INTERACTION OF RADIATION WITH MATTER

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INTERACTION OF RADIATION WITH MATTER

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BHUBANESWAR

CERTIFICATE – I

This is to certify that the thesis entitled, **"Interaction of Radiation With Matter"** *submitted in partial fulfillment of the requirements for the award of the degree of* ***Master of Science*** *in* ***Physics*** *of the* ***Odisha University of Agriculture and Technology****, Bhubaneswar, is a faithful record of bona fide research work carried out by* ***Soumya Ranjan Swain*** *under my guidance and supervision and that no part of this thesis has been submitted for any other degree or diploma or published in any form.*

It is further certified that the help and sources of information availed of during the course of study have been duly acknowledged.

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CERTIFICATE – II

*This is to certify that the thesis entitled, "**Interaction Of Radiation With Matter**" submitted in partial fulfillment of the requirements for the award of the degree of **Master of Science** in **Physics** of the **Odisha University of Agriculture and Technology**, Bhubaneswar, is a faithful record of bona fide research work carried out by **Soumya Ranjan Swain** under my guidance and supervision and that no part of this thesis has been submitted for any other degree or diploma or published in any form.*

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DECLARATION

I hereby declare that the project work entitled **"INTERACTION OF RADIATION WITH MATTER"** submitted by me for the partial fulfillment of the Master of Science to the **CBSH, Odisha University of Agriculture & Technology**, Bhubaneswar is my own original work and has not been submitted earlier to OUAT or to any other institution for the fulfillment of the requirement for any course of study. I also declare that no chapters of this manuscript in whole or in part in lifted and incorporated in this report from any earlier work done by me or others.

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ABSTRACT

This work elucidates and makes an in-depth analysis of interactions of electron beam, gamma rays, X-ray, laser beam at molecular level. All these interactions avoid use of chemicals and hence environment friendly. The interactions produce no wastes with very short processing time in modification of the materials. The industry is now in search of innovative techniques in production of new materials, exhibiting superior properties compared to the traditional materials in cost effective, environment friendly and in time saving manner. So it's necessary to understand the mechanism of molecular interactions of these radiations with materials so that design of new materials can be more yielding and fecund. This work describes the complex mechanisms of principles of treatment of each radiation on matter in solid-state. Different molecular interaction mechanisms such as physical sputtering, itching, ablation, polymerization, graft copolymerization etc are discussed for each interaction. Formation of metastable particles, ions, free radicals, functional groups is discussed in details. Different key parameters such as dose of irradiation, beam configuration, line speed, energy of the beams, exposure time, penetration capability, etc are discussed along with the working principle of accelerators generating these radiations.

CONTENT

CHAPTER-I

INTRODUCTION

The communication of radiation with issue can be viewed as the main cycle known to mankind. At the point when the universe started to chill off at a beginning phase in its advancement, stars, similar to the Sun, and planets showed up, and components like hydrogen (H), oxygen (O), nitrogen (N), and carbon (C) joined into basic atoms like water (H2O), alkali (NH3), and methane (CH4). The bigger hydrocarbons, alcohols, aldehydes, acids, and amino acids were eventually worked because of the activity (1) of far-bright light (frequency under 185 nanometres) before oxygen showed up in the climate, (2) of entering alpha, beta, and gamma radiations, and (3) of electric releases from lightning storms when the temperature dropped and water started to consolidate. These straightforward mixtures communicated and at last formed into living matter. How much—if by any stretch of the imagination—the radiations from radioactive rot added to the combination of living matter isn't known, however the event of high-energy-light impacts on issue at early occasions throughout the entire existence of this world is recorded in specific micas as infinitesimal, concentric rings, called pleochroic coronas, delivered as the aftereffect of the rot of minuscule spots of radioactive material that discharged infiltrating items, like alpha particles. At the ends of their ways, particles of this sort delivered synthetic changes, which can be seen minutely as dim rings. From the widths of the rings and the known entering forces of alpha particles from different radioactive components, the idea of the spots of radioactive matter can be set up. Sometimes, alpha particles couldn't have been liable for the impacts noticed; in different cases, the rudimentary bits that involved the focuses of the coronas were not those of any as of now known components.

It tends to be promptly gathered that a portion of the components that partook in the advancement of the world were not initially present yet were delivered as the aftereffect of outer high-energy assault, that some vanished as the aftereffect of such cycles, and that many mixtures needed for the living cycles of creatures developed as an outcome of the great energy illumination to which all matter is oppressed. Subsequently, radiation is accepted to play had a significant impact in the development of the universe and is at last capable for the presence of life as well as for the assortment of its structures.

CHAPTER-2

Radiations dose units

Exposure describes the amount of radiation travelling in air. The units of exposure are:

(1)Roentgen (R)

(2)Coulomb/Kg

The amount of radiation engrossed by an object or a person is measured in

(1)Radiation absorbed dose(rad)

(2)Gray(Gy)

Effective dose combines the amount of radiation absorbed and the medical effects of the radiation.It is measured in

1-Roentgen Equivalent Man (rem)

2-Sievert (Sv)

Biological effective dose

It is also known commonly as BED. It gives information about dose of radiation delivered to a particular biological tissue.The biological effective dose is measured in units of rem.

For beta and gamma irradiation,

Absorbed dose = Biological effective dose

For alpha and neutron irradiation,

Biological effective dose > absorbed dose

Now the relation among different units can be expressed as

1R (exposure) = 1 rad = 1 rem= 1000 m rem

If unit is Ci, it represents radio activity.

R→Radioactive → measured in Ci,Bq

E→Exposure→ measured in Roentgen, C/kg

A→Absorbed→ measured in rad, Gy

D→Equivalent dose→measured in rem, Sv

1 Bq represents how many particles or photons are emitted per second by a source measured by Geiger counts.

Gray(Gy) represents the energy deposited in a kilogram of a substance by radiation.

1 Gy = 1 Joule/Kilogram = 100 rad

It is expressed by

$$Sv = (f)(Gy)$$

where f is radiation weighing factor

the value of f is 1 for gamma rays, electrons and X-rays and it is 20 for α- particles

Product of dose and radiation weighing factor is known as equivalent dose.

$$(Dose)(f) = \text{Equivalent dose}$$

Product of equivalent dose and tissue weighing factor is defined as effective dose

Effective dose= Equivalent dose x tissue weighing factor

Effective dose indicates the probability of a harmful effect from radiation exposure.

The table -1 lists different weighing factor for different tissues

Table-1:Weighing factor of various animal tissues

Animal tissue	Weighing factor
Redbone marrow Large intestine Lung(alveolus) Abdomen Breast	0.12
Genitalias	0.08
Urinary bladder larynx Liver Thyroid	0.04
Bone surface Brain Salivary gland	0.01

The dose therapy depends upon the size of the treated area and the target dose **and the therapeutic** is the amount needed to treat the disease.

CHAPTER-3

Interaction of LASER with matter

Interaction of light with matter can be explained by means of various phenomena such as

- Reflection
- Refraction
- Linear absorption
- Nonlinear absorption
- Scattering(Rayleigh, Mie, Raman)
- Frequency doubling
- Optical doppler effect
- Athermal(ablation) & thermal(melting,vapourization)

The laser accurately delivers large amounts of energy to confined areas of the material**.** If the material is opaque, it will absorb energy at the surface, thus changing its surface, crystalline structure, and shape without changing the overall characteristics**.** The absorption characteristics of **the** surface can be controlled by **changing** its **texture and the** presence of chemical impurities **on** the **surface. The laser** interaction is unique **in that** it **can cause** permanent changes in material properties, which **cannot** be achieved **by others. media.**

For s polarization, the reflectance is expressed as

$$Rs=\left(\frac{E_r}{E_i}\right)^2=\left(\frac{n_1\cos\theta_i-n_2\cos\theta t}{n_1\cos\theta_i+n_2\cos\theta t}\right)\text{.....(1)}$$

n_1, n_2 are refractive indices of 1st and 2nd medium

θ_i , θt are angle of incidence & angle of transmission.

For p polarization, the reflectance is expressed as

$$Rp=\left(\frac{E_r}{E_i}\right)^2=\left(\frac{n_1\cos\theta t-n_2\cos\theta_i}{n_1\cos\theta t-n_2\cos\theta_i}\right)^2 \text{.....(2)}$$

For normal incidence,

$$Rs = Rp=\left(\frac{n_1-n_2}{n_1-n_2}\right)^2$$

R lies between 0.4 and 0.95 for UV & visible rays and lies between 0.9 and 0.99 for IR.

R depends upon temperature. Temperature changes permittivity, band structure, plasma oscillation and phase.For example when Si melts, R changes by 2 and when Ni changes, R changes by few %.

Due to photon-electron interactions, optical resonance phenomena such as surface Plasmon resonance, bulk plasma resonance and polaritons arise. When laser penetrates the material, it is absorbed. Intensity of the light decays with depth Z and is formulated by **Beer- Lambert's law**

$$I(Z)=I_0 e^{-\alpha z}$$

Here I_0 represents the intensity of light inside the surface after loss from reflection .

d $=\frac{1}{\alpha}$ =optical absorption depth.For metals, d is of 10nm.

Adsorption depends upon wavelength, choosing wavelength for shorter absorption depth, allows modification of surface properties and not bulk properties. Optical absorption depth for a particular material depends upon the wavelength. So high absorption depth changes the bulk properties and low absorption depth changes the surface properties.

3.1 NON-LINEAR ABSORPTION

Materials like glasses exhibit nonlinearities in their refractive index. When an intense laser beam passes through a material, it can induce a change in the refractive index of the material and if n is proportional to I , it is nonlinear effect or Kerr effect. Kerr effect is observed when light propagate in crystals, glasses and also in gases.

$$\Delta n \propto E^2$$

3.2:KERR ELECTRON OPTIC EFFECT (DC kerr effect)

A light beam passes through a matter experience a polarization dependent change of optical phase. Birefringence is induced even its naturally absent. That material can now be used as wave plate.The phase difference is propotional to square of the strength of the electric field.

$\Delta\phi = 2\pi k E^2$

But $\Delta\phi = \frac{2\pi}{\lambda}\Delta n$

Where k= kerr constant of the material.

Polar liquids like nitro-toluene, nitro-benzene, are having large values of kerr constant. These molecules can be oriented by the applied electric field, such molecules can be used as reinforcements.

3.3:OPTICAL KERR EFFECT (AC kerr effect)

$$\boxed{\Delta n = n_2 I}$$

n_2 is non-linear refractive index and is proportional to third order of susceptibility χ^3. Electrostriction significantly contribute to the value of non-linear index. The electric field of light causes density variation, generating acoustic waves. Acoustic waves influence the refractive index. This phenomenon is known as photo-elastic effect.

The non linear refractive index is of the order of 10^{-16}cm²/W to 10^{-14}cm² /W for glasses and for fused silica/silica fibers , n_2 is of the order of 2.7×10^{-16} cm²/W.

3.4 DIFFERENT MECHANISM OF NON-LINEAR PHENOMENA

Non linear phenomena can be explained via different mechanisms like

- Self focusing
- Defocusing
- Soliton propagation
- optical breakdown
- single photon interaction
- multi photon interaction

3.5: ENERGY ABSORPTION MECHANISM

Depending on the energy of the photon, the photon will be coupled to the available electron or vibrational state. In isolators and semiconductors, the absorption of laser light occurs through resonance excitation**,** such as the transition from VB to CB or in-band**.** These excited electronic states transfer energy to the lattice photons.

INVERSE BREMSSTRAHLUNG IN METALS

Energy is carried to lattice phonons by collision. The plasma frequency is expressed as

$$\omega_p = \sqrt{\frac{N_e e^2}{m_e \varepsilon_0}} \quad .$$

Reflectivity and absorbance for light having frequency less than plasma frequency is normally very high.The permittivity of a material can be expressed in terms of plasma frequency as

$$\varepsilon = 1 - \frac{{\omega_p}^2}{\omega^2},$$

For metals the plasma frequency is of the order of 10^{15} Hz.

$$\varepsilon = 1 - \frac{\left(10^{15}\right)^2}{\omega^2}$$

When frequency of the incoming wave (ω) is less than plasma frequency(ω_p), the permittivity is negative otherwise positive. Metals absorb visible light, reflect visible light but transmit other high frequency component. Light of frequency above the plasma frequency is transmitted by the metal because the electron in the metal can't respond fast enough to screen it.When energy is not enough to excite electrons, they are transmitted.

Glass allows visible light and IR light to pass, but absorbs UV light. UV excites electrons and electrons interact with UV. Metals allow UV light.

Above plasma frequency, electronic state, vibrational states associated with impurities, surface phenomena or plasmas, polaritons also can be excited.

3.6: PLASMONS AND POLARITONS

Plasmons and polaritons are both quantum mechanical quasi particles which are used to describe interactions in a solid. Free electrons in a metal are considered electron plasma; quantization of plasma oscillation gives rise to plasma. They are bosons having energy.

$$E = \hbar w = \hbar \sqrt{\frac{ne^2}{m_e \varepsilon_0}}$$

Polaritons

Polaritons are bosonic quasi particles. They result from strong coupling of em waves with electric dipole or magnetic dipole that carries excitation.

In a system of two coupled oscillations, with two natural frequencies as the couple strength increases, the lower frequency decreases, higher frequency increases. This is known as repulsion of frequencies. Different types of interactions are observed:

- phonon-polariton
  observed in NaCl where IR photon interacts with optic phonons
- exciton-polariton-
  visible photons interact with exciton
- surface plasma-polariton-

surface plasma interacts with light

Polarons

Electron coupling with its stream field is polarons. This is observed in insulators. A conductivity electron in an ionic crystal together with induced polarization of the surround lattice. The thermalization time is of the order of 10^{-12} to 10^{-10} sec for most of the metals. In non metals it is 10^{-16}sec.

Quantum confined electronic states and presence of defects play a noteworthy role in slowdown of thermalization time. The excited electron states take some time to transfer energy to phonons and thermalize the materials and this time is defined as thermalization time.This can be explained for two different cases.

CASE-1: When laser induced excitation rate $is\ less\ than$ thermalization rate.

- Transient electronic excitation states are not significant.
- Absorbed laser energy converted directly to heat energy.
- Photo thermal process or pyrolytic process occur,

suppose for laser: $\Delta t > 10^{-9}$sec or $\Delta f < 10^{9}$ Hz, then laser process of metals/ semiconductors is by photo-thermal mechanisms.

CASE-II: Laser induced excitation rate is greater than thermalization rate

Large excitations are build up during this. These excited electrons can break bonds known as photo-decomposition. This is non thermal material modification and known as photo chemical/

photolytic decomposition where temperature remains same. Irradiation of polymer with short wavelength laser light, where photon energy is of the order of chemical bond energy.

Ultra fast femoto seconds (10^{-15}) laser can enable photo chemical processes of metals or semiconductors. In photo physical process, materials exhibit both pyrolytic and chemolytic reaction.

3.7 MATERIAL RESPONSE

In photo thermal process, the absorbed laser energy is directly converted to heat energy. Material response depends upon:

- local material heating/cooling rate
- maximum temperature attained
- maximum temperature gradient , etc.

Temperature increase rate can reach 10^9K/sec for nano second pulses, bringing significant changes. These are various temperature dependent processes.

3.7.1: Melting of surface:

Fluences which are above the threshold of melting activate formation of liquified material on the surface.

- Liquified material will result in rapid material homogenization.
- Rapid **cooling** can freeze defects and supersaturated solutes.
- Recrystalization of large grains.
- Hydrodynamic movement can reshape and redistribute materials.
- Connective forces causing significant deformation.

3.7.2: Ablation

Laser ablation is the removal of material from the substrate by directly absorbing laser energy. The creep threshold of metals is between 1 and 10 J/cm², for inorganic insulators, between 0.5 and 2 J/cm², and for organic materials, between 0.1 and 1 J/cm². Above the ablation threshold,

according to Beer-Lambert's law, the thickness or volume of the material removed by each pulse increases logarithmically.

Beer- Lambert's law

It relates the attenuation of light with properties of the material.

$$A = \log_{10}\left(\frac{I_0}{I}\right)$$

$$A \propto c \text{ (concentration)}$$

$$\propto l \text{ (length of light path)}$$

$$A \propto c\, l$$

$$\boxed{A=\log_{10}\left(\frac{I_0}{I}\right) = \epsilon lc}$$

ϵ is known as molar extinction coefficient and is a measure of probability of electronic transition.

Ablation depends upon wavelength of incident laser, fluence and pulse length . Photo chemical ablation occurs when the excitation time is shorter than the radiation time. Direct ionization of material and the presence of dense- electron- hole plasmas transform the material by direct bond breaking followed by lattice disintegration .

A highly focused plasma is ejected from the zone of irradiation. The dense vapor holds solid and liquid cluster of the material. A prominent portion of the material become plasma at very high intensities. The plasma can aswell absorb and scatter flux received. Recoil from the plane generates shock waves in the material. It leads to deformation of plastic followed by hardening. More energy is rapidly deposited into the material with shortening of pulses. With shortening of pulses, the materials have much less time available with them for transfer of energy to the surrounding.

3.7.3: FREQUENCY DOUBLING

The phenomena in which an input wave in a non linear material can generate a wave with twice the optical frequency is known as frequency doubling.Thesea re observed in materials like

$LiNbO_3$, $KTiOPO_4$, LiB_3O_5 .

MECHANISM OF FREQUENCY DOUBLING

When light propagates in a medium, the electric field causes some electric polarization in the material. Non linear polarization is observed at optical frequencies.

For nonlinearity, the polarization vector is expressed as a tensor.

$$P_i = \sum_j \chi_i Ej(t) + \sum_{j,k} \chi_{jk}^{\ 2} Ej(t)\, Ek(t)$$

where P_i is the ith cartesian coordinate of polarization.

$$P_i(t) = \varepsilon_0 \sum_j \chi_i Ej(t) + 2 \sum_{jk} d_{jk}\, Ej(t) Ek(t)$$

where d_{jk} is the non linear tensor.

The non linear polarization contains frequency components which are not present in the incident beams.

3.7.4: LASER DOPPLER VELOCIMETRY (LVD)

When the highly monochromatic laser beam is allowed to incident on the target, part of the laser beam is reflected by the target.The reflected radiated beam is collected. The change in wavelength of the reflected beam in comparison to the wavelength of the incident beam is calculated and expressed as a function of relative velocity of the object. The relative velocity of the object can be obtained from measurement of change in wavelength. An interference pattern is observed by superposition of the incident beam and the reflected beam.

CHAPTER-4

BIOLOGICAL EFFECTS OF RADIATION

Whatever be the source of radiation , i.e natural or synthetic, whether the dose is high or small, it always affect the biological material. There will always be short and long term consequences to radiation. Radiation ionizes atoms. When atoms are ionized, they affect molecules. The affected molecules charge the cells. The affected cells further charge the tissues leading to affected organs and finally the whole body is affected. All biological effects begin with ionization of atoms, interaction of atoms with radiation. Radiation effects proceed from lowest to highest level.

There are two mechanisms where radiation interacts with cells:

(a) Direct effect (b) Indirect effect.

(a)Direct effect

In case of direct biological effect, the incident radiation interconnects with atoms of DNA. This interaction affects the reproductivity and survival potential of cells. If a large number of atoms are affected, chromosomes cant replicate normally leading to significant alternation in DNA .

(b)Indirect effect

As the critical components like DNA occupy very small volume in body, the probability of direct radiation effect is less. Each cell is composed of water, so indirectly radiation interacts with water.

$$H_2O \xrightarrow{radiation} H^+ + OH^-$$

These ions may further combine with either water molecules or some toxic substances like H_2O_2.

Not all living cells are equally sensitive to radiation, and actively multiplying cells are more sensitive to radiation. Lymphocytes are very sensitive. Germ cells and gastrointestinal cells do not regenerate, so they are less sensitive. Nerves and ganglion cells are less sensitive because they regenerate more slowly. The effects of radiation are not completely irreversible. In many cases, cells can completely repair any damage and function. In some cases, cells die, and in other cases, cells can mutate. It leads to the formation of tumors. As the tumor is exposed to more radiation, the outer layer of rapidly dividing cells is destroyed.

Reduce the size. If a small dose of tumor is given every day, the tissue has a chance to recover from any damage.

Whole body sensitivity depends upon: (a) delivered dose (b)different types of cell (c)kinds of radiation (d)Age (e)Part of body (f)Tissue volume exposed (g)Time of irradiation

Acute effect of radiation is exposure to high doses of radiation over short period. The other type is exposure to low dose for long time interval. High doses kill cells while low doses change cell.

Biological effects of radiation result from damage to DNA. It is valuable to have understanding o radiation mechanism at the level of DNA. Radiation therapy utilizes high energy charged and uncharged particles. Charged and uncharged particles interact very differently. Uncharged particles interact through a small number of catastrophic interactions or non-linear interactions or cross side interactions. The interaction results are surprise and can't be predicted. Charged particles interact with their surroundings by coulombs interaction. The interaction of charge particles gradually slows down because of friction like effects. The interactions of both charged and uncharged particles depend upon: (a)energy of incident beam (b)particle type (c)medium where the beam is propagating.

As the number of radio nuclides decrease exponentially with time, the no. of particles remaining in the uncharged beam decreases exponentially with depth.

$$N=N_0\, e^{-\lambda t}$$

Here we can express,

$$N=N_0\, e^{-\lambda x} \quad ;x \text{ is the depth inside the medium.}$$

The probability of the decay is then

$$\frac{dN}{dt}=-\lambda N_0\, e^{-\lambda t}=-N\lambda$$

$$\Rightarrow \frac{dN}{N} = -\lambda dt$$

Similarly, here we can express the probability of interactions in terms of depth

$$\frac{dN}{N} = -\lambda dx$$

So even the number of particles decrease with the depth, but the probability for interaction of each particle remains the same. If a poly energetic beam is incident, lower energetic beams will be eliminated resulting in filteration and a harder beam.

4.1: PHOTON INTERACTION

Interaction of high energy photons kept in gamma rays or X-rays which are used for radiation therapy purposes can be explained via different mechanisms such as-(a) Photo electric effect (b)Compton interaction (c) Pair production (d)Rayleigh scatter (e) Photo disintegration.

4.1.1: Photo electric effect

In photoelectric effect, the incident photo is completely absorbed by bound electrons in the atom. The kinetic energy of the emitted photo electrons is equal to the difference between incident photon energy and binding energy. Photon can't be absorbed by free electrons in the atom. The interaction mechanics of PE depends upon binding energy and it increases for inner electrons and with increase in mass number or atomic number. Thus it is preferred at low energy and high atomic numbers. If we compare bone with soft tissues, bone is having high density and high binding energy. Thus, probability of interaction by photoelectric emission is more I bone as compared to soft tissues. So we find contrast x-ray imaging of bone and soft tissues.Bone is made from proteins such as collagen and minerals like calcium. Due to higher atomic number of elements in bone, they are more sensitive to photoelectric effect.

4.1.2: Compton effect

In Compton effect, when the photon is incident, it is scattered by the electrons and the electrons recoil thereafter. During this process, a certain amount of energy available with photon is received by electron. This Compton interactions depend upon number of electrons available or interactions. Here the electrons are both bound as well as free. The scattered electrons are set free when the incident photon energy exceeds the binding energy. For an atomic number Z, atomic weight W and Avogadro number N_A , the total number of electrons available in the material will be expressed as N_AZ/W. As we know, for low atomic numbers, Z/W practically remains constant. Thus compton interactions with atoms having low mass number remains practically

same. But with increase in atomic number, n/p (neutron to proton) ratio increases, and hence Z/W decreases. Thus the number of electrons available in the material per unit mass (N_AZ/W) decreases for higher elements. As the absorbed dose is expressed as energy available per unit mass, thus it is proportional to number of available electrons per unit mass. Thus the response gradually decreases for higher elements for a given dose of irradiation. Compton interaction probability per unit mass is independent with atomic number of light elements. Therefore to understand the mechanism, density is taken into consideration. If we multiply number of electrons per unit mass by density, we get number of electrons per unit volume.

Number of electrons available per unit volume= (number of electrons available per unit mass)×(density)

So difference in density plays a vital role. If the density of tissue varies then interaction will vary depending upon the energy supplied.Compton effect is observed is megavolt domain. Compton interaction with light materials depends upon density whereas compton interactions with heavy material depends upon both density and mass number.

4.1.3:Pair production

Incident radiant energy is directly converted to matter during the pair production. It usually takes place in the vicinity of nucleus, in the nuclear coulomb field. The rest mass energy of the combination of electron-positron pair is 1.022 MeV. And this much energy is known as the threshold energy required for pair production. Thus photons with high energy (MeV), pair production is the dominant mode when photon interacts with matter.

$$\gamma \rightarrow e^{+} + e^{-}$$

Medical x-ray imaging operates at 150KV, so pair production doesn't occur there. But the output of medical linear accelerations (LINAC) are in MeV range. Thus pair production is the dominant interaction mechanism between radiation, imparted to treat cancer patients. Also the photon must penetrate the matter and interaction occurs near nucleus for conservation of momentum. This pair product is dominant in high energy radiation and inside matter with high at mass.

4.1.4:Rayleigh scattering

In Rayleigh scattering, the electron is scattered , but unlike Compton scattering, photon doesn't transfer any energy to the medium. As energy is not transferred from irradiated beam to the material, this interaction carries little significance. It scatters energy of shorter wavelength compared to energy of longer wavelengths. When particles diameter are larger than wavelength of incident radiation, Rayleigh scattering occurs. This scattering is known as coherent scattering and is important only at low energy(<<50 KeV) of radiation.

4.1.5:Photo disintegration

Photodisintegration is the process by which the x-ray photon is captured by the atom. During this process, complete energy of the x-ray is transferred to the nucleus followed by ejection of particle from the nucleus. Atomic nucleus is excited and immediately decays. X-ray photon is possessing a minimum of 10 MeV energy can interact directly with the nucleus. Lets inside a deuteron nucleus,

$$^{2}_{1}D + \gamma \rightarrow {}^{1}_{1}H + \eta$$

In the above process, a photo neutron is emitted. These photo neutrons can significantly affect biological materials, neutrons are uncharged particles. They show exponential attenuation in the matter. Neutrons usually interact with nuclei of the matter through elastic interaction or inelastic interaction.

In the elastic radiation, the scattering of nuclei is observed. And in the inelastic interaction, certain amount of energy is absorbed. Protons and neutrons are nearly having equal mass. So when neutrons collide with protons, neutrons transfer almost all its energy to the proton. The neutrons transfer very less energy to a heavier nucleus and transfer all its energy to a hydrogen nucleus. Therefore in case of high energy neutrons, interaction with hydrogen nuclei is the dominant reaction mechanism with neutrons. The amount of energy transferred from uncharged neutrons to charged nucleus is then deposited by the charged nucleus via coulomb interactions. When photon interacts with matter, protons and nucleus are set in motion.

4.2 ELECTRON INTERACTIONS

Electrons are charged particles. Thus when an electron beam is incident on a material, electrons interact through small coulomb force interactions. Electrons interact with other electrons or with nucleus, maximum energy is transferred when an electron strikes another electron. Thus it creates another energetic electron. However when an electron interacts with nucleus, its path is deflected and it causes bremsstrahlung radiation and x-rays are emitted. The energy of x-rays is equal to lost kinetic energy of the electron. These x-rays are used for radio therapy purpose. Electrons are light particles, thus their path can easily be deflected by other electrons of a nucleus. The probability of scattering is much more as compared to the direct collision of electrons.

The diameter of the nucleus is of the order of 10^{-15}m and atomic diameter is of the order of 10^{-10}m. Thus the atom is mostly empty. Thus probability of direct collision is much less and electrons mainly interact by scattering. Thus the interactions of photon and electrons with matter results in these important phenomena attenuation, absorption and scattering.

4.3:NUMERICAL DETAILS OF PHOTON INTERACTION

Numerical details are based upon classical reasoning as well as quantum principles. Photon interactions are exponentially attenuated and expressed in terms of cross-section and attenuation coefficient. Electrons gradually loose energy and are stopped ultimately after losing energy completely. Therefore interaction of electron with matter is evaluated with the help of range of electron and stopping power of the material.

When N number of photons are randomly directed at n number of targets in area A, a is being area of each target, then the total number of photon interactions is expressed as

$$\Delta N = \frac{N n a}{A}$$

where $\frac{\Delta N}{N}=\frac{na}{A}$= probability of interaction

a= area of each target and also known as crossectional area

A= total area

$\frac{a}{A}$= fraction of area blocked by the targets

If atoms are considered, cross-section are measured in barn where 1 barn=10^{-28} m^2.

The different interactions are having different cross-section:

(1)The photoelectric effect interaction cross-section is expressed as

$$\sigma(\text{photo electron}) = k\frac{Z^n}{(h\nu)^m}$$

Here n lies between 3.0 to 5.3, and is largest for low atomic number. And m lies between 2.5 to 3.5, and is largest for low atomic number.

The cross-section varies inversely proportional to photon energy with same discontinuity.

A discontinuity is observed at 69.5 KeV for tungsten due to interaction with k-shell electrons.

(2)Differential scattering cross-section:

When the photons are scattered by electrons $\frac{d\sigma}{d\Omega}$ is known as differential scattering cross-section.

$$\sigma(\text{total}) = \int \frac{d\sigma}{d\Omega}\, \delta\Omega$$

$$\frac{d\sigma}{d\Omega} = \frac{r_0^2}{2}(1+\cos^2\theta)$$

where $r_0 = ke^2/m_0e^2 = 2.81794 \times 10^{-15}$ m , is the classical radius of electron.

The total cross-section is thus given as

$$\sigma = \frac{r_0^2}{2}\int_0^{\pi} 2\pi(1+cos^2\theta)sin\theta d\theta$$

$$= 66.52\times10^{-30}\ m^2$$

Thus according to classical theory, total scattering is constant and is independent of incident radiation energy. The photon is scattered inclusively by the electrons present in an atom. An interference pattern finally determines the resultant angular distribution .

The corrected expression for total scattering (coherent) is given as

In the forward direction, all the atomic electrons act together. F is independent of θ and is equal to Z. The differential scattering cross-section is proportional to Z^2.

For Compton scattering,

$$\frac{h\nu'}{h\nu} = \frac{1}{1+\alpha(1-cos\theta)}$$

The kinetic energy of the electron is the difference between energy of the incident photon and scattered photon

$$K = h\nu - h\nu'$$

$$= h\nu \frac{\alpha(1-\cos\theta)}{1+\alpha(1-\cos\theta)}$$

For 20 kev photon, maximum energy transferred is 1.5 KeV, FOR 50 kEv photon, maximum energy transferred is 8.2 KeV.

When a photon having energy hν is scattered through an angle θ, then its crossection is expressed as

$$\frac{d\sigma}{d\Omega} = \frac{r^{02}}{2}(1+\cos^2\theta)\, f$$

where $f = \left[\frac{1}{1+\alpha(1-\cos\theta)}\right]^2 \times \left[1 + \frac{\alpha^2(1-\cos\theta)^2}{1+\alpha(1-\cos\theta)(1+\cos\theta)}\right]$

The total crossesction can be evaluated by integrating the differential crossection

$$\sigma = 2\pi r_0^2\left[\left(\frac{1+\alpha}{\alpha^2}\right)\left(\frac{2(1+\alpha)}{1+2\alpha} - \frac{\ln(1+2\alpha)}{\alpha}\right) + \frac{\ln(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2}\right]$$

Now during the process of pair production, the photon is transformed into a pair of electron and positron .If the kinetic energy of electron and positron are T_+ and T_- respectively then

$$h\nu = T_+ + T_- + 2m_0c^2$$

Due to the generation of pairs in the core field, the cross-section of this interaction roughly changes to Z^2. When a high-energy photon approaches an orbiting electron, the photon can interact with the electron's Coulomb field through a process called triplet generation. The target electron ejects itself with considerable energy. Two electrons and one positron start to move. The energy threshold for triplets is $4m_0c^2$.

CALCULATION OF LINEAR ATTENUATION COEFFICIENT

Macroscopic interactions of photons inside a matter can be explained by: (a) Linear attenuation coefficient and (b) Mass attenuation coefficient

When a photon interacts across a thick section of the material say Dx, then the probability of interaction of individual photon is given by $N_a\sigma dX$

N_a represents the number of centers of interactions available per unit volume .This is also the number of atoms available per unit volume and σ is the total interaction cross-section per atom.

$$N_a\sigma = \frac{1000 N_a \rho}{A_0}\sigma$$

Here the intensity or fluencies of the incident photon attenuates exponentially and can be expressed by Beers law

$$\varphi = \varphi_0 e^{-\mu x}$$

ϕ is the fluence of photon after it has traversed through x. φ represents no. of photons which have not interacted after photon travelled a distance x through the material.

The μ is defined as linear attenuation coefficient and measured in m^{-1}.

$\frac{\mu}{\rho}$ where ρ is the density of the material is expressed as m^2/kg, is known as mass attenuation coefficient.

The total mass attenuation coefficient will be sum of mass attenuation coefficient contribution from each individual interaction.

$$\left(\frac{\mu}{\rho}\right)\text{total} = \left(\frac{\mu}{\rho}\right) + \left(\frac{\mu_{oh}}{\rho}\right) + \left(\frac{\mu_{in}}{\rho}\right) + \frac{k}{\rho}$$

4.4: NUMERICAL DETAILS OF ELECTRON INTERACTION

When electron beam traverses through the matter, it loses energy due to different reasons like loss due to collisions with other electrons, radiative loss.

Energy lost by charged particles can be described by stopping power. The stopping power is expressed as

$S = \frac{dE}{dx}$ where dE is the loss of kinetic energy of electron beam after traversing dx.

If we divide stopping power by density of the material, it is known as mass stopping power.

$\frac{S}{\rho} = \frac{1}{\rho}\frac{dE}{dx}$ is the mass stopping power.

Stopping power(S) is measured by Joule m^{-1}, and mass stopping power is measured by joule m^2 kg^{-1} or MeV cm^2 g^{-1}.

The expression was given by Sternheimer,

$$\frac{S}{\rho} = 2\pi r_0^2 N_e \frac{\mu_0}{\beta}\left[ln\frac{E^2(E+2\mu_0)}{2\mu_0 I^2} + \frac{\frac{E^2}{8}-(2E)\mu_0 ln2}{(E+\mu_0)^2} + 1 - \beta^2 - \delta\right]$$

This is due to ionization process or collision of electrons with other electrons.

Here r_0 is the radius of electrons obtained classically.

$N_e = NA\left(\frac{Z}{A}\right)$; NA is Avogadro's no.

$\mu_0 = M_0c^2$ is rest mass energy of electron.

E is the kinetic energy of electron

$B = \frac{v}{c}$ where v and c are speed of electron and speed of light respectively.

Electrons also loose energy by Bremsstrahlung effect, where electrons interact with electric field of nuclei and decelerated rapidly. During this process, some energy is radiated away. The mass stopping power during this is expresses as

$$\frac{S(rad)}{\rho} = \sigma_0 \frac{NA}{A}[Z^2(E+\mu_0)F]$$

where $\sigma_0 = \frac{1}{137}\left(\frac{e^2}{\mu}\right)^2 = 0.580$ barn/nucleus

and $F = F\left(\frac{h\nu}{E}\right)$

The energy lost during this process depends upon the atomic number.