. Don't put sharp objects or tools into your pockets. You might cut your hand or get stabbed. Make sure that your clothing is suited to the job and that you do not have a dangling tie, loose sleeves, and so forth, that could get caught in moving machinery. Wipe excess oil or grease off your hands, because oil or grease makes your hands slippery so that you cannot get a good grip on tools or parts. Do not use a compressed-air hose to blow dirt from your clothes, and never point the hose at another person. Particles of dirt may be blown at sufficient speed to penetrate the skin or the eyes. Goggles should be worn when the air hose is used, as well as during chipping, grinding, or any other job where there is danger to the eyes from flying particles. When using a car jack, make sure that it is centered, so that it will not slip and allow the car to drop. Never jack up a car when someone is working under it. Use car stands or supports, properly placed, before going under a car.
§254. Taking care of your tools

Tools should be clean and in good condition, as noted in following articles. Greasy or oily tools will be hard to hold and use; wipe them off before trying to use them. Always use the proper tool for the job; using the wrong tool may damage the tool or the part being worked on, or it might lead to personal injury. Do not use a hardened hammer or punch on a hardened surface. Hardened steel is brittle—almost like glass—and may shatter from heavy blows. Slivers from the head of the hammer or from the punch might fly out and embed in the hand or, worse, in the eye. Use of a soft hammer or punch on hardened parts.

§255. Using power-driven equipment

A great variety of power-driven equipment is used in the automobile shop. The instructions for using any equipment should be carefully studied before the equipment is operated. Hands and clothing should be kept away from moving machinery, such as the engine flywheel, fan, and so forth. Keep hands out of the way when using any cutting device, such as cylinder-boring equipment or a drum lathe. Do not attempt to feel the finish while the machine is in operation, since there may be slivers of metal that will cut your hands badly. When using any honing or grinding equipment, keep hands away from rotating parts and do not try to feel the finish with the machine in operation. When working on any device with compressed springs, such as clutches or valves, use great care to prevent the springs from slipping and jumping loose. If this should happen, the spring might take off at high speed and hurt someone.

Never attempt to adjust or oil moving machinery unless the instructions specifically state that this should be done.

§256. Fire prevention

The automobile requires gasoline to operate, and gasoline is a highly flammable substance. Therefore, you should be particularly careful around the shop to avoid spilling gasoline. If gasoline is spilled, it should be wiped up at once and the rags put outside or in a safe place to dry. Naturally, smokers should be very careful, since open flames in the presence of gasoline vapors will cause the vapors to explode. This is so great a danger that smoking is strictly prohibited in many automobile shops. Oily rags or waste are another potential source of fire, since they may ignite by spontaneous combustion, that is, by the oil on the rags (by chemical action) causing so much heat to develop that the rags
catch fire. Oily rags or waste should be placed in covered metal containers provided for them.

An engine that has a gasoline leak in the fuel line, tank, pump, or carburetor is extremely dangerous, since the gasoline could catch fire very easily. Before such an engine is started, the leak should be repaired and all gasoline be wiped up. Care should be used to avoid shorts or grounds in the electric circuit which could cause sparks, especially around the carburetor or the fuel pump. In particular, the ground cable should be disconnected from the battery first when a battery is being removed from a car. This prevents the possibility of a ground when the cable clamp is being loosened from the insulated terminal. For the same reason, the grounded cable should be reconnected last on reinstallation of the battery.

§257. Screw drivers Do not use a screw driver as a pry bar or as a punch or chisel; you are apt to break it. Keep the tip properly ground (Fig. 16-1), with the sides practically parallel at the end.

Fig. 16-1. Right and wrong ways to grind screw-driver tip. (General Motors Corporation)

Fig. 16-2. Phillips-head screw and screw driver. (General Motors Corporation)

If the sides are tapered, the tip will tend to rise up out of the screw slot when it is turned. Always select the proper screw driver for the job; the tip should fit snugly in the screw slot. A screw driver that is too large or small is hard to use and may damage the screw or part being worked on.

The Phillips screw driver (Fig. 16-2) has two slots that cross at
the center. It is widely used on automobile trim and molding; there is less chance that the screw driver will slip out of the slots and damage the finish. Three sizes, 4-, 6-, and 8-inch, handle most automotive work.

Offset screw drivers (Fig. 16-3) are handy for removing screws in hard-to-get-at places. The two blades are at right angles; the ends can be reversed as a screw is tightened or loosened.

![Offset screw driver. (General Motors Corporation)](image)

§258. Hammers The ball-peen hammer (Fig. 16-4) is the one most commonly used by mechanics. It should be gripped on the end, and the face should strike the object squarely, as shown in Fig. 16-5. Hammers for striking on easily marred surfaces are shown in Fig. 16-6.

Check the hammer-head attachment to the handle occasionally. A wedge or screw is jammed into the head end of the handle (Fig. 16-7) to spread it and keep it from coming loose. Make sure the

![Wrong and right ways to grip and use hammer. (General Motors Corporation)](image)
§259. Wedge or screw is tight each time you start to use the hammer. If the head should fly off, it might injure someone.

§259. Pliers A few of the many kinds of cutting and gripping pliers are shown in Fig. 16-8. Do not use pliers to grip hardened-steel surfaces; this will dull the teeth in the plier jaws. Do not use pliers on nuts or bolts; this will damage the nut or bolthead so that wrenches will not fit on them.
§260. Wrenches

Wrenches of many types are available, including open-end, box, combination open-end and box, adjustable, monkey, pipe, socket, setscrew, and spanner. Each has its special use.

Open-end wrenches are designed to tighten or loosen nuts or bolts (Fig. 16-9). The opening is usually at an angle to the body to permit turning a nut or bolt in a restricted space. After the nut or the bolt is turned as far as the restricted space will allow, the wrench can be turned over 180 degrees to permit further turning of the nut or bolt. By turning the wrench over after each swing, the nut or bolt can be loosened or tightened satisfactorily (Fig. 16-10). It is usually better to pull against the wrench rather than to push. If it is necessary to push, push with the palm of the hand and keep the fingers out of the way so that if the nut or bolt suddenly gives, the knuckles will not be hurt. Make sure that the wrench fits the nut or bolthead snugly. If it fits loosely, excessive strain is thrown on the...
wrench and it may spring or break. The nut or bolthead may also be
damaged. Do not use a pipe or other wrench on the end of the
wrench to gain additional leverage. The wrench is designed to with­
stand the maximum leverage a man can apply by hand on its end;
gaining added leverage with a pipe or another wrench may cause
the wrench to break. Never use a hammer to strike on a wrench
except where the wrench has been especially designed to be used
in this manner.

Fig. 16-10. Manner in which wrench may be turned over to turn nut in restricted
space. (General Motors Corporation)

Box wrenches (Fig. 16-11) serve the same purpose as open-end
wrenches. However, the opening into which the nut or bolthead
fits completely surrounds or boxes the nut or bolthead. Box wrenches
can be used in very restricted spaces because of the thinness of the
metal in the wrench head (Fig. 16-12). The wrench cannot slip off
the nut. The 12-point box wrench, now almost universally used,
has 12 notches in the head, so that a nut or bolt can be installed or
removed even where there is a swing of only 15 degrees. Some box
wrenches have the heads at an angle of 15 degrees to the handle to
provide added clearance for the hand (Fig. 16-13).
Combination open-end and box wrenches have a box wrench on one end and an open-end wrench on the other. The box wrench is more convenient than an open-end wrench for final tightening or breaking loose of a nut or a bolt, but is less convenient for otherwise turning the nut or the bolt. The box must be lifted completely off the nut and then placed back on for each swing. On the other hand, the open-end wrench is less convenient for final tightening or breaking loose of a nut or a bolt, since it is more apt to slip off, but it is more convenient for running a nut or a bolt off or on. Thus the

![Fig. 16-11. Set of box wrenches. (General Motors Corporation)](image1)

![Fig. 16-12. The box wrench can be used in a restricted space. (General Motors Corporation)](image2)

![Fig. 16-13. Fifteen-degree box wrench. (General Motors Corporation)](image3)

combination open-end and box wrench enables the mechanic to use one type and then the other by merely reversing the ends.

Socket wrenches are somewhat similar to box wrenches, except that the sockets are detachable and are used with special handles. Figure 16-14 illustrates a set of socket wrenches with several types of handle. The sockets fit into the handles, the proper type of handle being selected for the job at hand. One type of handle has a sliding offset which permits application of added leverage by sliding the handle out. Another type has the handle attached through a hinge. The speed handle permits rapid running up or down of a bolt or nut. It works like a carpenter’s brace, which is used with a bit to bore [472]
Fig. 16-14. Set of socket wrenches with handles. (New Britain Machine Company and General Motors Corporation)
holes in wood. The ratchet handle has a ratchet that eliminates the necessity of lifting the socket off the nut or the bolt. The ratchet locks the socket as the handle is turned in one direction so that the socket turns with the handle. As the handle is moved back, the ratchet permits the handle to move without moving the socket. A universal joint is handy for working in restricted spaces where a straight wrench will not fit, since it allows the handle to be worked at an angle with the socket.

The torque wrench (Fig. 16-15) is necessary for working on the
modern automotive vehicle, since many nuts and bolts must be tightened to the correct amount—not too little or too much. Through long experience, it has been found that excessive tightening of nuts or bolts causes distortion of parts and danger of stripped threads or broken bolts, while insufficient tightening may permit the nut or the bolt to loosen. By using a torque wrench, the amount of torque being applied can be read on the dial, to permit tightening within the specified limits.

Setscrew wrenches, also called Allen wrenches, are used on Allen setscrews (Fig. 16-16). This type of setscrew is not widely used on automobiles, although the caster and camber adjustments on the front wheels of many cars are made by turning an Allen-setscrew type of pivot pin.

Figure 16-17 shows the wrong way and the right way to use an adjustable wrench. Be sure that the wrench jaws are tightened on the nut or bolt flats.

§ 261. Chisels Cold chisels are supplied in a number of different shapes (Fig. 16-18); all are for cutting metal by driving with a hammer. The chisel is normally held in the left hand. It should be held rather loosely so that, if the hammer does not strike square or misses, the hand will tend to give with the hammer blow and will be less subject to injury. For chipping with a chisel, goggles should be worn to prevent the possibility of chips flying into the eye. A chisel that has mushroomed on the end because of repeated hammer blows should not be used until the end has been dressed on a grinding wheel so that the turned-over metal is removed (Fig. 16-19).

§ 262. Punches Punches are used to knock out rivets or pins, to align parts for assembly, and to mark locations of holes to be drilled. Punches for knocking out rivets or pins are of two kinds, the start-
ing and the pin punch (Fig. 16-20). The starting punch is tapered and is used merely to break the rivet loose after the rivet head had been ground off or cut off with a chisel. The pin punch is then used to drive the rivet out.

The center punch (Fig. 16-21) is handy not only for marking hole locations for drilling but also for marking parts before they are disassembled, so that they can be reassembled in the same relative location. Unless the hole location is marked with a center punch before a hole is drilled, the drill may wander or move around on the surface of the piece through which the hole is to be drilled (Fig. [476])
If the hole location is first center-punched, the drill will not do this.

§263. Files

Files are cutting tools with a large number of cutting edges or teeth. Files have many uses, and consequently there are hundreds of styles of file with many different types of cut. A typical file with the various parts named is shown in Fig. 16-23. The term "cut" refers to the cuts that have been made across the face of the file to form the file teeth. When the cuts are relatively far apart, the file is termed a rough or coarse-cut file. When they are close together the file is termed a smooth or dead-smooth file. The terms indicating coarseness or fineness are, in order: rough, coarse, bastard, second-cut, smooth-cut, and dead-smooth. Figure 16-24 illustrates three of these. The coarser the file, the more metal it will remove with each file stroke.

When only one series of cuts has been taken across the face of the file, with all cuts parallel to each other, the file is known as a single-cut file, regardless of its coarseness. When the file has two series of cuts across its face in two different directions, it is known as a double-cut file (Fig. 16-25). Double cutting a file produces a large number of small teeth, each little tooth being much like the point of a chisel.
In addition to the above classification, files are classified according to their shape. Files may be flat, triangular, square, half-round, or round, either with or without taper from the heel to the top. Many special types of file are also available. Selection of the cut and shape of a file depends upon the work to be done. A few types of files are shown in Fig. 16-26.

A handle should be put on a file before it is used. Otherwise, you might accidently drive the pointed tang into your hand. Handles are made in various sizes for various-sized files. To install the handle, place the file tang into the hole in the handle and tap the butt end of the handle on the bench (Fig. 16-27). Never hammer on the file to drive it into place. The file is brittle and may shatter.

[478]
Be sure that the part to be filed is held securely. Clamp it in a vise, if possible, and use the soft vise faces if necessary to protect the part from scarring. It is difficult to describe the exact procedure of using a file, since the procedure varies greatly with the type of job and the material. The forward, or cutting, stroke should be smooth and firm, with the proper amount of pressure. Insufficient pressure will allow the file teeth to slip over the work, so that the teeth are dulled. Excessive pressure tends to overload the file teeth so that the cut is irregular. Use only enough pressure to keep the file cutting. On the back, or return, stroke, the file should be lifted clear of the work. Dragging the file back wears the cutting edge of the file teeth. However, if the file is used on soft metal, such as lead, the file should be dragged on the return stroke, as this tends to clean the teeth. Also, in the process known as drawfiling, a finishing operation, the file is pushed along the work crosswise and may not be lifted for the return stroke.

If the file is not cutting, a file card should be used to clean the file teeth. The file card is a wire-bristled brush. Tapping the handle on the bench every few strokes during filing tends to keep the file clean, but the file card will also be required.

When a file is not in use, it should be carefully put away. If a file is thrown into a drawer with other tools, the file teeth will be chipped and dulled. They should be protected by putting the file in a file rack or by wrapping it. Also, files are subject to rusting and should therefore be kept away from moisture.

**Caution:** Never attempt to use a file as a pry bar and never hammer on it. The file is brittle and will break easily. If it is hit with a hammer, it is liable to shatter in a dangerous manner.

§264. Hack saws

The hack saw is a special type of saw for sawing metal (Fig. 16-28). The blades are replaceable and the frame is adjustable for various blade lengths. It is very important that the correct type of blade be selected for the work to be done. Blades...
Use 14 teeth for cutting materials in thick sections made of mild or soft materials.

Use 18 teeth for cutting materials thicker than \( \frac{3}{16} \) inch in sections of annealed tool steel, high-speed steel, rail, bronze, aluminum, light structural shapes, copper.

Use 24 teeth for cutting material thicker than \( \frac{7}{32} \) inch in sections of iron, steel, brass and copper tubing, wrought iron pipe, drill rod, conduit, light structural shapes, metal trim.

Use 32 teeth for cutting material similar to recommendations for 24 tooth blades but thinner than \( \frac{3}{32} \) inch.

FIG. 16-29. Correct and incorrect number of teeth for various cutting jobs. The correct number is shown at left on each job. (Henry Disston and Sons, Inc.)
are made with 14 to 32 teeth per inch. Using a blade with the wrong number of teeth will not only make the job more difficult, but will also damage or break the blade. Figure 16-29 illustrates correct and incorrect blades for various jobs.

After the correct blade for a job has been selected, it should be placed in the hack-saw frame and tightened to the proper tension (Fig. 16-30). Insufficient tension will cause the blade to bend and probably to break. The teeth should be pointed away from the handle so that they will cut when the hack saw is pushed (Fig. 16-31).

In using the hack saw, it should be held as shown in Fig. 16-32. On the forward, or cutting, stroke, move the hack saw evenly and with uniform pressure. Lift the blade slightly from the work on the return stroke to avoid wear on the back of the teeth, since this would soon dull them. Never twist or bend the blade when cutting, since such treatment may break it. In sawing sheet metal it may be found that even with the 32-tooth blade only one tooth will be in
contact with the metal. For such work, the sheet metal may be clamped in the vise between two blocks of wood and the cut taken through both the wood and the metal.

Take good care of the blades. Do not throw them into a toolbox with other tools and thus dull the teeth. Wipe the blades with an oily cloth occasionally to keep them from rusting.

§ 265. **Taps and dies**  Taps and dies are devices used for cutting inside and outside threads. Taps cut threads inside holes, while dies cut outside threads. Various styles of thread are used; among them are the American National, square, sharp V, and SAE (Society of Automotive Engineers) standard, each style having various sizes and numbers of threads per inch. The SAE standard is the one most commonly used in automotive service work.

Taps are made in several styles (Fig. 16-33). The taper tap is used to thread a hole completely through a piece of metal, the plug tap to thread a hole only part way, and the bottoming tap to thread a hole to the bottom when the hole does not go all the way through the metal.

The tap is help in a tap wrench (Fig. 16-34). The wrench jaws are adjustable and can be tightened to hold the tap securely. The tap should be started square in the hole and the wrench turned smoothly and evenly, with both hands. A lubricant such as lard should be applied to the tap. Every time two complete turns of the tap have been made, the tap should be backed off about a quarter turn and lubricant applied.

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Dies cut outside threads (Fig. 16-35). Dies are held in die stocks (Fig. 16-36) during the cutting operation. The procedure is similar to that required for tapping. The rod should be chamfered on the end, so that the die will start easily. Every two complete turns, the die should be backed off a quarter turn and lubricant such as lard applied.

§266. Measuring devices The measuring of linear distances is one of the most important of all the jobs performed in an automotive service shop. In almost every step of automotive service, measurements are taken to determine size, fit, or clearance. And unless the measurements are properly taken, the service job will not be correct; improper operation or failure of the unit being serviced will result.

Almost everyone is familiar with the ruler or scale for measuring on flat surfaces. To measure the diameter of a shaft or the thickness of a part, an outside caliper or micrometer is used. To measure the diameter of a hole, an inside caliper or micrometer is used. Special dial-indicator gauges are also available to take such measurements. Measurement of small clearances or gaps is required in brake work, setting valve tappets, fitting pistons, adjusting spark plugs, and so forth. For such work, feeler gauges are used. The procedures of using these measuring devices are detailed in following paragraphs.
Feeler gauges are essentially strips or blades of hardened and tempered steel or other metal, ground or rolled with extreme accuracy to the proper thickness. They are generally supplied in sets (Fig. 16-37), each blade marked with its thickness in thousandths of an inch. In Fig. 16-37, for example, the “3” means 0.003 inch, the “4” means 0.004 inch, and so on. Some feeler gauges have two steps or thicknesses and are called stepped feeler gauges (Fig. 16-38). The tip of the blade is somewhat thinner than the remainder of the blade. The blade marked “10-12” in Fig. 16-38 for example, is 0.010 inch thick at the tip and 0.012 inch thick on the thicker portion, which starts about \(\frac{1}{2}\) inch from the end of the blade. This type of feeler gauge is handy on certain jobs, such as valve-tappet-clearance adjustment where the specifications might call, for example, for a clearance of 0.006 to 0.008 inch. By making the adjustment so that the 0.006-inch gauge will fit and the 0.008-inch gauge will not fit, the specified clearance is obtained.

Wire feeler gauges are similar to the flat feeler gauges, except that the wire feelers are made of carefully calibrated steel wire of the proper diameter. They are useful in making spark-plug gap and similar checks.

Feeler gauges should never be forced into a space to be measured. They should not be allowed to become bent, torn, or battered. They should be wiped with a clean, oily cloth occasionally. With care, feeler gauges will last a long time without losing their accuracy.

Calipers can be used to take a number of different measurements. Figure 16-39 illustrates the use of an outside caliper to measure the diameter of a shaft. The caliper should be adjusted to slip over the shaft easily of its own weight. It should not be forced, since this
would spring the caliper and prevent accurate measurement. After the caliper has been adjusted, the caliper can be placed against a scale, as shown in Figure 16-40, in order to determine the shaft diameter. One leg of the caliper should be held against the end of the scale and the reading on the scale at the other leg noted.

Inside calipers are used in a similar manner to measure the diameter of holes. Figure 16-41 illustrates an inside caliper in use. It should be entered in the hole at an angle, as shown by the dotted lines, and then slowly straightened. Adjust until it will slip in the hole with a slight drag. The caliper must be held square across the diameter of the hole. After the caliper is adjusted, the measurement can be read from the scale, as shown in Fig. 16-42.

The micrometer (Fig. 16-43) or “mike,” as it is often called, is a special type of caliper designed to measure in thousandths of an
inch. It is a precision instrument and must be carefully treated. When the thimble is turned clockwise, the spindle moves toward the anvil; when the thimble is turned in the opposite direction, the spindle moves away from the anvil. The hub or barrel of the micrometer is marked off in uniform spacings, each of which is 0.025 inch. The thimble is spaced off into 25 graduations around its circumference, each graduation indicating 0.001 inch (Fig. 16-44).

![Fig. 16-43. A micrometer. (General Motors Corporation)](image1)

![Fig. 16-44. Hub and thimble markings on micrometer. (General Motors Corporation)](image2)

The internal gearing of the thimble is such that every revolution of the thimble moves the thimble on the hub 0.025 inch. When the thimble has been turned to bring the spindle up against the anvil, the thimble will have been brought up to the "0" mark on the hub, and the "0" mark on the thimble will have aligned with the lateral line on the hub. If the thimble is backed off to give 0.010-inch clearance between the anvil and the spindle, the "10" marking on the thimble will align with the lateral line on the hub; this indicates 0.010 inch. If the thimble is backed off four revolutions exactly, the
thimble will clear the "1" marking on the hub, which indicates 0.10 inch, or 4 times 0.025. If the thimble were then turned back part of a revolution, say to the "12" marking, then the total distance between the anvil and the spindle would be 0.10 inch plus 0.012 inch, or 0.112 inch. By thus adding the hub and thimble markings and remembering that each hub marking represents 0.025 inch and

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Each spindle marking represents 0.001 inch, the measurement to which the micrometer has been adjusted can easily be read. Once the reading has been taken, it can be translated from decimals to fractions, if desired, by reference to the decimal-equivalent chart, Fig. 16-45.

Inside micrometers are also available for taking measurements of hole diameters (Fig. 16-46) as, for instance, the bore of an engine cylinder. Other special micrometers find use in automotive
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shops. The special micrometer shown in Fig. 15-4 has long anvil and spindle jaws which permit easy measurement of the crankshaft-journal diameter. Much of the precision machinery used in the automotive shop has micrometer adjustments; cylinder honing or boring equipment, other hones, machine lathes, crankshaft lathes, precision grinders—all have such adjustments.

In the use of the micrometer, extreme care must be exercised to prevent damaging it. In particular, it should never be clamped on the piece to be measured. The micrometer should be tightened only enough to cause a slight drag as it is slid over the piece being measured. Clamping will distort the micrometer or ruin the screw threads.

Dial indicators are gauges that utilize a dial face and needle to register measurements. The needle is connected by gearing and linkage to a movable contact point. Movement of the contact point registers in thousandths of an inch on the dial face. Figure 15-16 illustrates a dial indicator being used to check cylinder walls in an engine.

§267. Drills Drills are tools for making holes. The type of material into which a hole is to be made determines the type of drill bit that must be used. The drill bit, or twist drill, is a cylindrical bar with helical grooves and a point (Fig. 16-47). The point is formed to
Fig. 16-47. The parts of a twist drill.

Fig. 16-48. Twist-drill points for various materials.
provide cutting edges to cut into material. The helical grooves provide passages through which the chips that have been cut can pass away from the working surface. The shape of the point varies with the material (Fig. 16-48).

Grinding twist-drill points requires considerable skill. The two cutting edges must have the same angle with the center line of the drill, both edges must be of the same length, and the angle of clearance must be correct and the same for both cutting edges. Usually, when a considerable number of drills are used, a special grinding fixture is employed that assures the correctness of all angles (Fig. 16-49).

Twist drills have either a tapered or a straight shank, such as that shown in Fig. 16-47. The straight-shank drill is the more commonly used in ordinary shopwork.

For most shopwork, electrically operated drills are employed. These may be portable or permanently assembled into a floor- or bench-mounted press. The drill must have good care and must be correctly used. It must be kept clean and must be oiled periodically in line with the manufacturer's recommendations. Always turn off the drill before attempting to oil it. That is one of the fundamentals of safety practice in any shop. Always turn off a machine before attempting to oil it.

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Never overload a drill so much that it stalls. This is very damaging. Do not click the switch off and on in an attempt to start a stalled drill. This is likely to burn out the switch or the motor. Relieve the feed pressure as the drill bit breaks through the finished work, to avoid stalling.

If a portable drill is used, do not drag it round by the cable, and do not leave it lying around on the floor so that the cable or the drill bit will be stepped on or run over and damaged.

§ 268. Removing broken studs  Occasionally studs or bolts will break off, and the removal of the broken part will be necessary. If the break is above the surface, it may be possible to file flats on two sides of the stud or the bolt, so that a wrench can be used to back it out. Also, a slot may be cut so that a screw driver can be used. If the break is below the surface, an extractor may be required. The first step in the removal of a stud broken off below the surface is to center-punch the stud and drill a small hole down into it. Follow this with a larger drill that makes a hole in the stud nearly as large as the small diameter of the threads, leaving only a thin shell. Then the screw extractor is brought into use. One type, called the Ezy-Out, is tapered and has a coarse spiral thread with sharp edges. An extractor of the right size is selected, inserted into the hole in the stud, and turned in a counterclockwise direction with a
wrench (Fig. 16-50). The thread edges bite into the sides of the hole in the stud so that the stud is screwed out.

A second type of extractor has a series of tapered flutes with sharp edges. The extractor is driven into the hole in the stud so that the edges bite into the sides of the hole. A wrench is then used to turn the extractor and back out the stud. Another type of extractor is similar in construction, except that it is not tapered and has three sharp splines instead of flutes. It is used in a similar manner.

If a stud extractor is not available, it is sometimes possible to tap a diamond-pointed chisel into the hole in the stud and turn the chisel to back out the stud (Fig. 16-51).

§269. Soldering Soldering is the uniting of pieces of metal with solder. Solder is a combination, or alloy, of metals that has a lower melting point than the metals being soldered. In the soldering process, the solder is melted to make it flow in and around the area of juncture between the pieces of metal being united. Flux must be used in soldering. Flux, made up of acids or acid-bearing substances, dissolves the oxides on the surfaces of the metals to be soldered so that a good bond will be formed. A common flux is made by putting zinc in hydrochloric acid to form zinc chloride, which has an acid reaction. Other fluxes are in use, one of them being rosin, which has only a slight acid reaction. Rosin flux is recommended for soldering electric wiring and parts, since it is not corrosive and will not cause a deterioration of electric connections, as would a more acid flux.

The device used to melt solder is the soldering copper, often called the soldering iron. There are two common types of soldering copper, differing mainly in the provision for heating the copper. One type is heated by being placed in a gas-fired furnace or by a gasoline blowtorch. The second type contains an electric heating coil inside the head that heats the copper tip.

Regardless of the means of heating the soldering copper, there are certain general rules to be followed if a good soldering job is to be done. First, the material to be soldered must be clean. Secondly, the soldering copper must be clean and free of oxide. The soldering copper may be cleaned by filing until the soldering faces are bright. The faces should then be coated with solder applied with a flux, a process known as tinning the soldering
copper. For ordinary metalwork, a block of sal ammoniac may be used as the flux. For electrical work, rosin flux should be used.

Then, with the pieces of metal to be united firmly together, soldering flux is applied, and the hot soldering copper held at the point of juncture. At the same time, solder is applied. When the metals and the solder have attained sufficient temperature, the solder will melt and spread round the area of juncture. Removal of the soldering copper will then permit the area to cool, causing the solder to solidify.

Solder is supplied in a number of forms for various types of work. It is supplied in bars, in rods, and in wire form. The wire form often has a core of flux, which eliminates the necessity of applying flux separately during the soldering operation.

A torch or open flame is sometimes used on special applications to melt the solder, as, for example, when a dent in a body panel is being filled with solder.

§270. **Welding**

Welding is the process of joining two pieces of metal by fusing them together when they are in a molten or plastic state. The metals are heated until they are plastic or molten so that the joint between the two pieces becomes an integral part of each. Quite often, welding rods are melted to add metal at the joint. There are three basic methods of welding—forge, gas, and electric—which differ according to the process and the devices used.

In forge welding, the metals to be united are heated to a plastic state in a coke, charcoal, or coal forge, and then they are joined by pressure or hammering. This process is not often seen in the automotive service shop.

In gas welding, a blowpipe or torch is employed. In this process a mixture of oxygen and a highly flammable gas, such as hydrogen or acetylene, is burned. The gases are supplied in cylinders and are mixed in the welding torch in various proportions by regulating valves.

In electric welding, electric current supplies the heat. Electric welding can be divided into two main categories, electric arc welding and electric-resistance welding. In electric-resistance welding, the two parts to be joined are held together while a heavy electric current is passed through them, causing the fusion or welding of the two parts. Spot welding is a common type of


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electric-resistance welding. In electric-arc welding, the electric-welding process most commonly used in automotive shops, an electric arc produces the welding heat.

§271. Metalizing The term “metalizing” covers a process of spraying liquid metal onto a prepared surface to build it up. If a shaft journal, for example, has worn, it may be built up by sprayed metal and then turned down to its original diameter. The metal-spraying gun makes use of a gas flame somewhat similar to the blowpipe flame. A metal rod of the proper material is melted in this flame and sprayed at high velocity onto the prepared surface to be built up. To prepare a shaft journal for metal spraying, it is first rough-threaded, then placed in a lathe and rotated. The metal-spraying gun is then employed. As a final step, the shaft is turned down almost to finished size and then final-ground to size.

§272. Bench vise The bench vise (Fig. 16-52) is used to hold a piece or part while it is being sawed, filed, chiseled, or otherwise worked on. When the handle is turned, a screw in the base of the vise moves the movable jaw toward or away from the stationary jaw. To avoid marring or otherwise damaging finished surfaces of parts that are to be clamped in the vise, caps of copper or similar
soft metal are placed over the steel jaws of the vise. These are usually referred to as “soft” jaws.

§ 273. Arbor presses Arbor presses have many uses in the automobile shop. The simplest (Fig. 16-53) has a handle that rotates a gear which is meshed with a rack. This causes the rack to move down or up as required. The lower end of the rack has a tool- or arbor-holding device. A considerable amount of pressure can be exerted on the arbor through the handle, and this makes it relatively easy to remove or install bearings and bushings, to burnish bushings, and to perform other similar jobs. The larger presses of this type may be operated hydraulically, that is, by liquid pressure acting in a cylinder.

§ 274. Oilstone There are many types of oilstones, varying not only in shape and size, but also in the fineness or coarseness of the abrasive dust that makes up the stone. Stones should always be moistened with oil when used or they will become clogged or glazed and will no longer cut properly. If this should happen, the stone may be cleaned with solvent and then reoiled. Since stones are brittle, they should not be dropped or otherwise subjected to rough treatment.

§ 275. Grinding wheels Grinding wheels can be broken by hard blows, by heavy pressure, or by excessive tightening of the spindle nut. Thus, reasonable caution should be exercised in the use of the grinding wheel. Goggles should always be worn, and the safety shield should be in place, when the wheel is used. Figure 16-54 shows the wheel being used to grind a screwdriver, while Fig. 16-49 shows the use of a special drill-grinding fixture. In general, the purpose of using the grinding wheel is to restore the working
edges of the tool to their original shape and sharpness. Overheating of the tool should be avoided, since this would draw the temper of the steel. The tool should be repeatedly dipped in water during the grinding process, to prevent it from becoming too hot. The type of steel being ground can be determined by watching the sparks thrown off by the grinding operation. See Fig. 16-55.

![Fig. 16-55. Identification of different types of steel by spark test.](image)

§276. Lathe work. The subject of lathe work is such a large one that no attempt is made herein to do more than provide an introduction to the lathe. The lathe, essentially, is a precision machine for shaping objects. The object to be shaped is mounted in the machine and rotated, while a cutting tool, thrust against it, cuts it down to the shape desired. A typical lathe is illustrated in Fig. 16-56, with the principal parts named.

A great variety of jobs can be performed in a lathe. A few of the more common ones will be mentioned below.

To turn a shaft down to a smaller diameter, the shaft is mounted on centers in the faceplate and in the tailstock. The shaft is caused
to rotate by means of a lathe dog which is clamped on the shaft. The tail of the lathe dog is placed into one of the slots provided in the faceplate. The cutting tool, which is assembled into the tool post, is then brought to bear on the shaft as it rotates, causing the metal to be cut away.

The tool post, and thus the tool, can be moved in two ways, longitudinally or parallel to the work, and across or perpendicular to the work. The tool can be moved longitudinally by operation of the longitudinal-feed handwheel, and across the work by operation of the cross-feed knob. The tool can be automatically fed in either direction by tightening the automatic-feed friction clutch in the lathe apron. The position of the feed change lever determines the direction in which the tool moves. If the feed change lever is up, the tool moves longitudinally. If the lever is down, the tool is cross-fed into the work. The center position is neutral. In the longitudinal-feed position, the tool can be made to move from right to left or from left to right by operating the feed reverse lever.
Likewise, in cross-feed, the tool can be made to move from the center out or from the outside in.

When the object to be turned cannot be mounted on centers, it is usually held in a chuck. The chuck contains a series of three or four jaws that can be tightened against the object to hold it securely. The chuck is first installed on the lathe in place of the faceplate; next, the object to be turned is mounted in the chuck, or "chucked up." The cutting tool is then brought in against the object for the turning operation.

A screw thread can be turned on a shaft by the use of a properly shaped tool and by setting the cutting speed and feed speed to the correct values. Drilling, tapping, taper turning and boring, lapping, polishing, valve refacing, coil and spring winding, grinding, knurling, milling, and reaming are some of the other jobs that can be performed in this versatile machine, the lathe.

**§277. Service publications** Manufacturers of automobiles, automobile parts, accessories, and service tools issue shop manuals, service bulletins, and parts catalogues which supply information on their equipment. These publications are for the guidance of the automotive mechanic and are designed to make his job easier. In case there is doubt as to the proper procedure to follow or as to the proper dimensions or specifications, the factory-issued manual should always be consulted.

Automobile manufacturers issue, in addition to the above publications, flat-rate booklets which list the average time required to perform the various service jobs on their vehicles. These booklets are handy in figuring the cost of a service job, since, if the time required and the parts needed are known, it becomes a simple matter to calculate the cost.
Glossary

THIS GLOSSARY of automotive terms used in the book provides a ready reference for the student. The definitions may differ somewhat from those given in a standard dictionary; they are not intended to be all-inclusive but have the purpose of serving as reminders, so that the student can quickly refresh his memory on automotive terms about which he may be doubtful. More complete definitions and explanations of the terms are found in the text.

**Abrasive**  In automotive service, a substance used for cutting, grinding or polishing metal.

**Accelerator**  The foot-operated pedal linked to the throttle valve in the carburetor.

**Accelerator pump**  In the carburetor, a pump linked to the accelerator which momentarily enriches the mixture when the accelerator pedal is depressed.

**Air cleaner**  A device mounted on the carburetor for filtering out dirt and dust from air being drawn into the engine.

**Air horn**  In the carburetor, the tubular passage through which the incoming air must pass.

**Air pressure**  Atmospheric pressure (14.7 pounds per square inch at sea level) or pressure of air produced by pump, by compression in engine cylinder, etc.

**Antifriction bearings**  Ball or roller bearings.

**Antiknock**  In engine fuels, that property that opposes knocking.

**Arbor**  A shaft for holding or mounting parts for machine operations.

**Atmospheric pressure**  Pressure of the atmosphere, or air, due to its weight pressing downward. Average is 14.7 psi at sea level.

**Axle.**  A crossbar supporting a vehicle, on which one or more wheels turn.

**Backfiring**  Pre-explosion of air-fuel mixture so that explosion passes the still-open intake valve and flashes back through the intake manifold.

**Backlash**  Clearance between meshing teeth of two gears, which will permit backward rotation of driven gear in direction opposite to driving rotation.
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**Ball-peen hammer** A hammer with a ball on one end of head.

**BDC** Bottom dead center, which see.

**Bearing** Generally, the curved surface on a shaft or in a bore; the part assembled onto one or into the other to permit relative rotation with minimum wear and friction.

**Bearing caps** In the engine, caps held in place by bolts or nuts which, in turn, hold bearing halves in place.

**Bell-shaped** Refers to type of wear of an opening (such as a bearing) where end is worn most so that opening flares out like a bell.

**Bhp** Brake horsepower, which see.

**Big end** Refers to the crankpin end of connecting rod.

**Blow-by** Leakage of compressed air-fuel mixture or burned gases from the combustion chamber past the piston rings and into the crankcase.

**Body** The assemblies of sheet-metal sections, together with windows, doors, seats, and other parts, that provides an enclosure for the passengers, engine, etc.

**Bore** Diameter of engine cylinder hole; also diameter of any hole, as for instance the hole in which a bushing fits.

**Boring bar** A cutting tool used to machine cylinders, thereby removing metal, enlarging the bore, and truing it.

**Bottom dead center** The piston position at which the piston has moved to the bottom of the cylinder and the center line of the connecting rod is parallel to the cylinder walls.

**Brake** A device for slowing or halting the motion of any object or mechanism.

**Brake drums** Metal drums mounted on the car wheels; brake shoes press against the drums to slow or stop drum and wheel rotation for braking.

**Brake horsepower** The power delivered by the engine which is available for driving the vehicle.

**Brake shoes** Arc-shaped metal pieces lined with heat-resistant fiber which are forced against the revolving drums to produce braking action.

**Brakes** The mechanism that enables the driver to slow or stop the car by depressing a foot pedal; this action results in the application of a braking or retarding force at the car wheels.

**Breather** The opening that allows air to circulate in the crankcase and thus produce crankcase ventilation.

**Burnisher** A cylindrical tool with integral collars that increase in diameter from one end of the tool to the other.

**Burr** A feathered edge of metal left on a part being cut with a file or other cutting tool.
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**Bushing** A sleeve placed in a bore to serve as a bearing surface.

**Butane** A type of LPG liquid below 32°F (at atmospheric pressure).

**Caliper** A measuring tool that can be set to measure the thickness of a block, the diameter of a shaft, or the bore of a hole (inside caliper).

**Cam** An irregularly shaped moving part designed to move or alter the motion of another part.

**Cam ground** Refers to oval-shaped piston, so ground as to permit piston expansion when heated, with piston assuming a round shape when hot.

**Cam-ground piston** A piston that is ground slightly oval in shape. It becomes round as it expands with heat.

**Camshaft** The shaft in the engine that has a series of cams for operating the valve mechanisms. It is driven by gears or sprockets and chain from the crankshaft.

**Carbon** A substance deposited on engine parts by the combustion of the fuel. Carbon forms on pistons, rings, valves, etc., inhibiting their action.

**Carbon dioxide** A gas resulting from burning of fuel.

**Carbon monoxide** A poisonous gas produced by a running gasoline engine.

**Carburetor** The device in the fuel system that mixes air and gasoline (vaporizing the gasoline as it does so) in varying proportions to suit engine operating conditions.

**Casing** The tire casing, made of fabric or cord to which rubber is vulcanized; it is the outer part of the tire assembly.

**Cetane** Ignition quality, or ease of ignition, of diesel fuel oil; the higher the cetane number, the lower the ignition temperature of the oil.

**Chassis** The assembly of mechanisms that make up the major operating part of the vehicle. It is usually assumed to include everything except the car body.

**Chisel** A cutting tool with a specially shaped cutting edge designed to be driven by a hammer.

**Choke** In the carburetor, a device that chokes off the air flow through the air horn, thus producing a partial vacuum in the air horn for greater fuel delivery and a richer mixture.

**Clearance** The space between two moving parts or between a moving and a stationary part such as a journal and a bearing. Clearance is considered to be filled with lubricating oil when engine is running.

**Clutch** In the vehicle, the mechanism in the power train that connects the engine crankshaft to, or disconnects it from, the transmission and thus the remainder of the power train.
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Clutch gear  See clutch shaft.
Clutch shaft  Also called the drive pinion and clutch gear. The shaft on which the clutch is assembled, with gear that drives the countershaft in transmission.
Coil spring  A spring made up of an elastic metal, such as steel, formed into a wire or bar and wound into a coil.
Combustion  Burning; in engine, the rapid burning of air-fuel mixture in cylinder.
Combustion chamber  The space at the top of the cylinder and in the head in which combustion of the air-fuel mixture takes place.
Compression gauge  A device for testing the amount of pressure developed in the engine cylinder during cranking.
Compression ratio  The ratio between the volume in the cylinder with the piston at BDC and the volume with the piston at TDC.
Compression rings  The upper ring or rings on a piston, designed to hold the compression in the cylinder and prevent blow-by.
Compression stroke  The piston stroke from BDC to TDC during which both valves are closed and the air-fuel mixture is compressed.
Connecting-rod bearing  Same as rod bearing, which see.
Connecting-rod cap  That part of the connecting-rod assembly that attaches the rod to the crankpin.
Connecting rods  In the engine, linkages between the cranks on the crankshaft and the pistons.
Cooling system  In the engine, the system that removes heat from the engine and thereby prevents overheating. It includes the water jackets, water pump, radiator, and thermostat.
Countershaft  In the transmission, a shaft with gears that turns counter to the clutch shaft.
Crank  A device for converting reciprocating motion into rotary motion, or vice versa.
Crankcase  The lower part of the engine, in which the crankshaft rotates. The upper part is lower section of the cylinder block while the lower part is made up of the oil pan.
Crankcase dilution  Dilution of the lubricating oil in the oil pan by liquid gasoline seeping down the cylinder walls.
Crankcase ventilator  The device that permits air to flow through the engine crankcase when engine is running.
Cranking motor  Same as starting motor, which see.
Crankpin  The bearing surface on a crank of the crankshaft, to which the connecting rod is attached.
Crankshaft  The main rotating member, or shaft, of the engine with cranks to which the connecting rods are attached.
Glossary

Cross firing Jumping of high-voltage surge in ignition secondary to wrong high-tension lead so that wrong spark plug fires. Usually caused by faulty insulation or defective distributor cap or rotor.

Cycle A series of events with a definite start and finish. In the engine, the four piston strokes (or two piston strokes) that complete the working process and produce power.

Cylinder A tubular-shaped structure. In the engine, the tubular opening in which the piston moves up and down.

Cylinder block The basic framework of the engine in and on which the other engine parts are attached. It includes the engine cylinders and the upper part of the crankcase.

Cylinder head The part that encloses the cylinder bores. Contains water jackets and, on I-head engine, the valves.

Cylinder sleeves Sleeves inset into the cylinder block to form the cylinder walls.

Degree 1/360 part of a circle.

Detonation In the engine, excessively rapid burning of the compressed charge which results in knock, which see.

Dial indicator A gauge that has a dial face and needle to register movement. Used to measure variations in size, movements too small to be measured conveniently by other means, etc.

Diamond-tipped tool A tool with a cutting edge made of a diamond.

Die A special cutting tool for cutting threads on a rod.

Diesel cycle An engine cycle of events in which air alone is compressed and fuel oil is injected at the end of the compression stroke. The heat produced by compressing the air ignites the fuel oil.

Diesel engine An engine operating on the diesel cycle and burning oil instead of gasoline.

Differential A mechanism at the rear axles (in passenger cars) that permits the rear wheels to turn at different speeds. It transmits power from the propeller shaft to the wheel axles.

Drill Also called twist drill. A cylindrical bar with helical grooves and a point for cutting holes in material. Also refers to the device that rotates the drill.

Dry friction The friction between two dry solids.

Dual carburetors Carburetors with two air horns, fuel nozzles, throttle valves, idle circuits, etc.

Dynamometer A device for measuring power output of an engine.

Eccentric Off center.

Efficiency Ratio between the effect produced and the power expended.

Electric system In the automobile, the system that electrically cranks the engine for starting, furnishes high-voltage sparks to the engine.
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cylinders to fire the compressed air-fuel charges, lights the lights, operates the heater motor, radio, etc. Consists, in part, of starting motor, wiring, battery, generator, regulator, ignition distributor, ignition coil.

**End play** As applied to crankshaft, the amount of end movement that the crankshaft has.

**Energy** The capacity or ability to do work.

**Engine** The assembly that burns fuel to produce power, sometimes referred to as the power plant.

**Engine tune-up** The procedure of checking and adjusting various engine components so engine is restored to top operating condition.

**Ethyl** Tetraethyllead, which see.

**Exhaust gas analyzer** A device for analyzing exhaust gases to determine carburetor action.

**Exhaust manifold** That part of the engine that provides a series of passages through which burned gases from the engine cylinders can flow.

**Exhaust stroke** The piston stroke from BDC to TDC during which the exhaust valve is open so that the burned gases are forced from the cylinder.

**Exhaust valve** The valve which opens to allow the burned gases to exhaust from the engine cylinder during the exhaust stroke.

**Expander** A device placed in a piston to expand it and thereby improve piston fit in the cylinder. Also, a ring placed under a piston ring to increase ring pressure on cylinder walls.

**Expansion plug** A plug that is slightly dished out. When driven into place, it is flattened and expanded to fit tightly.

**Fatigue of metal** A type of metal failure resulting from repeated stress which finally alters character of metal so that it cracks.

**Feeler stock** Strips of metal of accurately known thicknesses used to measure clearances.

**F-head engine** A type of engine in which some of the valves are in the cylinder head and some in the cylinder block, giving an F-shaped appearance.

**File** A cutting tool with a large number of cutting edges arranged along a surface.

**Final drive** That part of the power train that transmits the power from the transmission to the wheels, consisting of the propeller shaft, differential, and wheel axles.

**Firing order** The order in which the engine cylinders fire, or deliver their power strokes.

**Float bowl** In the carburetor, the reservoir from which gasoline feeds into the passing air.

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Flywheel The rotating metal wheel attached to the crankshaft, which helps even out the power surges from the power strokes and also serves as part of the clutch and engine-cranking system.

Four cycle Short for four-stroke cycle, which see.

Four-stroke cycle The four operations of intake, compression, power, and exhaust, or four piston strokes, that make up the complete cycle of events in the four-stroke-cycle engine.

Frame The assembly of metal structural parts and channel sections that supports the engine and body and is supported by the car wheels.

Friction The resistance to motion between two bodies in contact with each other.

Fuel nozzle The tube in the carburetor through which gasoline feeds from the float bowl to the passing air.

Fuel pump The device in the fuel system which delivers gasoline from the fuel tank to the carburetor.

Fuel system In the automobile, the system that delivers to the engine cylinders the combustible mixture of vaporized fuel and air. It consists of fuel tank, lines, gauge, carburetor, pump, manifold.

Fuel tank The metal tank that serves as a storage place for gasoline.

Fuzz Featheredged high spots left on shaft or other part by grinding wheel; roughness left after grinding.

Gasket In the engine, a cutout or perforated sheet of metal, cork, or other material designed to provide a tight seal between two assembled parts.

Gasket cement An adhesive material used to apply gaskets.

Gasoline A hydrocarbon suitable as an engine fuel, obtained from petroleum.

Gear ratio The relative speeds at which two gears (or shafts) turn; the proportional rate of rotation.

Gears Mechanical devices to transmit power, or turning effort, from one shaft to another: gears contain teeth that interlace or mesh as the gears turn.

Generator That part of the electric system that converts mechanical energy into electric energy for lighting lights, charging the battery, operating the ignition system, etc.

Goggles Special glasses worn over the eyes to protect them from flying chips, dirt, or dust.

Gravity The attractive force between objects that tend to bring them together. A stone dropped from the hand falls to the earth because of gravity.

Greasy friction The friction between two solids coated with a thin film of oil.
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**Grinder** A machine for removing metal by means of an abrasive wheel or stone.

**Grinding wheel** An abrasive wheel used for grinding metal objects held against it.

**Guide sleeve** A tubular sleeve that is put on rod bolt when connecting rod is removed, to prevent scratching of crankpin.

**Hack saw** A special form of saw with removable blade, used to saw metals.

**Heat-control valve** In the engine, a thermostatically operated valve in the exhaust manifold for varying heat to intake valve with engine temperature.

**Heat dam** In a piston, a groove cut out to reduce the size of the path through which heat can travel; this allows the piston skirt to run cooler.

**Heat of compression** Increase of temperature brought about by compression.

**Hesselman engine** An engine operating on the diesel cycle but with lower compression ratio, ignited by a gasoline-engine-type ignition system.

**Hone** An abrasive stone that is rotated in a bore or bushing to remove material.

**Horsepower** A measure of a definite amount of power; 33,000 ft-lb (foot-pounds) of work per minute.

**Hydraulic brakes** A braking system that uses hydraulic pressure to force the brake shoes against the brake drums as the brake pedal is depressed.

**Hydraulic valve lifter** A valve lifter that, by means of hydraulic oil pressure, maintains zero valve clearance so that valve noise is reduced.

**Idle circuit** In the carburetor, the passage through which fuel is fed when the engine is idling.

**Idling speed** The speed at which the engine runs without load when the accelerator pedal is released.

**Ignition coil** That part of the ignition system which acts as a transformer to step up the battery voltage to many thousands of volts; the high-voltage surge then produces a spark at the spark-plug gap.

**Ignition distributor** That part of the ignition system which closes and opens the circuit to the ignition coil with correct timing and distributes to the proper spark plugs the resulting high-voltage surges from the ignition coil.

**Ignition system** In the automobile, the system that furnishes high-
voltage sparks to the engine cylinders to fire the compressed air-fuel charges. Consists of battery, ignition coil, ignition distributor, ignition switch, wiring, and spark plugs.

**I-head engine** A type of engine with valves in the cylinder head. The combustion chamber is I-shaped.

**Ihp** Indicated horsepower, which see.

**Indicated horsepower** A measurement of engine power based on power actually developed in the engine cylinders.

**Inertia** Property of objects that causes them to resist any change in speed or direction of travel.

**Inner tube** The inside rubber tube assembled in the tire casing; it maintains the air at sufficient pressure to inflate the casing and to support the vehicle weight adequately.

**Intake manifold** That part of the engine that provides a series of passages from the carburetor to the engine cylinders through which air-fuel mixture can flow.

**Intake stroke** The piston stroke from TDC to BDC during which the intake valve is open and the cylinder receives a charge of air-fuel mixture.

**Intake valve** A valve that opens to permit air-fuel mixture to enter the cylinder on the intake stroke.

**Knock** In the engine, a rapping or hammering noise resulting from excessively rapid burning of the compressed charge.

**Lapping** A method of seating valves by which the valve is turned back and forth on the seat; no longer recommended by car manufacturers.

**Lathe** A machine tool used to shape objects. Its distinguishing feature is that it rotates the object while a cutting tool is brought to bear upon it so that material is cut from the object.

**Leaf spring** A spring made up of a series of flat steel plates of graduated length, assembled one on top of another.

**L-head engine** A type of engine with valves in the cylinder block; the combustion chamber is L-shaped.

**Lifter** Valve lifter, which see.

**Line ream** A method of finishing two or more aligned bushings or bearings so that accurate alignment is achieved.

**Liquefied petroleum gas** A hydrocarbon suitable for use as an engine fuel, obtained from petroleum and natural gas; a vapor at atmospheric pressure but liquefied if put under sufficient pressure.

**Lock nut** A second nut turned down on a holding nut to prevent loosening.

**LPG** Liquefied petroleum gas, which see.
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**Lubrication system** The system in the engine that supplies moving engine parts with lubricating oil.

**Lugging** Low-speed, full-throttle engine operation in which engine is heavily loaded and is worked hard.

**Main bearings** In the engine, the bearings for the crankshaft.

**Mandrel** A dimensioned shaft for holding or aligning parts (as when turning them in a lathe). Also called arbor.

**Master cylinder** The liquid-filled cylinder in the hydraulic braking system where hydraulic pressure is developed by depression of the brake pedal.

**Mechanical efficiency** In an engine, the ratio between brake horsepower and indicated horsepower.

**Mechanism** A system of interrelated parts that make up a working agency.

**Metalizing** A process of spraying liquid metal onto a prepared surface to build it up.

**Metering rod** A device in the carburetor that enlarges or decreases the fuel passage to the fuel nozzle, thus varying fuel delivery for various throttle openings.

**Micrometer** A measuring device that accurately measures such dimensions as shaft or bore diameter or thickness of an object.

**Mike** A slang term for micrometer, which see.

**Missing** In the engine, the failure of a cylinder to fire when it should.

**Muffler** In the exhaust, a device through which the exhaust gases must pass and which muffles the sound.

**Octane** A measure of the antiknock value of engine fuel.

**Oil-control rings** The lower ring or rings on a piston, designed to prevent excessive amounts of oil from working up into the combustion chamber.

**Oil pan** The detachable lower part of the engine, made of sheet metal, which encloses the crankcase and acts as an oil reservoir.

**Oil pump** In the lubrication system, the device that delivers oil from the oil pan to the various moving engine parts.

**Oil seal** A seal placed around a rotating shaft, etc., to prevent escape of oil.

**Oilstone** A block of abrasive material bonded together and used for removing metal.

**Orifice** A small opening, or hole, into a cavity.

**Otto cycle** The four operations of intake, compression, power, and exhaust, so named for the inventor, Dr. Nikolaus Otto.

**Overhead valve** Valve mounted in head above combustion chamber. Valve in I-head engine.
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Ping A metallic rapping sound from engine cylinder, caused by detonation.

Piston In engine, the cylindrical part that moves up and down in the cylinder.

Piston pin Also called wrist pin. The cylindrical or tubular metal piece that attaches the piston to the connecting rod.

Piston-pin bearing The bearings or bushings in the piston and upper end of the connecting rod, in which the piston pin rides.

Piston rings Rings fitted into grooves in the piston. There are two types, compression rings for sealing the compression into the combustion chamber and oil rings to scrape excessive oil off the cylinder wall and thereby prevent it from working up into and burning in the combustion chamber.

Piston skirt The lower part of the piston.

Piston slap Hollow, muffled, bell-like sound made by excessively loose piston slapping cylinder wall.

Piston vise A special form of vise for gripping a piston. It has round jaws of the same curvatures as the piston so that piston will not be damaged.

Pitman arm That part of the steering gear which is linked to the steering-knuckle arms of the wheels; it swings back and forth for steering.

Plastigage A plastic material that comes in strips; used to measure bearing clearance.

Poppet valve A mushroom-shaped valve, widely used in automotive engines.

Port In the engine, the valve port or opening in which valve operates and through which air-fuel mixture or burned gases pass.

Power The rate of doing work.

Power steering A device that uses hydraulic pressure to multiply the driver’s effort as he turns the steering wheel so that steering effort is reduced.

Power stroke The piston stroke from TDC to BDC during which the air-fuel mixture burns and forces the piston down so that the engine produces power.

Power train The group of mechanisms that carry the rotary motion developed in the engine to the car wheels; it includes clutch, transmission, propeller shaft, differential, and axles.

Precision-insert bearings Bearings of the type that can be installed in an engine without reaming, honing, or grinding.

Press fit A fit so tight, as a piston pin in a pin bushing, for example,
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that the pin has to be pressed into place (usually with an arbor press).

Prony brake A device for measuring power output of an engine.

Propane A type of LPG liquid below 44°F (at atmospheric pressure).

Propeller shaft A shaft in the power train that extends from the transmission to the differential and transmits power from one to the other.

Psi Pounds per square inch; usually used to indicate pressure of a liquid or gas.

Puller Generally, a service tool that permits removal of one part from another without damage. Contains a screw or screws which can be turned to apply gradual pressure.

Push rod In the I-head engine, the rod between the valve lifter and the rocker arm.

Radiator In the cooling system, the device that removes heat from water passing through, thus taking hot water from the engine and returning cooled water to the engine.

Reamer A metal-cutting tool with a series of sharp cutting edges that remove material from a hole when the reamer is turned in it.

Reciprocating motion Motion of an object between two limiting positions; motion back and forth, or up and down, etc.

Regulator In the electric system, a device that controls the generator output to prevent excessive voltage or excessive output.

Resizing As applied to pistons, increasing piston diameter by various means so as to improve piston fit in cylinder.

Ridge remover A service tool for removing ring ridge from cylinder.

Ring gap The gap between the ends of the piston ring with the ring in place in the cylinder.

Ring grooves Grooves cut in a piston, into which the piston rings are assembled.

Ring ridge Ridge left at top of cylinder as cylinder wall below it is worn by piston-ring movement.

Rocker arm In I-head engines, a device that rocks on a shaft as the cam actuates the push rod, to cause the valve to open.

Rod bearings In the engine, the bearings in the connecting rod in which a crankpin of the crankshaft rotates.

Rod bolts Bolts used on connecting rod to attach rod cap.

Rpm Revolutions per minute.

Scored Scratched or grooved, as a cylinder wall may be scored by abrasive particles moved up and down by the piston rings.

Scrapper A device used in engine service to scrape carbon, etc., from engine block, pistons, etc.
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Screw driver A device to loosen or tighten screws.

Scuff A type of wear of moving parts characterized by transfer of material from one to the other part and pits or grooves in the mating surfaces.

Shim A strip of copper or similar material used under a bearing cap, for example, to increase bearing clearance.

Shock absorber The assembly on the vehicle that checks excessively rapid spring movement and oscillation.

Shrink fit A tight fit of one part in another, as for instance a piston pin in pin bushings, achieved by heating the outer part (piston and bushing) and then assembling the two so that the outer part, in cooling, shrinks to a tight fit.

Slip joint In the power train, a variable-length connection that permits the propeller shaft to change effective length.

Sludge Accumulation in oil pan, containing water, dirt, and oil; sludge is very viscous and tends to prevent lubrication.

Socket wrench A wrench that fits entirely over head of bolt as opposed to an open-end wrench.

Soldering The uniting of pieces of metal with solder, flux, and heat.

Spark plug The assembly, which includes a pair of electrodes and insulator, that has the purpose of providing a spark gap in the engine cylinder.

Spline Slot or groove cut in a shaft or bore; a splined shaft onto which a hub, wheel, gear, etc., with matching splines in its bore is assembled so that the two must turn together.

Spring An elastic device which yields under stress or pressure, but returns to its original state or position when the stress or pressure is removed.

Steering motor The electric motor in the electric system that cranks the engine or turns the crankshaft for starting.

Steering gear That part of the steering system, located at the lower end of the steering shaft, that carries the rotary motion of the steering wheel to the car wheels for steering.

Steering system The mechanism that enables the driver to turn the wheel axles (usually the front) and thus turn the wheels away from the straight-ahead position so that the car can be guided.

Steering wheel The wheel at the top of the steering shaft in the driver’s compartment which is used to guide, or steer, the car.

Storage battery That part of the electric system which acts as a reservoir for electric energy, storing it in chemical form.

Streamlining The shaping of an object that moves through a medium (such as air or water), or past which the medium moves, so that
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less energy is lost by the parting and reuniting of the medium as
the object moves through it.

Stroke In an engine, the distance that the piston moves from BDC to
TDC.

Stud A headless bolt threaded on both ends.

Swage A process of spreading metal to tighten fit, of bushing in a bore,
for example.

Tap A special cutting tool for cutting threads in a hole.

Taper A decrease in diameter from one place to another, as taper in a
cylinder, taper of a shaft.

Tappet Another name for valve lifter, which see.

TDC Top dead center, which see.

Tel Tetraethyllead, which see.

Tetraethyllead A chemical put into engine fuel which increases octane
rating or reduces knock tendency.

Thermal efficiency Relationship between the power output and the en-
ergy in the fuel burned to produce the output.

Thermostat A device that operates on temperature changes. Several
thermostats are used in engines, in the cooling system, in the mani-
fold heat control, etc.

Throttle valve The round disk in the lower part of the carburetor air
horn that can be turned to admit more or less air.

Throwout bearing In the clutch, the bearing that can be moved in to
the release levers by clutch-pedal action so as to cause de-clutch-
ing, or a disconnection between the engine crankshaft and power
train.

Tie rods In the steering system, the rods that link the pitman arm
to the steering-knuckle arms.

Timing In the engine, refers to timing of valves and also timing of
ignition.

Tire The casing and tube assembled on a car wheel to provide
pneumatically cushioned contact and traction with road.

Top dead center The piston position at which the piston has moved
to the top of the cylinder and the center line of the connecting rod
is parallel to the cylinder walls.

Torque Turning or twisting effort, measured in pound-feet.

Torque wrench A special wrench, with a dial that indicates the amount
of torque applied to the nut or bolt being turned.

Torsional balancers Same as vibration damper, which see.

Transmission Also called the change gears. The device in the power
train that provides different gear ratios between the engine and
rear wheels, as well as reverse.
Glossary

Trouble-shooting The detective work necessary to run down the cause of a trouble. Implies the correction of the trouble by elimination of cause.

Turbulence The state of being violently disturbed. In the engine, the rapid swirling motion imparted to the air-fuel mixture entering the cylinder.

Two cycle Short for two-stroke cycle, which see.

Two-stroke cycle The series of events taking place in a two-stroke-cycle engine, which are intake, compression, power, and exhaust, all of which take place in two piston strokes.

Universal joint In the power train, a jointed connection in the propeller shaft that permits a change of driving angle.

Vacuum An absence of air or other substance.

Vacuum gauge In automotive engine service, a device that measures intake-manifold vacuum and thereby indicates actions of engine components.

Valve A device that can be opened or closed to allow or stop the flow of a liquid, gas, or vapor from one place to another.

Valve clearance The clearance between the adjusting screw on the valve lifter and the valve stem (in L-head engines) or between the rocker arm and the valve stem (in I-head engines).

Valve guide The cylindrical part in the cylinder block or head in which the valve is assembled and in which it moves up and down.

Valve-in-head An I-head engine, which see.

Valve lash Same as valve clearance, which see.

Valve lifter Also called valve tappet. A cylindrical part of the engine which rests on a cam of the camshaft and is lifted by the cam action so that the valve is opened. There is a valve lifter for each valve.

Valve refacer A machine for removing material from the seating face of valves so that a new face “appears.”

Valve-seat inserts Metal rings inserted in valve seats, usually exhaust; they are of special metal more able to withstand high temperatures.

Valve-spring retainer The device on the valve stem that holds the spring in place.

Valve-spring-retainer lock The locking device on the valve stem that locks the spring retainer in place.

Valve stem The long, thin section of the valve that fits in the valve guide.

Valve tappet See valve lifter.

Valve train The valve-operating mechanism from the camshaft to the valve.

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Vapor lock A condition in the fuel system in which gasoline has vaporized, as in the fuel line, so that fuel delivery to the carburetor is blocked or retarded.

V-8 engine A type of engine with two banks of cylinders set at an angle to each other to form a V.

Venturi In the carburetor, the restriction in the air horn that produces the vacuum responsible for the movement of gasoline into the passing air.

Vibration A complete rapid motion back and forth; oscillation.

Vibration damper A device attached to the crankshaft of an engine which opposes crankshaft torsional vibration.

Viscosity The term used to describe a liquid’s resistance to flow. A thick oil has greater viscosity than a thin oil.

Viscous Thick, tending to resist flowing.

Viscous friction Friction between layers of a liquid.

Vise A gripping device for holding a piece while it is being worked on.

Volumetric efficiency Ratio between the amount of air-fuel mixture that actually enters an engine cylinder to the amount that could enter under ideal conditions.

V-type engine Engine with two banks of cylinders set at an angle to each other in shape of a V.

Water-distributing tube In the engine cooling system, a tube that improves water circulation around exhaust valves and other areas that might overheat.

Water jacket The space between the inner and outer shells of the cylinder block or head through which cooling water can circulate.

Water pump In the cooling system, the device that maintains circulation of the water between the engine water jackets and the radiator.

Welding The process of joining pieces of metal by fusing them together with heat.

Wheel cylinders In the hydraulic braking system, hydraulic cylinders placed in the brake mechanisms at the wheels; hydraulic pressure from the master cylinder causes the wheel cylinders to move the brake shoes into pressure contact with the brake drums for braking.

Work Work is the changing of the position of a body against an opposing force, measured in foot-pounds.

Wrench A tool designed to tighten or loosen nuts or bolts.
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