BM T43 – MEDICAL PHYSICS

UNIT-1

2 MARKS

1. **List the normal sound levels. (May 2015)**

   At audible frequencies, sound waves are capable of moving the eardrum, and thus giving rise to the sensation of hearing. At higher (ultrasonic) frequencies, the sound is not audible, but can be used to image materials and measure the velocity of moving objects.

   - Normal human audible range – below 20 KHz
   - Ultrasound – 20 KHz to several gigahertz.

2. **Define Echo ranking. (May 2015)**

   - Echo ranging is the process of detecting underwater objects using sound signals.
   - The minimum distance between source and the reflecting body should be 17m for the formation of echo.
   - This technique is used to measure depth of sea with the help of Sonar.

3. **What is the Q of an ultrasound transducer and its significance?(May 2016)**

   In the blogs about transducers I made a point of telling readers that an ultrasonic transducer must be driven at its resonant frequency to achieve optimum performance. Very simply, the “Q” of a transducer defines the sensitivity of the transducer to changes in driving frequency.

4. **How does tissues act as a dielectric?(May 2016)**

   The dielectric properties of various mammalian tissues and biological fluids for the frequency range from 1 Hz to 10 GHz. The properties considered are the frequency variations of the relative permittivity and electrical conductivity.

5. **Define color vision. What are the types of cones? (Nov 2016)**

- Color vision is the capacity of an organism or machine to distinguish objects based on the wavelengths (or frequencies) of the light they reflect, emit, or transmit.
- The nervous system derives color by comparing the responses to light from the several types of cone photoreceptors in the eye.
- These cone photoreceptors are sensitive to different portions of the visible spectrum.
- For humans, the visible spectrum ranges approximately from 380 to 740 nm, and there are normally three types of cones. The visible range and number of cone types differ between species.
- There are three types of cones: blue, green, and red.

6. What is absorption? (Nov 2016)

Absorption is a condition in which something takes in another substance. The process of absorption means that a substance captures and transforms energy. The absorbent distributes the material it captures throughout whole and adsorbent only distributes it through the surface.

7. Define Doppler Shift? (May 2017)

Doppler shift is also known as the Doppler effect is defined as the change in the wavelength or frequency of the waves with respect to the observer who is in motion relative to the wave source.

$$f = \left(\frac{c \pm v_r}{c \pm v_s}\right) f_0$$

8. What are non ionizing radiations? (May 2017)

- Non-ionizing radiation is described as a series of energy waves composed of oscillating electric and magnetic fields traveling at the speed of light.
- Non-ionizing radiation includes the spectrum of ultraviolet (UV), visible light, infrared (IR), microwave (MW), radio frequency (RF), and extremely low frequency (ELF).
- Non-ionizing radiation is found in a wide range of occupational settings and can pose a considerable health risk to potentially exposed workers if not properly controlled.

9. What is Huygens's effect? (May 2019, Nov 2017)

Huygens's effect states that "Every point on a wave front is in itself the source of spherical wavelets which spread out in the forward direction at the speed of light. The sum of these spherical wavelets forms the wave front".

10. Differentiate low and high frequency effects. (Nov 2018)

LOW FREQUENCY EFFECT:

This low frequency current coming under non- ionizing radiation which does not produce hazards to body tissues. It ranges between 0.1 Hz to 100KHz.

- Electrical muscle stimulation
- Nervous stimulation
- Cardiac stimulation

HIGH FREQUENCY EFFECT:

This low frequency current coming under non- ionizing radiation which does not produce hazards to body tissues. It ranges above 100KHz.

- Surgical Diathermy
- Electro surgery equipment.

11. What is meant by Cavitation in ultrasound? (Nov 2018)

- Cavitation is a physical phenomenon of vaporization of a liquid by reducing the pressure, caused by the movement of sound waves.
- When low-frequency ultrasonic waves reach the adipose tissue they create positive and negative pressures, generating millions of microscopic air bubbles.

12. Name the four ways of interaction of ultrasound with tissues. (May 2018)

Ultrasound waves have four basic interactions with tissues. These interactions are:

- Reflection
- Scattering
- Refraction
- Attenuation.

13. Give the classification of non-ionizing radiations. (May 2018)

Non-ionizing radiation includes the spectrum of ultraviolet (UV), visible light, infrared (IR), microwave (MW), radio frequency (RF), and extremely low frequency (ELF). Lasers commonly operate in the UV, visible, and IR frequencies.

14. What is mean by non ionizing radiations? Give example. (Nov 2019)

Non-ionizing radiation is described as a series of energy waves composed of oscillating electric and magnetic fields traveling at the speed of light. Non-ionizing radiation includes the spectrum of ultraviolet (UV), visible light, infrared (IR), microwave (MW), radio frequency (RF), and extremely low frequency (ELF).

15. Write about the limits of vision? (Nov 2019)

- In very low light levels, vision is scotopic, meaning mediated by rod cells, and not detecting color differences; the rods are maximally sensitive to wavelengths near 500 nm.
- In brighter light, such as daylight, vision is photopic, in which case the cone cells of the retina mediate color perception, and the rods are essentially saturated; in this region, the eye is most sensitive to wavelengths near 555 nm.

16. List out the difference between absorption and scattering (May 2019, Nov 2017)

Scattering	**Absorption**
Scattering means the direction of transmission of the incident photon is changed.	Absorption of a photon means, the particle absorbs the energy of the photon.
There is no change in the energy of the photon or particle.	As a result, photon is annihilated and the energy is transferred to the particle.
The particle gets de-excited	The particle gets excited

17. Name the four ways of interaction of ultrasound with tissues? (Sep 2020)

- Reflection.
- Scattering.
- Refraction.
- Attenuation

18. Give the classification of Non – Ionizing radiation?(Sep 2020)

Non-ionizing radiation includes the spectrum of ultraviolet (UV), visible light, infrared (IR), microwave (MW), radio frequency (RF), and extremely low frequency (ELF). Lasers commonly operate in the UV, visible, and IR frequencies.

11 MARKS

1. Describe the electrical properties of tissue using suitable models and its significance in medicine?(May 2016)

- Electric current is the flow (movement) of electric charge.
- The amount of electric current (measured in amperes) through some surface is defined as the amount of electric charge (measured in coulombs) flowing through that surface over time.

Electric current

- Electric current flows to the organism from external sources
- It is generated as a result of actions in plasma cell membrane (excitable tissues)
- direct current (DC) - is the constant flow of electric charge, the electric chagres flow in the same direction
- alternating currnet (AC) - is a current whose magnitude and direction vary cyclically. A sine wave is a usual waveform.

Electrical properties of the tissues

- passive electric properties – tissue's and organ's behaviour in electric field
- active electric properties – electricity as a result of ogran activity

LIVE TISSUE BEHAVE AS A SPECIAL KIND OF CONDUCTOR IN ELECTRIC FIELD

- cell membrane conductance is lower (106 – 108 times) as extracellulary space and cytoplasm conductance
- extracellular space and cytoplasm – electrical current is realized as a ions movement (electrolyte)

- membrane capacity: Cm =1μF.cm-² , membrane surface resistance: 1000 - 1500Ω.cm-²
- Measurement of skin resistance Skin is the largest organ of the in teglumentary system made up of multiple layers of epithelial tissues that guard underlying muscles and organs.
- Skin is made up of a complex mosaic of three layers, the epidermis, dermis and sub dermis and accounts for 12-16 % of body weight.
- Skin represents a complex variable conductor when exposed to the electric field which is characterized by large non homogeneity.
- The electrons within dielectric molecules are influenced by electric field, causing the molecules to rotate slightly from their equilibrium positions. The air gap is shown for clarity; in a real capacitor, the dielectric is in direct contact with the plates.
- Capacitors also allow AC current to flow and block DC current.

Polarization of dielectric

- A dielectric is a physical model commonly used to describe how anelectric field behaves inside material.
- It is characterised by how an electric field interacts with an atom.
- Tissues consist of polar molecules, behave as electrical dipoles.
- Current (I) is what flows on a wire or conductor like water flowing down a river.
- Current flows from negative to positive on the surface of a conductor. Current is measured in amperes or amps (A).
- Voltage (V) is the difference in electrical potential between two points in a circuit.
- It's the push or pressure behind current flow through a circuit, and is measured in volts (V)
- Resistance (R) determines how much current will flow through a component.
- Resistors are used to control voltage and current levels.
- A very high resistance allows a small amount of current to flow. A very low resistance allows a large amount of current to flow.
- Resistance is measured in ohms (Ω).

Ohm's law

Ohm's law states that, in an electrical circuit, the current passing through a conductor between two points is directly proportional to the potential difference (i.e. voltage) across the two points, and inversely proportional to the resistance between them. I=V/R

Skin resistance

- Skin is a good insulator.
- It is difficult for low frequencies to pass through skin.
- Some people have very moist skin and others have very dry skin.
- It takes higher voltage to penetrate dry skin than wet skin.
- Moisture is the determining factor for penetration of el. current through the skin into the body.
- Skin resistance decreases over time.

Bioelectrical Impedance Analysis

- (BIA) sends minute electric currents that a patient is unable to feel.
- It measures biological impedance to measure body composition using the latest BIA technology rather than relying on empirical estimates.
- Bioelectrical impedance analysis (BIA) is a commonly used method for estimating body composition.

2. **Discuss the various Low and high frequency effects of radiation. (Nov 2019, May 2017)**

- Electromagnetic radiation can be classified into two types: ionizing radiation and non-ionizing radiation, based on the capability of a single photon with more than 10 eV energy to ionize atoms or break chemical bonds.
- Extreme ultraviolet and higher frequencies, such as X-rays or gamma rays are ionizing, and these pose their own special hazards: see radiation and radiation poisoning.

<u>EFFECTS BY FREQUENCY</u>:

- While the most acute exposures to harmful levels of electromagnetic radiation are immediately realized as burns, the health effects due to chronic or occupational exposure may not manifest effects for months or years

Low frequency:

- Electric and magnetic fields occur where electricity is generated or distributed in power lines, cables, or electrical appliances.
- Human responses depend on the field strength, ambient environmental conditions, and individual sensitivity.
- 7% of volunteers exposed to power-frequency electric fields of high- power, extremely-low-frequency RF with electric field levels in the low kV/m range reported painful currents that flowed to ground through a body contact surface such as the feet, or arced to ground where the body was well insulated.

Shortwave:

- Shortwave (1.6 to 30 MHz) diathermy can be used as a therapeutic technique for its analgesic effect and deep muscle relaxation, but has largely been replaced by ultrasound.
- Temperatures in muscles can increase by 4–6 °C, and subcutaneous fat by 15 °C.
- The FCC has restricted the frequencies allowed for medical treatment, and most machines in the US use 27.12 MHz.
- Shortwave diathermy can be applied in either continuous or pulsed mode.
- The latter came to prominence because the continuous mode produced too much heating too rapidly, making patients uncomfortable.
- The technique only heats tissues that are good electrical conductors, such as blood vessels and muscle.
- Adipose tissue (fat) receives little heating by induction fields because an electrical current is not actually going through the tissues.
- Studies have been performed on the use of shortwave radiation for cancer therapy and promoting wound healing, with some success.
- However, at a sufficiently high energy level, shortwave energy can be harmful to human health, potentially causing damage to biological tissues.

- The FCC limits for maximum permissible workplace exposure to shortwave radio frequency energy in the range of 3–30 MHz has a plane-wave equivalent power density of (900/f2) mW/cm2 where f is the frequency in MHz, and 100 mW/cm2 from 0.3 to 3.0 MHz.
- For uncontrolled exposure to the general public, the limit is 180/f2 between 1.34 and 30 MHz.

High frequency:

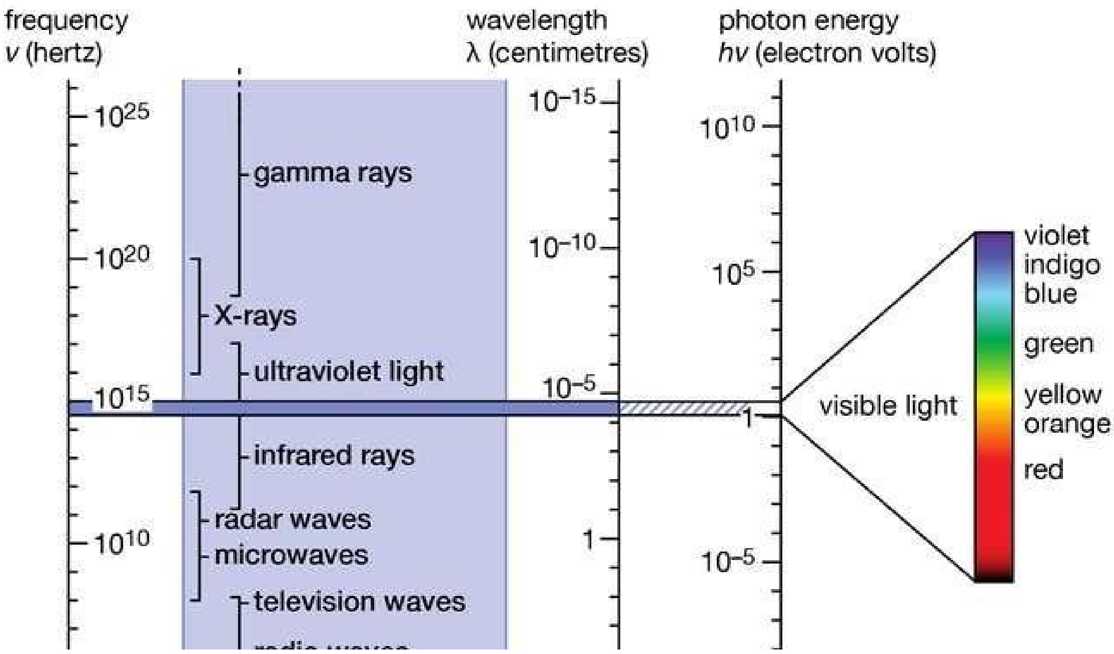
Radio frequency field:

- The designation of mobile phone signals as "possibly carcinogenic to humans" by the World Health Organization (WHO) (e.g. its IARC, see below) has often been misinterpreted as indicating that some measure of risk has been observed.
- However the designation indicates only that the possibility could not be conclusively ruled out using the available data.
- International Agency for Research on Cancer (IARC) classified mobile phone radiation as Group 2B "possibly carcinogenic" (rather than Group 2A "probably carcinogenic" nor the "is carcinogenic" Group 1).
- That means that there "could be some risk" of carcinogenicity, so additional research into the long-term, heavy use of mobile phones needs to be conducted.
- The WHO concluded in 2014 that "A large number of studies have been performed over the last two decades to assess whether mobile phones pose a potential health risk. To date, no adverse health effects have been established as being caused by mobile phone use."
- Since 1962, the microwave auditory effect or tinnitus has been shown from radio frequency exposure at levels below significant heating.
- Studies during the 1960s in Europe and Russia claimed to show effects on humans, especially the nervous system, from low energy RF radiation; the studies were disputed at the time.
- In 2019 reporters from the Chicago Tribune tested the level of radiation from smart phones and found it to exceed safe levels.[citation needed] The federal communications commission begun to check the findings.
- Radio frequency radiation is found to have more thermal related effects.
- A person's body temperature can be raised which could result in death if exposed to high dosage of RF radiation.

- Focused RF radiation can also cause burns on the skin or cataracts to form in the eyes. Overall, some health effects are observed at high levels of RF radiation, but the effects aren't clear at low levels of exposure.

3. Explain in detail about electromagnetic spectrum and visible light with schematic diagram. (May 2019)

- Electromagnetic spectrum, the entire distribution of electromagnetic radiation according to frequency or wavelength.
- Although all electromagnetic waves travel at the speed of light in a vacuum, they do so at a wide range of frequencies, wavelengths, and photon energies.
- The electromagnetic spectrum comprises the span of all electromagnetic radiation and consists of many sub ranges, commonly referred to as portions, such as visible light or ultraviolet radiation.
- The various portions bear different names based on differences in behavior in the emission, transmission, and absorption of the corresponding waves and also based on their different practical applications.
- There are no precise accepted boundaries between any of these contiguous portions, so the ranges tend to overlap.



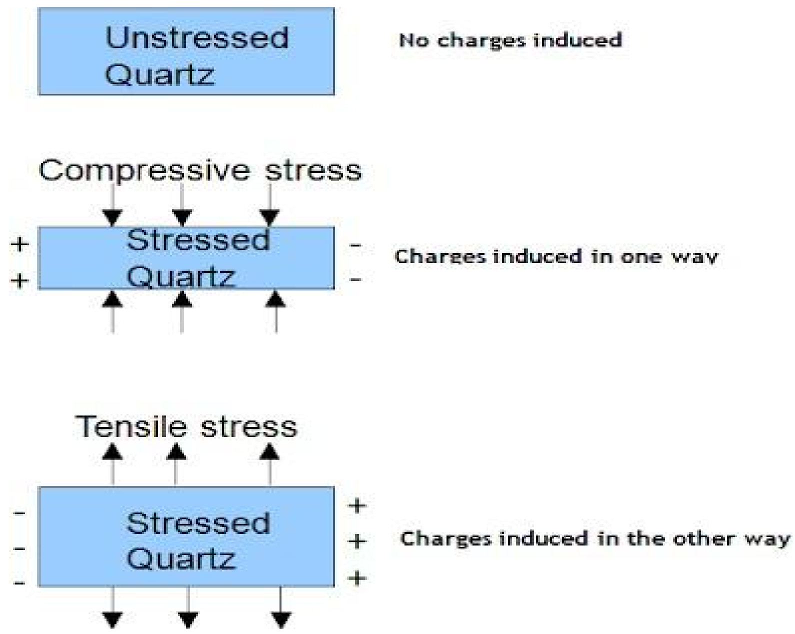
- The entire electromagnetic spectrum, from the lowest to the highest frequency (includes all radio waves (e.g., commercial radio and television, microwaves, radar) such as infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.
- Nearly all frequencies and wavelengths of electromagnetic radiation can be used for spectroscopy.
- Fine structure, in spectroscopy, the splitting of the main spectral lines of an atom into two or more components, each representing a slightly different wavelength.
- Fine structure is produced when an atom emits light in making the transition from one energy state to another.
- The split lines, which are called the fine structure of the main lines, arise from the interaction of the orbital motion of an electron with the quantum mechanical “spin” of that electron.
- An electron can be thought of as an electrically charged spinning top, and hence it behaves as a tiny bar magnet.
- The spinning electron interacts with the magnetic field produced by the electron’s rotation about the atomic nucleus to generate the fine structure.
- The amount of splitting is characterized by a dimensionless constant called the fine-structure constant.
- This constant is given by the equation $\alpha = ke2/hc$, where k is Coulomb’s constant, e is the charge of the electron, h is Planck’s constant, and c is the speed of light.
- The value of the constant α is $7.29735254 \times 10-3$, which is nearly equal to 1/137.
- In the atoms of alkali metals such as sodium and potassium, there are two components of fine structure (called doublets), while in atoms of alkaline earths there are three components (triplets).
- This arises because the atoms of alkali metals have only one electron outside a closed core, or shell, of electrons, while the atoms of alkaline earths have two such electrons.
- Doublet separation for corresponding lines increases with atomic number; thus, with lithium (atomic number 3), a doublet may not be resolved by an ordinary

spectroscope, whereas with rubidium (atomic number 37), a doublet may be widely separated.

4. Write in detail about the construction, working, advantages and disadvantages of Piezoelectric ultrasonic generator.(May 2016, May 2018,Nov 2018,Sep 2020)

Piezoelectric effect:

When crystals like quartz or tourmaline are stressed along any pair of opposite faces, electric charges of opposite polarity are induced in the opposite faces perpendicular to the stress. This is known as piezoelectric effect.



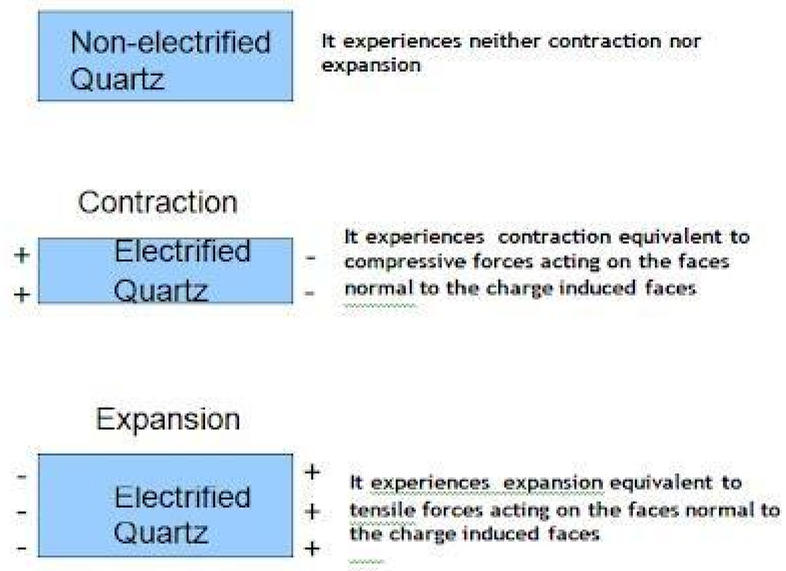
Piezoelectric effect- Mechanism:

- Piezoelectric and inverse piezoelectric effects are only exhibited by certain crystals which lack centre of symmetry.
- In a piezoelectric crystal, the positive and negative electrical charges are separated, but symmetrically distributed, so that the crystal overall is electrically neutral.
- Each of these sides forms an electric dipole and dipoles near each other tend to be aligned in regions called Weiss domains.

- The domains are usually randomly oriented, but can be aligned during poling , a process by which a strong electric field is applied across the material, usually at elevated temperatures.
- When a mechanical stress is applied, this symmetry is disturbed, and the charge asymmetry generates a voltage across the material. For example, a 1 cm cube of quartz with 2 kN (500 lbf) of correctly applied force can produce a voltage of 12,500 V.
- Piezoelectric materials also show the opposite effect, called converse (inverse) piezoelectric effect, where the application of an electrical field creates mechanical deformation in the crystal.

Inverse piezoelectric effect:

- When an alternating e.m.f is applied to the opposite faces of a quartz or tourmaline crystal it undergoes contraction and expansion alternatively in the perpendicular direction. This is known as inverse piezoelectric effect. This is made use of in the piezoelectric generator.

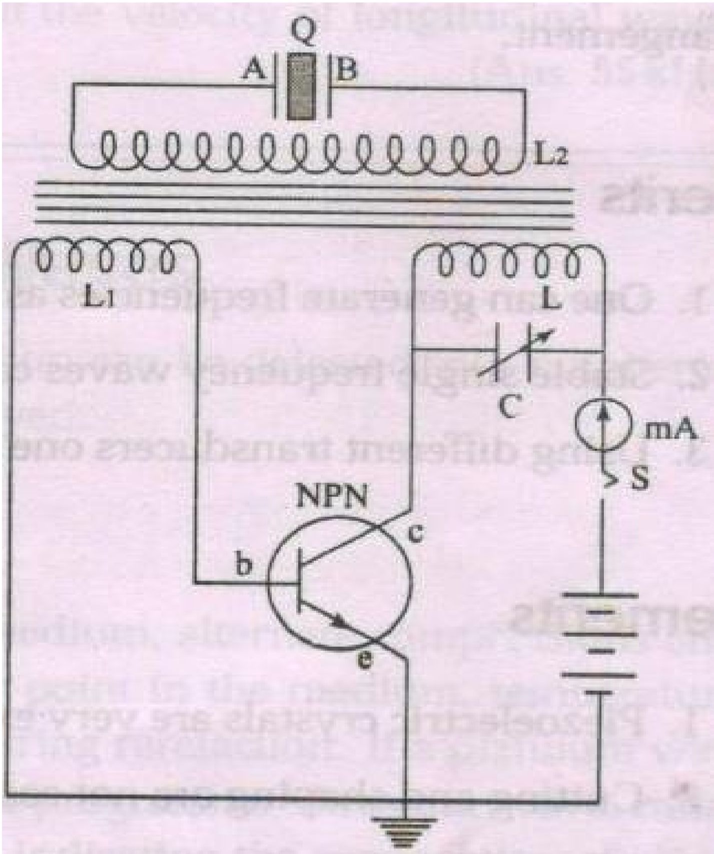


Piezoelectric generator:

- A slab of piezoelectric crystal is taken and using this a parallel plate capacitor is made.

- Then with other electronic components an electronic oscillator is designed to produce electrical oscillations >20 kHz.
- Quartz slabs are preferred because it possesses rare physical and chemical pro perties.

A typical circuit diagram is given below.



- The tank circuit has a variable capacitor 'C' and an inductor 'L' which decides the frequency of the electrical oscillations.
- When the circuit is closed current rushes through the tank circuit and the capacitor is charged, after fully charged no current passes through the same.
- Then the capacitor starts discharging through the inductor and hence the electric energy is in the form of electric and magnetic fields associated with the capacitor and the inductor respectively.

- Thus we get electrical oscillations in the tank circuit and with the help of the other electronic components including a transistor, electrical oscillations are produced continuously.
- This is fed to the secondary circuit and the piezoelectric crystal (in our case a slab of suitably cut quartz crystal) vibrates, as it is continuously subjected to varying (alternating) electric field, and produces sound waves.
- When the frequency of electrical oscillations is in the ultrasonic range then ultrasonic waves are generated. When the frequency of oscillation is matched with the natural frequency of the piezoelectric slab then it will vibrate with maximum amplitude. The frequency generated is given as follows:

$$f=\frac{P}{\;}\;\overline{\frac{E}{\;}}$$

E-The Young's modulus of the piezoelectric material
and ρ - the density of the piezoelectric material

5. Explain biological effects of Microwave and RF waves on vital organs.(May 2018,Sep 2020)

A large body of literature exists on the response of tissues to electromagnetic fields, primarily in the extremely-low-frequency (ELF) and microwave-frequency ranges. In general, the reported effects of radiofrequency (RF) radiation on tissue and organ systems have been attributed to thermal interactions, although the existence of nonthermal effects at low field intensities is still a subject of active investigation.

This chapter summarizes reported RF effects on major physiological systems and provides estimates of the threshold specific absorption rates (SARs) required to produce such effects. Organ and tissue responses to ELF fields and attempts to characterize field thresholds are also summarized. The relevance of these findings to the possible association of health effects with exposure to RF fields from GWEN antennas is assessed.

Nervous System:

- The effects of radiation on nervous tissues have been a subject of active investigation since changes in animal behavior and nerve electrical properties were first reported in the Soviet Union during the 1950s and 1960s.
- RF radiation is reported to affect isolated nerve preparations, the central nervous system, brain chemistry and histology, and the blood-brain barrier.

- In studies with in vitro nerve preparations, changes have been observed in the firing rates of Aplysia neurons and in the refractory period of isolated frog sciatic nerves exposed to 2.45-GHz microwaves at SAR values exceeding 5 W/kg.
- Those effects were very likely associated with heating of the nerve preparations, in that much higher SAR values have not been found to produce changes in the electrical properties of isolated nerves when the temperature was controlled.
- Studies on isolated heart preparations have provided evidence of bradycardia as a result of exposure to RF radiation at nonthermal power densities, although some of the reported effects might have been artifacts caused by currents induced in the recording electrodes or by nonphysiological conditions in the bathing medium.
- Several groups of investigators have reported that nonthermal levels of RF fields can alter Ca2+ binding to the surfaces of nerve cells in isolated brain hemispheres and neuroblastoma cells cultured in vitro.
- That phenomenon, however, is observed only when the RF field is amplitude-modulated at extremely low frequencies, the maximum effect occurs at a modulation frequency of 16 Hz.
- A similar effect has recently been reported in isolated frog hearts.
- The importance of changes in Ca2+ binding on the functional properties of nerve cells has not been established, and there is no clear evidence that the reported effect of low-intensity, amplitude-modulated RF fields poses a substantial health risk.
- Results of in vivo studies of both pulsed and continuous-wave (CW) RF fields on brain electrical activity have indicated that transient effects can occur at SAR values exceeding 1 W/kg.
- Evidence has been presented that cholinergic activity of brain tissue is influenced by RF fields at SAR values as low as 0.45 W/kg.
- Exposure to nonthermal RF radiation has been reported to influence the electroencephalograms (EEGs) of cats when the field was amplitude-modulated at frequencies less than 25 Hz, which is the range of naturally occurring EEG frequencies.
- The rate of Ca2+ exchange from cat brain tissue in vivo was observed to change in response to similar irradiation conditions.
- Comparable effects on Ca2+ binding were not observed in rat cerebral tissue exposed to RF radiation, although the fields used were pulsed at EEG frequencies, rather than amplitude-modulated.

- As noted above, the physiological significance of small shifts in Ca2+ binding at nerve cell surfaces is unclear.
- A wide variety of changes in brain chemistry and structure have been reported after exposure of animals to high-intensity RF fields.
- The changes include decreased concentrations of epinephrine, norepinephrine, dopamine, and 5-hydroxytryptamine; changes in axonal structure; a decreased number of Purkinje cells; and structural alterations in the hypothalamic region. Those effects have generally been associated with RF intensities that produced substantial local heating in the brain.
- Extensive studies have been carried out to detect possible effects of RF radiation on the integrity of the blood-brain barrier.
- Although several reports have suggested that non thermal RF radiation can influence the permeability of the blood-brain barrier, most of the experimental findings indicate that such effects result from local heating in the head in response to SAR values in excess of 2 W/kg.
- Changes in cerebral blood flow rate, rather than direct changes in permeability to tracer molecules, might also be incorrectly interpreted as changes in the properties of the blood-brain barrier.
- Effects of pulsed and sinusoidal ELF fields on the electrical activity of the nervous system have also been studied extensively.
- In general, only high-intensity sinusoidal electric fields or rapidly pulsed magnetic fields induce sufficient current density in tissue (around 0.1-1.0 A/m2 or higher) to alter neuronal excitability and synaptic transmission or to produce neuromuscular stimulation. Somewhat lower thresholds have been observed for the induction of visual phosphenes and for influencing the electrical activity of Aplysia pacemaker neurons when the frequency of the applied field matched the endogenous neuronal firing rate.
- Those effects, however, have been observed only with ELF frequencies and would not be expected to occur at the higher frequencies associated with GWEN transmitters. Recent studies with human volunteers exposed to 60-Hz electric and magnetic fields with intensities comparable with those of high-voltage power lines have shown no consistent effects on the EEG.

- Minor changes were observed in reaction time and heart rate, but the variations were within normal ranges.

6. Write a detailed note on electromagnetic radiation and its medical applications.(May 2019, Nov 2017,Nov 2018)

Applications involving heat generating RF waves are used for therapeutic purposes. The three main EMF applications and areas of medicine using EMF sources are:

- MRI – diagnostic imaging
- RF ablation – cardiology and cancer (tumour) therapy
- Localized dielectric heating (shortwave diathermy) – physiotherapy.

A magnetic resonance imaging (MRI) scan is a common procedure around the world. MRI uses a strong magnetic field and radio waves to create detailed images of the organs and tissues within the body. Since its invention, doctors and researchers continue to refine MRI techniques to assist in medical procedures and research. The development of MRI revolutionized medicine.

MRI scanning is a non-invasive and painless procedure:

- An MRI scan uses a large magnet, radio waves, and a computer to create a detailed, cross-sectional image of internal organs and structures.
- The scanner itself typically resembles a large tube with a table in the middle, allowing the patient to slide in.
- An MRI scan differs from CT scans and X-rays, as it does not use potentially harmful ionizing radiation.

Uses:

- The development of the MRI scan represents a huge milestone for the medical world.
- Doctors, scientists, and researchers are now able to examine the inside of the human body in high detail using a non-invasive tool.

The following are examples in which an MRI scanner would be used:

- Anomalies of the brain and spinal cord.
- Tumors, cysts, and other anomalies in various parts of the body.
- Breast cancer screening for women who face a high risk of breast cancer.

- Injuries or abnormalities of the joints, such as the back and knee.
- Certain types of heart problems.
- Diseases of the liver and other abdominal organs.
- The evaluation of pelvic pain in women, with causes including fibroids and endometriosis suspected uterine anomalies in women undergoing evaluation for infertility preparation.
- A person can listen to music in headphones to mask the loud and sometimes alarming sound of the MRI machine.
- There is very little preparation required, if any, before an MRI scan.
- On arrival at the hospital, doctors may ask the patient to change into a gown. As magnets are used, it is critical that no metal objects are present in the scanner. The doctor will ask the patient to remove any metal jewellery or accessories that might interfere with the machine.
- A person will probably be unable to have an MRI if they have any metal inside their body, such as bullets, shrapnel, or other metallic foreign bodies. This can also include medical devices, such as cochlear implants, aneurysm clips, and pacemakers.
- Individuals who are anxious or nervous about enclosed spaces should tell their doctor. Often they can be given medication prior to the MRI to help make the procedure more comfortable.
- Patients will sometimes receive an injection of intravenous (IV) contrast liquid to improve the visibility of a particular tissue that is relevant to the scan.
- The radiologist, a doctor who specializes in medical images, will then talk the individual through the MRI scanning process and answer any questions they may have about the procedure.
- Once the patient has entered the scanning room, the doctor will help them onto the scanner table to lie down. Staff will ensure that they are as comfortable as possible by providing blankets or cushions.
- Earplugs or headphones will be provided to block out the loud noises of the scanner. The latter is popular with children, as they can listen to music to calm any anxiety during the procedure powered by Rubicon Project

During an MRI scan

- Once in the scanner, the MRI technician will communicate with the patient via the intercom to make sure that they are comfortable. They will not start the scan until the patient is ready.
- During the scan, it is vital to stay still. Any movement will disrupt the images, much like a camera trying to take a picture of a moving object. Loud clanging noises will come from the scanner. This is perfectly normal. Depending on the images, at times it may be necessary for the person to hold their breath.
- If the patient feels uncomfortable during the procedure, they can speak to the MRI technician via the intercom and request that the scan be stopped.

After an MRI scan

- After the scan, the radiologist will examine the images to check whether any more are required. If the radiologist is satisfied, the patient can go home.
- The radiologist will prepare a report for the requesting doctor. Patients are usually asked to make an appointment with their doctor to discuss the results.

Side effects:

- It is extremely rare that a patient will experience side effects from an MRI scan.
- However, the contrast dye can cause nausea, headaches, and pain or burning at the point of injection in some people. Allergy to the contrast material is also seldom seen but possible, and can cause hives or itchy eyes. Notify the technician if any adverse reactions occur.
- People who experience claustrophobia or feel uncomfortable in enclosed spaces sometimes express difficulties with undergoing an MRI scan.

Functions:

- MRI scans work by rearranging water molecules in the body with magnets.
- An MRI scanner contains two powerful magnets. These are the most important parts of the equipment.
- The human body is largely made of water molecules, which are comprised of hydrogen and oxygen atoms. At the center of each atom lies an even smaller particle called a proton, which serves as a magnet and is sensitive to any magnetic field.
- Normally, the water molecules in the body are randomly arranged, but on entering an MRI scanner, the first magnet causes the water molecules to align in one direction, either north or south.

- The second magnetic field is then turned on and off in a series of quick pulses, causing each hydrogen atom to change its alignment when switched on and then quickly switch back to its original relaxed state when switched off.
- Passing electricity through gradient coils, which also cause the coils to vibrate, creates the magnetic field, causing a knocking sound inside the scanner.
- Although the patient cannot feel these changes, the scanner can detect them and, in conjunction with a computer, can create a detailed cross-sectional image for the radiologist.

Functional magnetic resonance imaging (fMRI):

- Functional magnetic resonance imaging or functional MRI (fMRI) uses MRI technology to measure cognitive activity by monitoring blood flow to certain areas of the brain.
- The blood flow increases in areas where neurons are active. This gives an insight into the activity of neurons in the brain.
- This technique has revolutionized brain mapping, by allowing researchers to assess the brain and spinal cord without the need for invasive procedures or drug injections.
- Functional MRI helps researchers learn about the function of a normal, diseased, or injured brain.
- fMRI is also used in clinical practice. Standard MRI scans are useful for detecting anomalies in tissue structure. However, an fMRI scan can help detect anomalies in activity.
- In short, fMRI tests what tissues do rather than how they look.
- As such, doctors use fMRI to assess the risks of brain surgery by identifying the regions of the brain involved in critical functions, such as speaking, movement, sensing, or planning.
- Functional MRI can also be used to determine the effects of tumors, stroke, head and brain injuries, or neurodegenerative diseases, such as Alzheimer's.

7. What are the processes the ultrasound undergoes when interacting with soft tissues? (Nov 2019, May 2017, Nov 2017, Nov 2016, May 2015)

The perfect echocardiographic machine would produce an infinitesimally small ultrasound beam, an incredible sweep speed and a uniform energy throughout its beam length. Even with the perfect echocardiographic machine, we are still left with the ultrasound interaction with tissues.

The interaction can cause measurement errors, artifacts, and poor picture quality. An understanding of the basic interactions of tissue with ultrasound provides the basis of avoiding errors and misdiagnosis. Tissue interaction has also lead to the development of new technologies, such as automatic border detection.

Ultrasound waves, when they strike a medium, cause expansion and compression of the medium. Ultrasound waves interact with tissue in four basic manners. Those interactions are:

- Reflection
- Scattering
- Refraction
- Attenuation

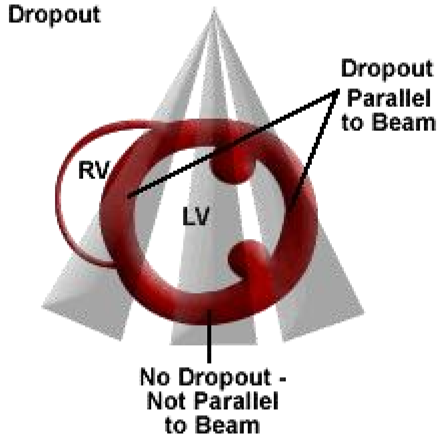
Reflection:

Reflection occurs when the ultrasound wave is deflected towards the transducer. The major factors affecting the amount of reflection are:

- Angle of incidence
- Acoustic impedance mismatch
- Width of the tissue boundary
- Angle of tissue boundary

The angle of incidence is the angle of the ultrasound beam and the tissue plane. For reflection, the angle of incidence is less than 90 degrees. Reflection occurs at tissue boundaries and tissue interfaces. Tissue boundaries that are perpendicular to the ultrasound wave's path act as excellent reflectors, whereas, tissue boundaries that are parallel to the ultrasound wave's path act as poor reflectors. When the ultrasound wave is not reflected, either due to a parallel tissue boundary or high acoustic impedance, the ultrasound signal is not recorded and the display shows a lack of signal or dropout of the ultrasound picture.

For example, the myocardial walls that are perpendicular to the ultrasound beam are easily visualized. The myocardial walls that are perpendicular to the ultrasound beam act as excellent reflectors of the ultrasound signal. The walls parallel to the beam are not easily visualized. Walls parallel to the ultrasound signal result in poor signal reflection. In fact, the part of the parallel wall is not seen because the signal has been lost, which is commonly called dropout.



- Besides angle of incidence, the tissue boundary width impacts the amount of the reflected signal. If the tissue boundary width is less than the wavelength of the ultrasound wave, the ultrasound wave will not be reflected. (Animation 1.2.2)
- Tissue boundaries that are smooth and have a width greater than the ultrasound wave act as a mirror or a specular reflector which results in a significant amount of reflection of the signal.

- As the ultrasound wave travels through one medium or tissue into another medium or tissue, a change in acoustic impedance occurs.
- The amount of change of acoustic impedance will determine the amount of reflection. Acoustic impedance is determined by the density of the tissue.
- Large changes in density between two tissues will result in a large change of acoustic impedance. The change in impedance between two structures is call acoustic impedance mismatch.
- The difference in acoustic impedance between two tissues accounts for the amount of reflection that will occur at the tissue border.

- As the ultrasound wave passes through each tissue boundary, it loses some energy or amplitude while some of the wave is reflected.

Scattering:

- Scattering occurs when the width or lateral dimension of the tissue boundary is less than one wavelength.
- If a large number of small tissue boundaries occurs, the scattering can radiate in all directions.
- The signal that reaches the transducer is a much weaker signal than the transmitted signal and is typically 100-1000 (40 - 60 dB) less than the transmitted signal.
- Most scattering occurs with red blood cells, which have a width of 7-10 Âµm, which is 20 times smaller than the ultrasound wavelength (0.2 to 1 mm).
- A filter can ignore small signals from red blood cells below a threshold value. Hematocrit has very little effect on the Doppler signal.

Refraction:

- Refraction occurs when the ultrasound signal is deflected from a straight path and angle of deflection is away from the transducer
- Ultrasound waves are only refracted at a different medium interface of diffe acoustic impedance.
- Refraction allows enhanced image quality by using acoustic lenses.
- Refraction can result in ultrasound double-image artifacts.

Attenuation:

- Attenuation is the result of an ultrasound wave losing energy. As the ultrasound w travels through a medium, the medium absorbs some of the energy of the ultrasound w
- The amount of energy absorption, or acoustic impedance (Z), is determined by product of the density of the medium and the propagation velocity of the ultraso wave. The acoustic impedance formula is shown below:
- Acoustic Impedence (Z) = Density (Ï•) x Propagation Velocity (c)
- During attenuation the ultrasound wave stays on the same path and is not deflected. it passes through tissues of different densities, the amplitude decreases.

- If all of the ultrasound wave energy is absorbed then structures distal to the point of total attenuation will not be visualized and will appear to be "dropped". This is called dropout.
- Energy is lost by reflection, scattering, and attenuation. The loss in energy results in a "noisy" background. If the signal-to-noise ratio is good then a clear picture will be displayed.
- A poor signal-to-noise ratio results in a blurry picture. Attenuation is frequency dependent. Low frequencies have better penetration and are therefore not attenuated as much as higher frequencies.

8. Elaborate on the non ionizing radiation effects. (Nov 2016, May 2015)

- We use and are exposed to nonionizing radiation sources every day.
- Microwave ovens use microwaves to heat food, toasters use infrared waves to heat and sometimes burn our toast, and we watch television, talk on cell phones, and listen to the radio through the use of radio waves.
- These are all nonionizing forms of radiation. Visible light, radar, laser light, and ultraviolet light also fall into this radiation category.
- Some forms of nonionizing radiation can damage tissues if we are exposed too much.
- For instance, too much ultraviolet (UV) light from lying out in the sun is known to cause some skin cancers; even moderate amounts can cause skin burns.
- In addition to the sun, UV waves (sometimes called UV radiation) are emitted by lights used in tanning beds, black lights, and lights used to pasteurize fruit juices.
- Some UV waves have an energy that is high enough to cause a structural change within atoms.
- Visible light waves are also a form of nonionizing radiation, as is the light beam emitted by a laser.
- A laser beam can be visible, as in the case of a laser pointer, or a laser can emit an invisible beam of UV or infrared waves.
- With enough energy, lasers can cause biological damage, which is why they are useful in medicine to remove warts and some skin cancers and even to break up kidney stones.
- As we talk about these different sources, we are moving along a continuum of energy called the electromagnetic spectrum.

- Ionizing radiation tops the spectrum with the highest energy, nonionizing ultraviolet waves are next.
- Then comes visible light waves followed by infrared waves. Infrared sources in our daily lives include toasters, toaster ovens, and heat lamps.
- Now we get down to the lower energies where our favorite devices operate—in the radiofrequency (RF) wave range.
- From highest to lowest energy, this includes microwave ovens, global positioning systems, cell phones, television stations, FM radio, baby monitors, cordless phones, garage-door openers, CB radios, and AM radio.
- Radiofrequency waves can cause tissue heating at high energies and with high intensities.
- The last type of nonionizing radiation we'll simply mention is extremely low-frequency (ELF) waves that are produced by electrical power lines and wiring.

BM T43 – MEDICAL PHYSICS

UNIT-III

2 MARKS

1. What is LET? (May 2015,Nov 2019)

Linear energy transfer (LET) is the amount of energy that an ionizing particle transfers to the material traversed per unit distance. It describes the action of radiation into matter. It is identical to the retarding force acting on a charged ionizing particle travelling through the matter.

2. Define secondary bremsstrahlung (May 2015)

Bremsstrahlung is a type of "secondary radiation", in that it is produced as a result of stopping (or slowing) the primary radiation (beta particles).

3. State the inverse square law of attenuation?(May 2016)

The propagation and attenuation of sound, the inverse square law is a principle whereby a point source emits a sound wave uniformly in all directions (essentially spherically), where the intensity of the sound wave energy at any given point away from the source is diminished as a function of the total surface area of the sphere coincident with that point.

4. What are the most important interactions between electromagnetic field and tissues?(May 2016)

The existence of an electrical potential across a cell membrane sustains a chemical gradient between intra- and extracellular spaces and this drives trans membrane transport of organic (e.g. glucose) or inorganic molecules and ions. It is also a driving force for different types of trans membrane currents which could result from carrier-specific or non-specific conductance and thus have vastly different biological effects.

5. What is meant by mass? (Nov 2015,May 2019)

Mass, is an quantitative measure of inertia, a fundamental property of all matter. It is, in effect, the resistance that a body of matter offers to a change in its speed or position upon the application of a force. The greater the mass of a body, the smaller the change produced by an applied force.

6. Define photo electric effect. (Nov 2017, May 2017, May 2018,Nov 2018,Sep 2020)

The phenomenon of metals releasing electrons when they are exposed to the li ght of the appropriate frequency is called the photoelectric effect, and the electrons emitted during the process are called photoelectrons**.**

7. Write the medical application of radionuclide? (Nov 2017,May 2019)

Radionuclide therapy can be used to treat conditions such as hyperthyroidism, thyroid cancer, skin cancer and blood disorders.

8. Write the type of neutron reaction(Nov 2016)

The three types of neurons:

- sensory neurons
- motor neurons
- inter neurons.

9. Define Compton scattering? (Nov 2016,Nov 2015)

Compton scattering, is the scattering of a photon by a charged particle, usually an electron. If it results in a decrease in energy (increase in wavelength) of the photon (which may be an X-ray or gamma ray photon), it is called the Compton effect.

10. How bremsstrahlung radiation produced? (May 2017,Nov 2018)

Bremsstrahlung(German:“braking radiation”),electromagnetic radiation produced by a sudden slowing down or deflection of charged particles (especially electrons) passing through matter in the vicinity of the strong electric fields of atomic nuclei.

11. Write the efficiency equation of bremsstrahlung radiation production? (May 2018,Sep 2020)

Bremsstrahlung energy efficiency (the ratio of the output energy emitted as x-rays to input energy deposited by electrons) in a linac target may be approximated as in equation .(eq: Bremsstrahlung efficiency) where Z is the target atomic number and E is the accelerating energy in volts.

12. What are the factors affecting photoelectric effect? (Nov 2019)

- ❖ The intensity of incident radiation.
- ❖ A potential difference between metal plate and collector.
- ❖ Frequency of incident radiation.

11 MARKS

1. Explain the various modes of interaction with gamma rays? (May 2015, Nov 2017,Nov 2016,May 2019 May 2018,Sep 2020)

- ❖ Gamma rays ionize matter primarily via indirect ionization.
- ❖ Although a large number of possible interactions are known, there are three key interaction mechanisms of gamma radiation with matter.
- ❖ Gamma rays, also known as gamma radiation, refers to electromagnetic radiation (no rest mass, no charge) of a very high energies.
- ❖ Gamma rays are high-energy photons with very short wavelengths and thus very high frequency.
- ❖ Since the gamma rays are in substance only a very high-energy photons, they are very penetrating matter and are thus biologically hazardous.
- ❖ Gamma rays can travel thousands of feet in air and can easily pass through the human body.
- ❖ Gamma rays are emitted by unstable nuclei in their transition from a high energy state to a lower state known as gamma decay.
- ❖ In most practical laboratory sources, the excited nuclear states are created in the decay of a parent radionuclide, therefore a gamma decay typically accompanies other forms of decay, such as alpha or beta decay.
- ❖ Radiation and also gamma rays are all around us. In, around, and above the world we live in.
- ❖ It is a part of our natural world that has been here since the birth of our planet.

- Natural sources of gamma rays on Earth are inter alia gamma rays from naturally occurring radionuclides, particularly potassium-40.
- Potassium-40 is a radioactive isotope of potassium which has a very long half-life of 1.251×10^9 years (comparable to the age of Earth).
- This isotope can be found in soil, water also in meat and bananas. This is not the only example of natural source of gamma rays.

Gamma Decay

- Gamma rays are emitted by unstable nuclei in their transition from a high energy state to a lower state known as gamma decay.
- In most practical laboratory sources, the excited nuclear states are created in the decay of a parent radionuclide, therefore a gamma decay typically accompanies other forms of decay, such as alpha or beta decay.
- The process of isomeric transition is therefore similar to any gamma emission, but differs in that it involves the intermediate metastable excited state(s) of the nuclei.

Interaction of Gamma Rays with Matter

Gamma rays ionize matter primarily via indirect ionization. Although a large number of possible interactions are known, there are three key interaction mechanisms with matter.

- Photoelectric effect.

  The photoelectric effect dominates at low-energies of gamma rays. The photoelectric effect leads to the emission of photoelectrons from matter when light (photons) shines upon them.
- Compton scattering.

  Compton scattering dominates at intermediate energies. Photons undergo a wavelength shift called the Compton shift.
- Pair production.

In order for electron-positron pair production to occur, the electromagnetic energy of the photon must be above a threshold energy, which is equivalent to the rest mass of two electrons. The threshold energy (the total rest mass of produced particles) for electron-positron pair production is equal to 1.02MeV (2 x 0.511MeV) because the rest mass of a single electron is equivalent to 0.511MeV of energy.

Gamma Rays Attenuation

The attenuation of gamma radiation can be then described by the following equation. $I=I_0.e^{-\mu x}$, where I is intensity after attenuation, I_o is incident intensity, μ is the linear attenuation coefficient (cm^{-1}), and physical thickness of absorber (cm).

Half Value Layer

The half value layer expresses the thickness of absorbing material needed for reduction of the incident radiation intensity by a factor of two.

There are two main features of the half value layer:

- ❖ The half value layer decreases as the atomic number of the absorber increases. For example 35 m of air is needed to reduce the intensity of a 100 keV gamma ray beam by a factor of two whereas just 0.12 mm of lead can do the same thing.
- ❖ The half value layer for all materials increases with the energy of the gamma rays. For example from 0.26 cm for iron at 100 keV to about 1.06 cm at 500 keV.

2. **Give an account of photo electric effect of an atom. (May 2015, Nov 2015, Nov 2017 ,May 2016,Nov 2018)**

   Photoelectric Effect:

   The phenomenon of metals releasing electrons when they are exposed to the light of the appropriate frequency is called the photoelectric effect, and the electrons emitted during the process are called photoelectrons.

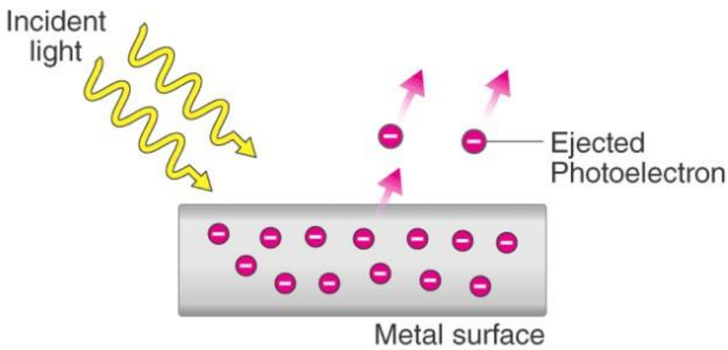
   Principle :

   The law of conservation of energy forms the basis for the photoelectric effect

OCCURRENCE OF PHOTOELETRIC EFFECT

The photoelectric effect is a phenomenon in which electrons are ejected from the surface of a metal when light is incident on it. These ejected electrons are called photoelectrons. It is important to note that the emission of photoelectrons and the kinetic energy of the ejected photoelectrons is dependent on the frequency of the light that is incident on the metal's surface. The process through which photoelectrons are ejected from the surface of the metal due to the action of light is commonly referred to as photoemission.

The photoelectric effect occurs because the electrons at the surface of the metal tend to absorb energy from the incident light and use it to overcome the attractive forces that bind them to the metallic nuclei. An illustration detailing the emission of photoelectrons as a result of the photoelectric effect is provided below.



The photoelectric effect cannot be explained by considering light as a wave. However, this phenomenon can be explained by the particle nature of light, in which light can be visualized as a stream of particles of electromagnetic energy. These 'particles' of light are called photons. The energy held by a photon is related to the frequency of the light via Planck's equation:

$E = h\ \ = hc/\lambda$

Where,

- E denotes the energy of the photon
- h is Planck's constant
- denotes the frequency of the light
- c is the speed of light (in a vacuum)
- λ is the wavelength of the light

Thus, it can be understood that different frequencies of light carry photons of varying energies. For example, the frequency of blue light is greater than that of red light (the wavelength of blue light is much shorter than the wavelength of red light). Therefore, the energy held by a photon of blue light will be greater than the energy held by a photon of red light.

Threshold Energy for the Photoelectric Effect

For the photoelectric effect to occur, the photons that are incident on the surface of the metal must carry sufficient energy to overcome the attractive forces that bind the electrons to the nuclei of the metals. The minimum amount of energy required to remove an electron from the metal is called the threshold energy (denoted by the symbol Φ). For a photon to possess energy equal to the threshold energy, its frequency must be equal to the threshold frequency (which is the minimum frequency of light required for the photoelectric effect to occur). The threshold frequency is usually denoted by the symbol $_{th}$ and the associated wavelength (called the threshold wavelength) is denoted by the symbol λ_{th}. The relationship between the threshold energy and the threshold frequency can be expressed as follows.

$\Phi = h\ _{th} = hc/\lambda_{th}$

Relationship between the Frequency of the Incident Photon and the Kinetic Energy of the Emitted Photoelectron

Therefore, the relationship between the energy of the photon and the kinetic energy of the emitted photoelectron can be written as follows.

$E_{photon} = \Phi + E_{electron}$

$\Rightarrow h = h\ _{th} + ½m_e v^2$ Where,

- E_{photon} denotes the energy of the incident photon, which is equal to h
- Φ denotes the threshold energy of the metal surface, which is equal to h $_{th}$

- $E_{electron}$ denotes the kinetic energy of the photoelectron, which is equal to $\frac{1}{2}m_e v^2$ (m_e = mass of electron = $9.1*10^{-31}$ kg)

Photoelectric Effect Formula

According to the Einstein explanation of the photoelectric effect is:

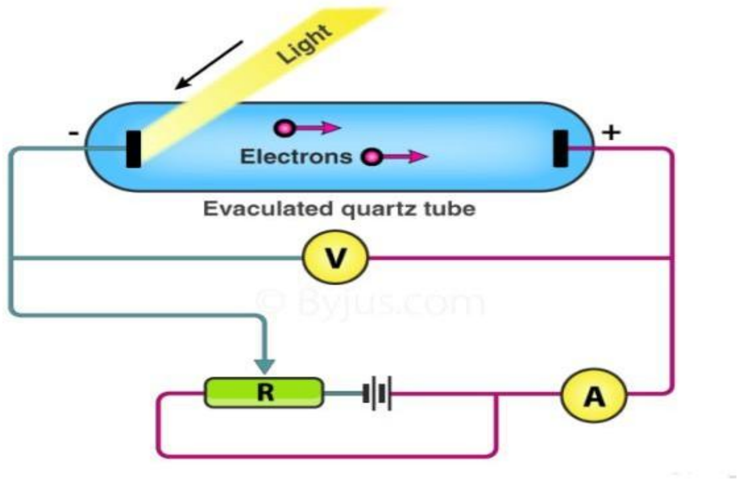
The energy of photon = energy needed to remove an electron + kinetic energy of the emitted electron

$$h\nu = W + E$$

Where,

- h is Planck's constant.
- ν is the frequency of the incident photon.
- W is a work function.
- E is the maximum kinetic energy of ejected electrons: $1/2\ mv^2$.

EXPERIMENTAL SETUP:



Photoelectric Effect: Experimental Setup

The given set up D experiment is used to study the photoelectric effect experimentally. In an evacuated glass tube. Two zinc plates C and D are enclosed. Plates C acts as anode and D acts as a photosensitive plate.

Two plates are connected to a battery B and ammeter A. If the radiation is incident on the plate D through a quartz window W electrons are ejected out of the plate and current flows in the circuit this is known as photocurrent. Plate C can be maintained at desired potential (+ve or – ve) with respect to plate D.

Characteristics Of Photoelectric Effect

- The threshold frequency varies with material, it is different for different materials.
- The photoelectric current is directly proportional to the light intensity.
- The kinetic energy of the photoelectrons is directly proportional to the light frequency.
- The stopping potential is directly proportional to the frequency and the process is instantaneous.

Factors affecting Photoelectric Effect

With the help of this apparatus, we will now study the dependence of the photoelectric effect on the following factors.

1. The intensity of incident radiation.
2. A potential difference between metal plate and collector.
3. Frequency of incident radiation.

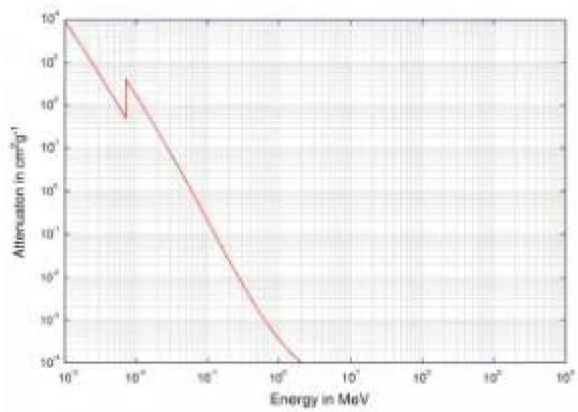
Cross-Sections of Photoelectric Effect

At small values of gamma ray energy the photoelectric effect dominates. The mechanism is also enhaced for materials of high atomic number Z. It is not simple to derive analytic expression for the probability of photoelectric absorption of gamma ray per atom over all ranges of gamma ray energies. The probability of photoelectric absorption per unit mass is approximately proportional to:

$$\boldsymbol{\tau_{(photoelectric)} = \text{constant x } Z^N/E^{3.5}}$$

where **Z** is the atomic number, the exponent **n** varies between 4 and 5. **E** is the energy of the incident photon. The proportionality to higher powers of the atomic number Z is the main reason for using of high Z materials, such as lead or depleted uranium in gamma ray shields.

Although the probability of the photoelectric absorption of gamma photon decreases, in general, with increasing photon energy, there are **sharp discontinuities** in the cross-section curve. These are called **"absoption edges"** and they correspond to the binding energies of electrons from atom's bound shells. For photons with the energy just above the edge, the photon energy is just sufficient to undergo the photoelectric interaction with electron from bound shell, let say K-shell. The probability of such interaction is just above this edge much greater than that of photons of energy slightly below this edge. For gamma photons below this edge the interaction with electron from K-shell in energetically impossible and therefore the probability drops abruptly. These edges occur also at binding energies of electrons from other shells (L, M, N …..).



Cross section of photoelectric effect.

3. Describe in detail about the interaction of neutron with matter (Nov 2015, Nov 2018,Nov 2019,May 2019)

Neutrons have no charge. They interact via physical collisions with nuclei (target nuclei).A neutron might scatter off the nucleus or combine with the nucleus. When the neutron combines with a nucleus, some type of particle might be emitted (e.g., proton, alpha particle) and/or a "prompt" gamma ray.

Neutrons, like other indirectly ionizing radiation (e.g., gamma rays), can travel substantial distances .The probability that a given type of reaction will occur depends on:

• The neutron energy

• The identity of the target nuclide

Neutron Energies

• The types of reactions that are possible and their probability depends on the neutron kinetic energy.

• Neutrons are classified according to energy. There is no agreement as to the precise.The following is approximate:

– Thermal (0.025 eV)

– Slow (< 10 eV)

– Intermediate (10 eV – 100 keV)

– Fast (>100 keV)

Typical Fate of Neutrons

Neutrons are born fast. They slow down due to scattering (referred to as moderation) until they reach thermal energies. Finally, they are absorbed by a target nucleus.

Fast neutron →Thermal Neutron →Capture

NEUTRON CROSS SECTIONS

Each type of interaction can be characterized by its cross section.The cross section, given the symbol F, describes the probability of the interaction. It depends on: the nuclide (e.g., H-1 vs H-2) and the neutron energy. The unit of the cross section is the barn. One barn is .

The macroscopic cross section is the total cross section of all the atoms of a given nuclide in a cubic centimeter. The units of the macroscopic cross section are (i.e., /).

= N = (6.02) ( ) (A)

is the total macroscopic cross section (cm-1)

N is the number of atoms of the nuclide per cm3

is the microscopic cross section (cm2)

is the density (g/cm3)

A is the isotopic mass (g/mole)

Some sources of neutrons

- Spontaneous fission of isotopes
- Photonuclear interactions
- Neutron generator

Interactions of neutrons:

- Collisions with atomic nuclei often in a *'billiard-ball'* type interaction.
- Rare events, because neutron and nucleus are tiny compared to atom.
- So, neutrons can travel long distances through matter before interacting.

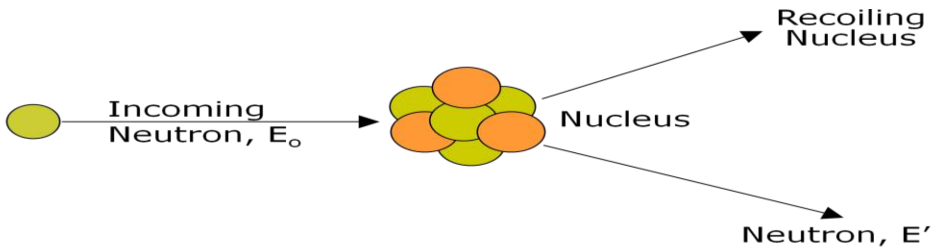
Types of neutron interaction:

1. Elastic scattering
2. Inelastic scattering
3. Neutron capture

Elastic Scattering

- Elastic scattering is a billiard ball type of collision where kinetic energy is conserved, i.e., the total kinetic energy is the same before and after the collision.
- Elastic scattering is the most likely interaction for almost all nuclides and neutron energies.
- The greatest amount of energy can be transferred from the neutron to a target nucleus when the latter has the same mass as the neutron. As such, the lower the atomic mass number of the target, the more effective it is as a moderator.

- Moderators (e.g., water, paraffin, plastic, and graphite) slow neutrons by elastic scattering.



- Conservation of Energy and Momentum:

$$E = E_o\left(\frac{M-m}{M+m}\right)^2$$

E = energy of scattered neutron

E_o =initial energy of neutron

M = mass of the scattered nucleus

m = mass of neutron

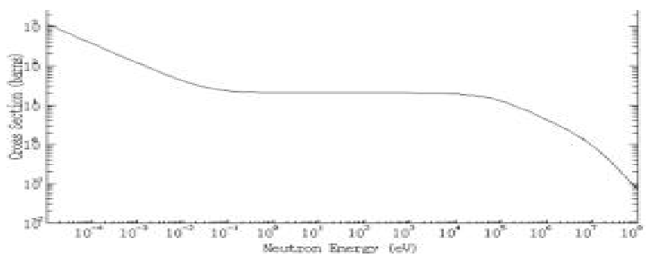
$\Rightarrow$ Energy transferred to nucleus $\uparrow$ as target mass $\rightarrow$ neutron mass.

$\Rightarrow$ Hydrogen good for stopping neutrons e.g. fat better than muscle.

- Elastic scattering important at low neutron energies (few MeV) and not effective above 150 MeV

Elastic Scattering

• This curve shows the dependence of the H-1 elastic scattering cross section on neutron energy.



Inelastic Scattering

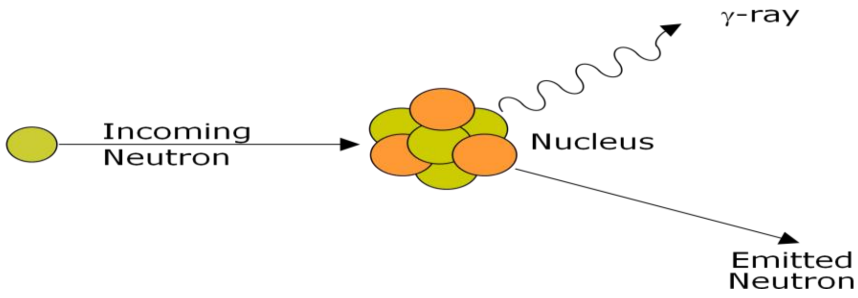
• Inelastic scattering is a type of scattering collision where kinetic energy is not conserved. The total kinetic energy was greater before the collision than after collision than after.

• The remaining energy is given to the target nucleus as excitation energy.

• When the scattered nucleus de-excites, it emits one or more gamma rays.

• Inelastic scattering is not common. When it does occur, it is most likely to involve high Z nuclei and high energy neutrons.

• It is sometimes used as a mechanism to moderate very high energy neutrons.



- Interaction probability ↑ as: neutron energy ↑

  target size ↑

  ⇒ Important at high neutron energies in heavy materials

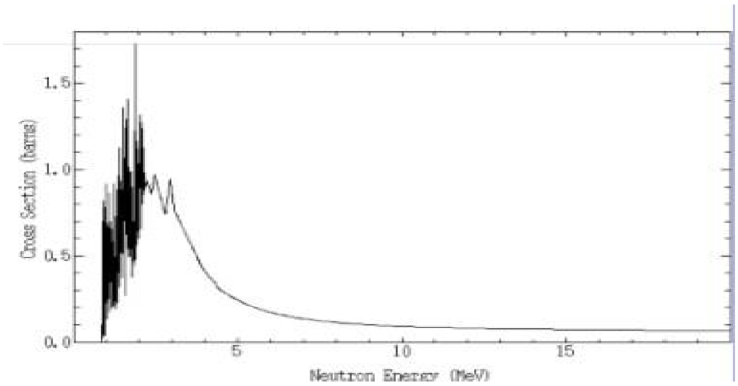
  ⇒ Energy transferred to the target nucleus and emitted energy:

$E = E_o - E_g$

E = Energy of the neutron after collision

E_o = Initial energy of the neutron

This curve shows the dependence of the Fe-56 inelastic scattering cross section on neutron energy. Inelastic scattering does not occur below a certain threshold – the minimum energy required to excite the target nucleus.



Neutron Capture

- Neutron captured by nucleus of absorbing material
- Only g-ray emitted.
- Probability of capture is inversely proportional to the energy of the neutron.

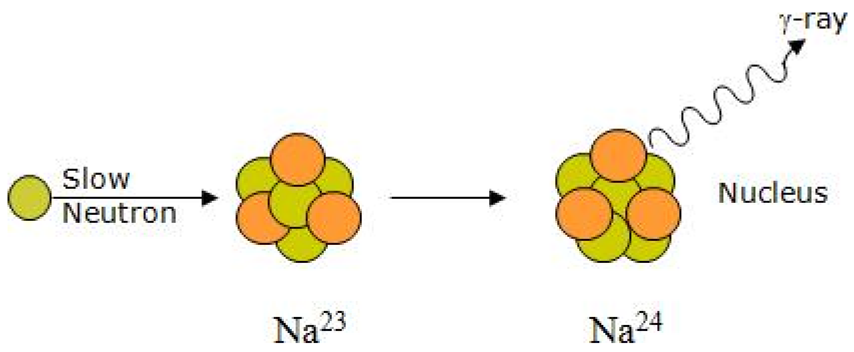
⇒ Low energy (=thermal neutrons) have the highest probability for capture.

⇒ When neutrons lose sufficient energy through scattering, they can interact directly with the nucleus of the absorbing material

⇒ If the energy of the neutron is known, the probability of capture by a specific nucleus can be defined by a term called "**Capture Cross Section**" which is expressed in Barns (1 s =10-24 cm2).

⇒ The capture cross section is different for each target nucleus, each isotope of the target nucleus and for each energy level of neutron.

⇒ The cross section of nuclei vary greatly from almost 0 for helium to 2.5 X 10 6 Barns for a Xenon nucleus. When a neutron is captured by a nucleus, the progeny has an increased mass number of 1 and will emit a particle, electromagnetic radiation or the fission of the nucleus. The progeny itself may also be unstable and decay emitting various type of ionizing radiation.



4. Explain in detail about interaction of charged particles with matter?(May 2017)

• "The interaction of charged particles with matter" concerns the transfer of energy from the charged particles to the material through which they travel.

•The"charged particles"considered here are:

- Alpha particles (+2 charge)

- Beta particles (+ or -1 charge) or electrons

• Photons and neutrons, which have no charge, interact very differently.

• Charged particles passing through matter continuously interact with the electrons and nuclei of the surrounding atoms.

• In other words, alpha and beta particles are continually slowing down as they travel through matter.

• The interactions involve the electromagnetic forces of attraction or repulsion between the alpha or beta particles and the surrounding electrons and nuclei.

Force of the Interaction

• The force associated with these interactions can be described by Coulomb's equation:

$$F = \frac{k\, q_1\, q_2}{r^2}$$

k is a constant = 9 x N-/ .

q1 is the charge on the incident particle in Coulombs.

q2 is the charge on the "struck" particle.

r is the distance between the particles in meters.

Things to notice about the equation:

• The force increases as the charge increases• The force increases as the distance decreases (it quadruples if the distance is cut in half)

• The force can be positive or negative (attractive or repulsive)

Four Types of Charged Particle Interactions

• The four types of interactions are:

- Ionization (alphas and betas)
- Excitation (alphas and betas)
- Bremsstrahlung(primarily betas)
- Cerenkov radiation (primarily betas)

• Ionization is almost always the primary mechanism of energy loss.

• A charged particle (alpha or beta particle) exerts sufficient force of attraction or repulsion to completely remove one or more electrons from an atom.

• The energy imparted to the electron must exceed the binding energy of the electron.

• Ionization is most likely to involve atoms near the charged particle's trajectory.

• Each ionization event reduces the charged particle's velocity, i.e., the alpha or beta particle loses kinetic energy.

Ion pairs:

• Ionization turns a neutral atom into an ion pair.

• The electron stripped away from the atom is the negative member of the ion pair. It is known as a secondary electron.

The secondary electron has some, but not much, kinetic energy - usually less than 100 eV. Sometimes it has enough energy to ionize additional atoms. Then it is referred to as a delta ray.

• The atom , now with a vacancy in one of its electron shells, is the positive member of the ion pair.

Excitation

- The charged particle (alpha or beta particle) exerts just enough force to promote one of the atom’s electrons to a higher energy state (shell).Insufficient energy was transferred to ionize the atom.
- Excitation usually occurs farther away from the charged particle's trajectory than ionization.
    - The excited atom will de-excite and emit a low energy ultraviolet photon.
    - Each excitation event reduces the charged particle's velocity.

Bremsstrahlung

- Bremsstrahlung radiation is electromagnetic radiation that is produced when charged particles are deflected (decelerated) while traveling near an atomic nucleus.

- Bremsstrahlung is almost exclusively associated with electrons (beta particles)because the latter are easily deflected.

- Large particles (e.g., alpha particles) do not produce significant bremsstrahlung because they travel in straight lines. Since they aren’t deflected to any real extent, bremsstrahlung production is inconsequential.

- Bremsstrahlung photons may have any energy up to the energy of the incident particle.For example, the bremsstrahlung photons produced by P-32 betas have a range of energies up to 1.7 MeV, the maximum energy of the P-32 alphas.

- Bremmstrahlung is most intense when:
    - ➢ The beta particles or electrons have high energies

- The material has a high atomic number

- The greater the charge in the nucleus (atomic number), the greater the deflection of the electrons and the greater the intensity of the bremsstrahlung.

Cerenkov Radiation Production

- Cerenkov radiation is the blue light emitted by charged particles that travel through a transparent medium (e.g., water) faster than the speed of light in that medium.
- Just as a plane going faster than sound produces a cone of sound (a sonic boom), a charged particle going faster than light produces a cone of light (Cerenkov radiation)
- The production of Cerenkov radiation is essentially limited to high energy (i.e., fast) beta particles and electrons.
- Cerenkov radiation is often associated with reactor fuel pools or nuclear criticality accidents.
- It is possible to quantify beta emitters by measuring the intensity of their Cerenkov radiation

5. **Explain in detail about bremsstrahlung. (Nov 2016,May 2016)**

Bremsstrahlung (from bremsen "to brake" and Strahlung "radiation"; i.e., "braking radiation" or "deceleration radiation") is electromagnetic radiation produced by the deceleration of a charged particle when deflected by another charged particle, typically an electron by an atomic nucleus (as depicted in the image above). The moving particle loses kinetic energy, which is converted into a photon, thus satisfying the law of conservation of energy. The term is also used to refer to the process of producing the radiation. Bremsstrahlung has a continuous spectrum, which becomes more intense and whose peak intensity shifts toward higher frequencies as the change of the energy of the decelerated particles increases. The maximum radiation frequency is related to the kinetic energy of the electrons by the relationship

$$E = h\nu_{max}$$

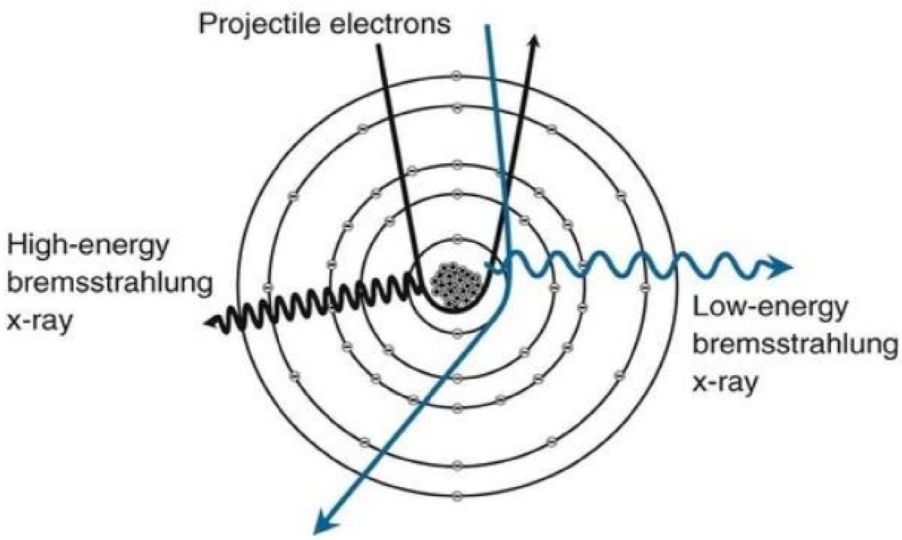
and therefore the minimum value for the wavelength of the emitted radiation is also known:

$$\lambda_{min} = \frac{c}{\nu_{max}} = \frac{hc}{E}$$

Broadly speaking, bremsstrahlung or braking radiation is any radiation produced due to the deceleration (negative acceleration) of a charged particle, which includes synchrotron radiation (i.e. photon emission by a relativistic particle), cyclotron radiation (i.e. photon emission by a non-relativistic particle), and the emission of electrons and positrons during beta decay. However, the term is frequently used in the more narrow sense of radiation from electrons (from whatever source) slowing in matter.

Theory:

According to Maxwell's equations, accelerated charges emit electromagnetic radiation. In particular, when an electron hits a material, it is subjected to a scattering by the coulomb field of an atomic nucleus, so it can be thought that it is "braked". If the energy of the bombarding electrons is high enough, the emitted radiation lies in the X-ray region of the electromagnetic spectrum.

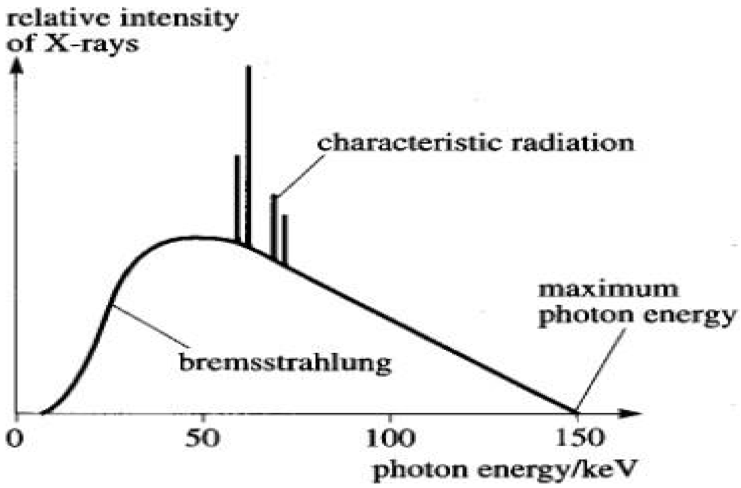


The energy loss for bremsstrahlung is significant – that is, over the ionization and nucleus excitation processes – for highly energy electrons (in the order of hundreds of MeV in air and water, and tens of MeV in heavy materials such as lead or iron). The average energy loss per length unit can be roughly calculated with the following :

$$-\langle\frac{dE}{dx}\rangle \approx \frac{4N_a Z^2 \alpha^3 (\hbar c)^2}{m_e^2 c^4} E \ \ln\frac{183}{Z^{1/3}}$$

Where N_a is the number of atoms per volume unit, Z is the atomic number of the target material, is α the fine structure constant and is the electron m_e mass.

It is therefore clear that the loss of energy is proportional to Z2 , to the energy of particle E and inversely proportional to the mass of the particle. For particles heavier than the electron the bremsstrahlung radiation is negligible. The logarithmic term is due to the partial shielding of nuclear charge by atomic electrons. The formal treatment through quantum mechanics was carried out by Hans Bethe and Walther Heitler in 1934.



This continuous spectrum overlaps even single strong lines, as bombarding electrons can expel electrons from the most internal atomic shells of the target, and the rapid filling of these gaps by other electrons of the upper layers produces characteristic X-ray for each atom (called “X ray fluorescence”), As shown in the image to the side. Alternatively, the energy difference between the two orbits will result in the further expulsion of electrons. This phenomenon is the Auger effect.

6. **Explain Compton scattering and pair production with suitable diagram?(May 2018,Nov 2019,Sep 2020)**

Compton scattering is the inelastic or nonclassical scattering of a photon (which may be an X-ray or gamma ray photon) by a charged particle, usually an electron. In Compton scattering, the incident gamma ray photon is deflected through an angle Θ with respect to its original direction. This deflection results in a decrease in energy (decrease in photon's frequency) of the photon and is called the Compton effect.

The photon transfers a portion of its energy to the recoil electron. The energy transferred to the recoil electron can vary from zero to a large fraction of the incident gamma ray energy, because all angles of scattering are possible. The Compton scattering was observed by A. H.Compton in 1923 at Washington University in St. Louis. Compton earned the Nobel Prize in Physics in 1927 for this new understanding about the particle-nature of photons.

Key characteristics of Compton Scattering

- Compton scattering dominates at intermediate energies.
- It is the scattering of photons by atomic electrons
- Photons undergo a wavelength shift called the Compton shift.
- The energy transferred to the recoil electron can vary from zero to a large fraction of the incident gamma ray energy

Compton Scattering Formula

- The Compton formula was published in 1923 in the Physical Review.
- Compton explained that the X-ray shift is caused by particle-like momentum of photons.
- Compton scattering formula is the mathematical relationship between the shift in wavelength and the scattering angle of the X-rays.
- In the case of Compton scattering the photon of frequency f collides with an electron at rest. Upon collision, the photon bounces off electron, giving up some of its initial energy (given by Planck's formula E=hf), While the electron gains momentum (mass x velocity), the **photon cannot lower its velocity**.
- As a result of momentum conservetion law, the photon must lower its momentum given by:

$$p_{\text{photon}} = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$$

So the decrease in photon's momentum must be translated into decrease in frequency (increase in wavelength $\Delta\lambda = \lambda' - \lambda$).

The shift of the wavelength increased with scattering angle according to the Compton formula:

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}(1 - \cos(\theta))$$

where

λ is the initial wavelength of photon

λ' is the wavelength after scattering,

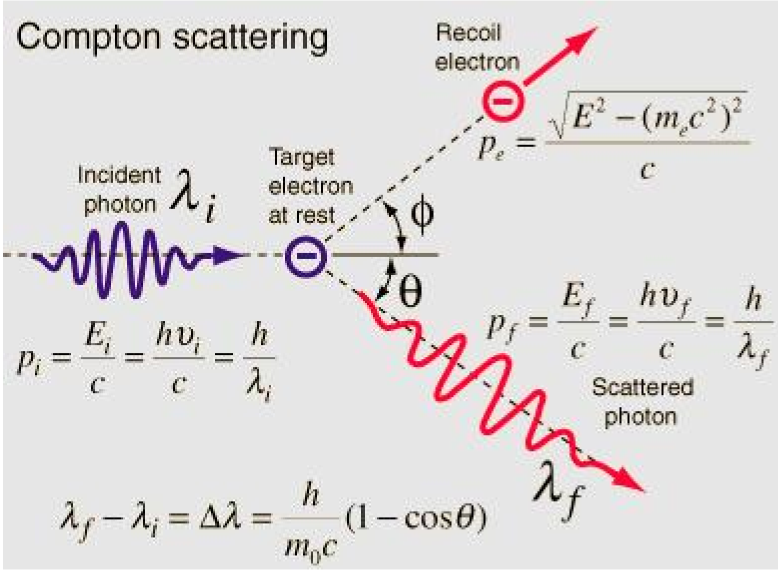
h is the Planck constant = 6.626×10^{-34} J.s

m_e is the electron rest mass (0.511 MeV)

c is the speed of light

Θ is the scattering angle.

- The minimum change in wavelength $(\lambda' - \lambda)$ for the photon occurs when Θ = 0° (cos(Θ)=1) and is at least zero.
- The maximum change in wavelength $(\lambda' - \lambda)$ for the photon occurs when Θ = 180° (cos(Θ)=-1).
- In this case the photon transfers to the electron as much momentum as possible.
- The maximum change in wavelength can be derived from Compton formula:



$$\Delta\lambda = \frac{h}{m_ec}(1-(-1)) = \frac{2h}{m_ec} = \frac{2\times(6.626\times10^{-34}[\mathrm{J\cdot s}])}{9.1\times10^{-31}\ [\mathrm{kg}]\ \times\ 3\times10^{8}[\mathrm{m/s}]} = 4.86\times10^{-12}\,\mathrm{m}$$

The quantity h/m_ec is known as the **Compton wavelength** of the electron and is equal to **2.43×10^{-12} m**.

Compton Scattering – Cross-Sections

The probability of Compton scattering per one interaction with an atom increases linearly with atomic number Z, because it depends on the number of electrons, which are available for scattering in the target atom. The angular distribution of photons scattered from a single free electron is described by the Klein-Nishina formula:

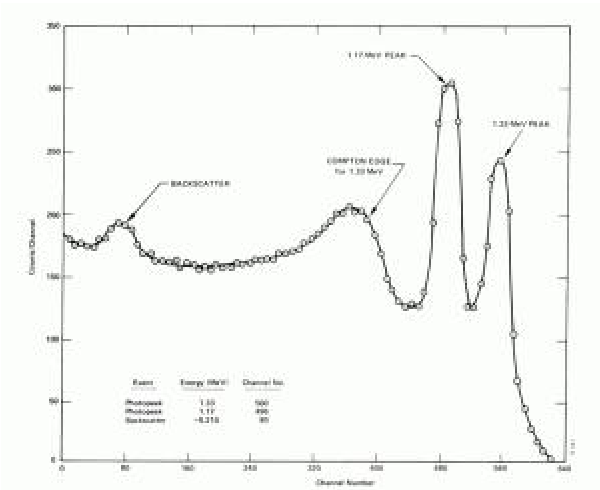
$$\frac{d\sigma}{d\Omega} = \frac{1/2r_0^2\left[1+\cos^2\Theta\right]}{\left[1+2\varepsilon\sin^2\Theta/2\right]^2}\left\{1+\frac{4\varepsilon^2\sin^4\Theta/2}{\left[1+\cos^2\Theta\right]\left[1+2\varepsilon\sin^2\Theta/2\right]}\right\}$$

Compton Edge

In spectrophotometry, the Compton edge is a feature of the spectrograph that results from the Compton scattering in the scintillator or detector. This feature is due to photons that undergo Compton scattering with a scattering angle of 180° and then escape the detector. When a gamma ray scatters off the detector and escapes, only a fraction of its initial energy can be deposited in the sensitive layer of the detector. It depends on the scattering angle of the photon, how much energy will be deposited in the detector. This leads to a spectrum of energies. The Compton edge energy corresponds to full backscattered photon**.**

Inverse Compton Scattering

Inverse Compton scattering is the scattering of low energy photons to high energies by relativistic electrons. Relativistic electrons can boost energy of low energy photons by a potentially enormous amount (even gamma rays can be produced). This phenomenon is very important in astrophysics.



Compton edge of 60Co on gamma spectrometer Na(Tl).

Positron-Electron Pair Production

In general, pair production is a phenomenon of nature where energy is direct converted to matter. The phenomenon of pair production can be view two different ways. One way is as a particle and antiparticle and the other is as a particle and a hole. The first way can be represented by formation of electron and positron, from a packet of electromagnetic energy (high energy photon – gamma ray) traveling through matter. It is one of the possible ways in which gamma rays interact with matter. At high energies this interaction dominates.

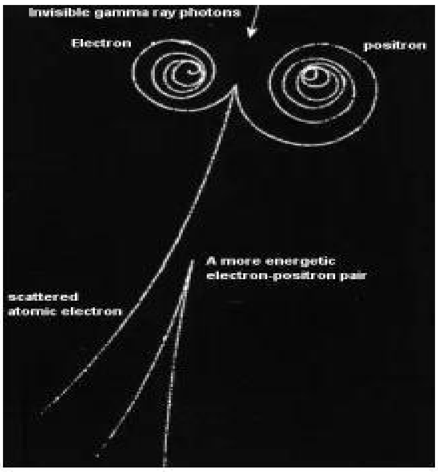
In order for electron-positron pair production to occur, the electromagnetic energy of the photon must be above a threshold energy, which is equivalent to the rest mass of two electrons. The threshold energy (the total rest mass of produced particles) for electron-positron pair production is equal to 1.02MeV (2 x 0.511MeV) because the rest mass of a single electron is equivalent to 0.511MeV of energy.

If the original photon's energy is greater than 1.02MeV, any energy above 1.02MeV is according to the conservation law split between the kinetic energy of motion of the two particles.The presence of an electric field of a heavy atom such as lead or uranium is essential in order to satisfy conservation of momentum and energy. In order to satisfy both conservation of momentum and energy, the atomic nucleus must receive some momentum. Therefore a photon pair production in free space cannot occur.

Moreover, the positron is the anti-particle of the electron, so when a positron comes to rest, it interacts with another electron, resulting in the annihilation of the both particles and the complete conversion of their rest mass back to pure energy (according to the $E=mc^2$ formula) in the form of two oppositely directed 0.511 MeV gamma rays (photons). The pair production phenomenon is therefore connected with **creation and destruction of matter** in one reaction.

Positron-Electron Pair Production – Cross-Section

The probability of pair production, characterized by cross section, is a **very complicated function based on quantum mechanics**. In general the cross section increases approximately with the square of atomic number **($\sigma_p \sim Z^2$)** and increases with photon energy, but this dependence is much more complex.



Cross section of pair production in nuclear field and electron field.

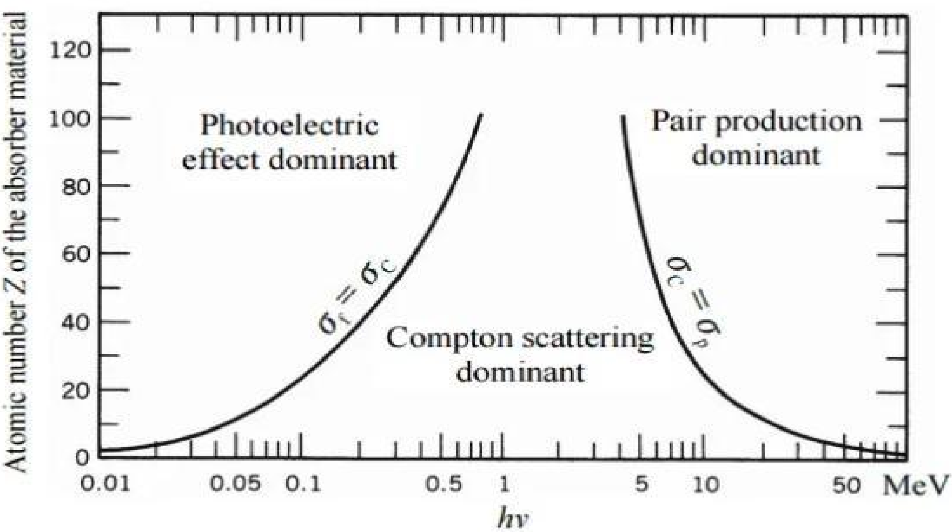
Gamma Rays Attenuation

The total cross-section of interaction of a gamma rays with an atom is equal to the sum of all three mentioned partial cross-sections: $\boldsymbol{\sigma = \sigma_f + \sigma_C + \sigma_p}$

- **σ_f – Photoelectric effect**
- **σ_C – Compton scattering**
- **σ_p – Pair production**

Depending on the gamma ray energy and the absorber material, one of the three partial cross-sections may become much larger than the other two. At small values of gamma ray energy the **photoelectric effect** dominates. **Compton scattering** dominates at intermediate energies. The compton scattering also increases with decreasing atomic number of matter, therefore the interval of domination is wider for light nuclei. Finally, **electron-positron pair production** dominates at high energies.

Based on the definition of interaction cross-section, the dependence of gamma rays intensity on thickness of absorber material can be derive. If **monoenergetic gamma rays** are collimated into a **narrow beam** and if the detector behind the material only detects the gamma rays that passed through that material without any kind of interaction with this material, then the dependence should be simple **exponential attenuation of gamma rays**. Each of these interactions removes the photon from the beam either by absorbtion or by scattering away from the detector direction.



The relative importance of various processes of gamma radiation interaction with matter.

Therefore the interactions can be characterized by a fixed probability of occurance per unit path length in the absorber. The sum of these probabilities is called the **linear attenuation coefficient**:

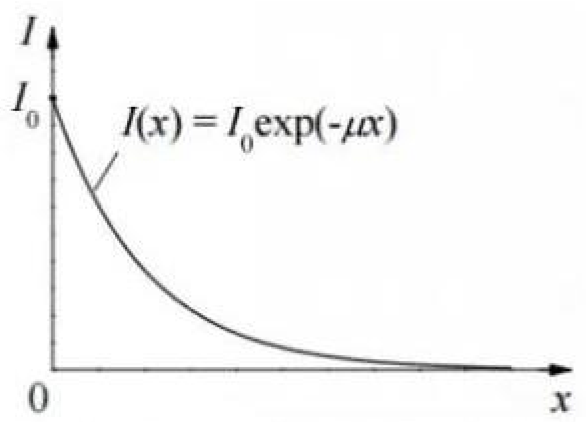
$$\mu = \tau_{(photoelectric)} + \sigma_{(Compton)} + \kappa_{(pair)}$$

Linear Attenuation Coefficient

The attenuation of gamma radiation can be then described by the following equation.

$$I = I_0 . e^{-\mu x}$$

, where I is intensity after attenuation, I_o is incident intensity, μ is the linear attenuation coefficient (cm^{-1}), and physical thickness of absorber (cm).



Dependence of gamma radiation intensity on absorber thickness

The materials listed in the table beside are air, water and a different elements from carbon (*Z*=6) through to lead (*Z*=82) and their linear attenuation coefficients are given for three gamma ray energies. There are two main features of the linear attenuation coefficient:

- The linear attenuation coefficient increases as the atomic number of the absorber increases.
- The linear attenuation coefficient for all materials decreases with the energy of the gamma rays.

Half Value Layer

The half value layer expresses the thickness of absorbing material needed for reduction of the incident radiation intensity by a **factor of two**. There are two main features of the half value layer:

- The **half value layer** decreases as the atomic number of the absorber increases. For example 35 m of air is needed to reduce the intensity of a 100 keV gamma ray beam by a factor of two whereas just 0.12 mm of lead can do the same thing.
- The **half value layer** for all materials increases with the energy of the gamma rays. For example from 0.26 cm for iron at 100 keV to about 1.06 cm at 500 keV.

Mass Attenuation Coefficient

- When characterizing an absorbing material, we can use sometimes the mass attenuation coefficient.
- **The mass attenuation coefficient** is defined as the ratio of the linear attenuation coefficient and absorber density **(μ/ρ)**.
- The attenuation of gamma radiation can be then described by the following equation:

$$\mathbf{I=I_0.e^{-(\mu/\rho).\rho l}}$$

- where ρ is the material density, (μ/ρ) is the mass attenuation coefficient and ρ.l is the mass thickness.
- The measurement unit used for the mass attenuation coefficient cm^2g^{-1}.
- For intermediate energies the Compton scattering dominates and different absorbers have approximately equal mass attenuation coefficients.
- This is due to the fact that cross section of Compton scattering is proportional to the Z (atomic number) and therefore the coefficient is proportional to the material density ρ.
- At small values of gamma ray energy or at high values of gamma ray energy, where the coefficient is proportional to higher powers of the atomic number Z (for photoelectric effect $\sigma_f \sim Z^5$; for pair production $\sigma_p \sim Z^2$), the attenuation coefficient μ is not a constant.

BM T43 – MEDICAL PHYSICS

UNIT - 2

2 MARKS

1. What is the purpose of LINAC? (May 2015)

A medical linear accelerator (LINAC) customizes high energy x-rays or electrons to conform to a tumor's shape and destroy cancer cells while sparing surrounding normal tissue. It features several built-in safety measures to ensure that it will deliver the dose as prescribed and is routinely checked by a medical physicist to ensure it is working properly.

2. What is half life period? (May 2015,May 2016,Nov 2017, Nov 2018)

Half-life, in radioactivity, the interval of time required for one-half of the atomic nuclei of a radioactive sample to decay (change spontaneously into other nuclear species by emitting particles and energy), or, equivalently, the time interval required for the number of disintegration per second of a radioactive.

3. What is isometric transaction give example? (May 2016,Nov 2019)

A nuclear isomer is a meta stable state of an atomic nucleus, in which one or more nucleons (protons or neutrons) occupy higher energy levels than in the ground state of the same nucleus. "

Example: As the name suggests, it refers to the compounds that have the same chemical formula but different functional groups attached to them. An example of functional isomerism can be observed in the compound C_3H_6O.

4. What is radioactive decay? (Nov 2016,May 2019)

Radioactive decay (also known as nuclear decay, radioactivity, radioactive disintegration or nuclear disintegration) is the process by which an unstable atomic nucleus loses energy by radiation. A material containing unstable nuclei is considered radioactive.

5. What is internal Conversion? (Nov 2016)

Internal conversion is a non-radioactive decay process wherein an excited nucleus interacts electromagnetically with one of the orbital electrons of the atom. This causes the electron to be emitted (ejected) from the atom

6. What are the different types of radioactive decay? (May 2017)

- Alpha decay

- Beta decay
- Gamma decay

7. Distinguish Natural and artificial radioactivity. (May 2017,May 2018,Sep 2020)

Natural radioactivity comes from elements in nature. Artificial radioactivity comes from elements created in nuclear reactors and accelerators. so the person is exposed to radioactivity for a limited-time.

8. What is Spontaneous emission? (Nov 2017, Nov 2019,May 2019)

Spontaneous emission is the process in which a quantum mechanical system (such as a molecule, an atom or a subatomic particle) transits from an excited energy state to a lower energy state (e.g., its ground state) and emits a quantized amount of energy in the form of a photon.

9. Define radiation decay series. (May 2018, Nov 2019,Sep 2020)

Radioactive series, any of four independent sets of unstable heavy atomic nuclei that decay through a sequence of alpha and beta decays until a stable nucleus is achieved.

10. What is Milking process? (Nov 2018,May 2018)

Radionuclide generators are devices that produce a useful short-lived medical radionuclide (known as "daughter") from the radioactive transformation of a non-medical long-lived radionuclide (called a "parent"). By having a supply of parent on hand at a facility, the daughter is continually generated on site. The generator permits ready separation of the daughter radionuclide from the parent.

11 MARKS

1. Describe the radionuclide's generator system for Nuclear medicine.(May 2015,May 2016, Nov 2016, Nov 2017, May 2019, Nov 2015, Dec 2017, May 2017)

Need of Radionuclide Generator:

- Short-lived radionuclides are often the agents of choice in nuclear medicine because they permit the use of ample radioactivity while keeping the absorbed dose to the patient within acceptable limits.
- In general, however, the use of short-lived radionuclides entails many problems that stem from their fast decay. For example, the time available for processing, transportation, storage and dispensing is very limited and is often insufficient to assure quality in labeling and in radionuclidic purity.
- A generator solves some of the problems associated with the transportation of short-lived radionuclides.

Radionuclide generator:

- Radionuclide generators are devices that produce a useful short-lived medical radionuclide (known as "daughter") from the radioactive transformation of a non-medical long-lived radionuclide (called a "parent").
- By having a supply of parent on hand at a facility, the daughter is continually generated on site.
- The generator permits ready separation of the daughter radionuclide from the parent.
- Once separation occurs, the generator starts generating more daughter that can be again separated in sufficient quantity at a later time.
- For generator systems to be practical, the parent must have a relatively long half-life compared to that of the daughter, and the generator device (often referred as a "cow") must provide for repeated separations of the daughter product.
- This separation process is called an elution (colloquially it is also referred to as a "milking") .
- The example of outstanding importance is the 99Mo - 99mTc ("Moly") generator. 99Mo has a half-life of 66 hours and can be easily transported over long distances without serious loss of activity.
- Its short half-life decay product, technetium-99m, can be extracted and used at the remote facility.

- The useful life of a 99Mo - 99mTc generator is about 3 parent half lives, or approximately one week.

Process of getting Tc-99m from a cow:

- A technetium-99m generator, or colloquially a technetium cow, is a device used to extract the meta stable isotope 99mTc from a source of decaying molydenum-99.
- Mo-99 used in these generators is produced either by neutron irradiation of Mo-98 ($98Mo + n \rightarrow 99Mo + \gamma$) or by fission of U-235 (Uranium-235) in a nuclear reactor.
- Most commercial 99Mo - 99mTc generators use column chromatography, in which 99Mo is adsorbed onto acid alumina (Al_2O_3).
- Pulling or pushing normal saline solution.
- The column of immobilized 99Mo elutes the soluble 99mTc, resulting in a saline solution containing radioactive 99mTc and a good amount of Tc-99.
- The Tc-99 is carrier that is, for all practical purposes, stable. Chemically, it behaves identically to Tc-99.
- Since Tc-99 cannot be separated from 99mTc, it is a by-product that is included with the isomer but which has no medical advantage.
- Also included in the elution will be a small amount of Mo-99 and some Aluminum ions.
- These latter two substances are contaminants, the quantities of which must be limited for the protection of the patient.

Process of milking the cow:

- The heart of the generator consists of a ceramic column with 99Mo adsorbed onto its top surface.
- A solution called an eluent is passed through the column and reacts chemically with any Technetium.
- The arrangement shown in figure 1 below is called a positive pressure system where the eluent is forced through the ceramic column by a pressure, slightly above atmospheric pressure, in the eluent vial.

Figure 1

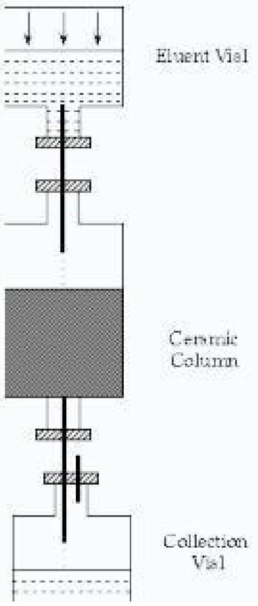
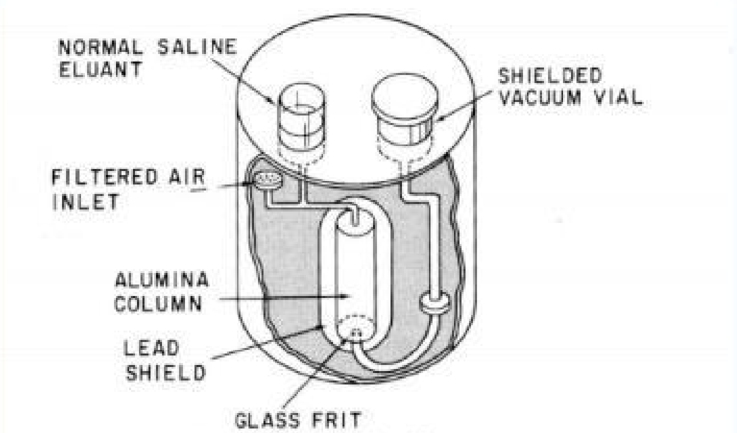
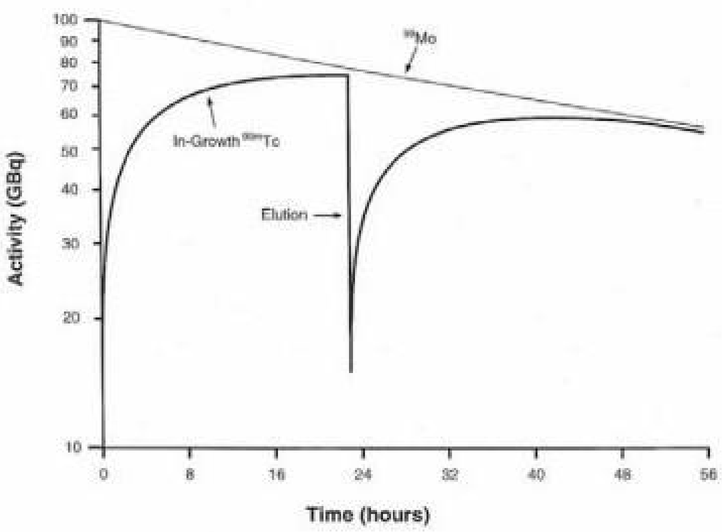


Figure 2

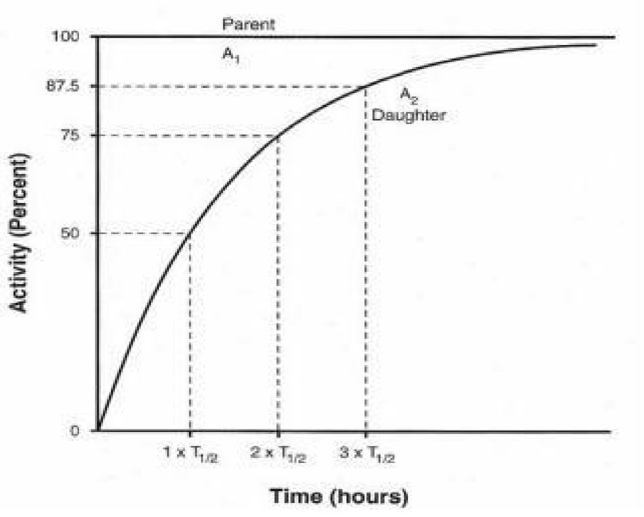


Cross-sectional drawing of a ^{99}Mo-^{99m}Tc generator. (Courtesy of the Society of Nuclear Medicine and Thomas R. Gnau.)

- ❖ The ceramic column and collection vials need to be surrounded by lead shielding for radiation protection purposes.
- ❖ In addition all components are produced and maintained in a sterile condition since the collected solution will be administered to patients.
- ❖ Physics and chemistry of nuclear cows. As the parent, Mo-99, decays, the concentration of the daughter, Tc-99m, increases in the column. Tc-99m reaches a maximum after about 24 hours .



- ❖ Because the daughter element is chemically different from its parent, it is not bound to the column, and it accumulates in the solvent.
- ❖ When the column is flushed with aqueous sodium chloride, it yields a solution containing sodium pertechnetate, $NaTcO_4$. After flushing, the concentration of Tc-99m is largely depleted from the column but immediately starts to increase again.
- ❖ This increase of daughter activity continues but ultimately begins to slow.
- ❖ Eventually the daughter activity is produced at a rate that nearly equals that at which it decays.
- ❖ When the ratio of the rate of production of the daughter and rate of decay of the daughter stabilize, the system is said to be in equilibrium.
- ❖ It demonstrates in simple terms that the Mo-99-Tc-99m radionuclide generator in which the half-life of the parent nuclide is much longer than that of the daughter nuclide.
- ❖ About 50% of the equilibrium activity is reached within one daughter half-life, 75% within two daughter half-lives and so on.
- ❖ It takes about 4 daughter half-lives to reach equilibrium with the parent. Once equilibrium has been achieved between the parent and daughter radio activities, it can be disturbed only by chemical separation.
- ❖ Removing the daughter nuclide from the generator ("milking" the generator) is reasonably done every 6 hours or, at most, twice daily in a Mo-99-Tc-99m generator.
- ❖ Because the half-life of Mo-99 is 66 hours or slightly less than 3 days, the supply of parent product will deplete to insufficient levels in roughly one week and must be replaced with a fresh system.



Regulatory requirements on quality control of generators:

State and federal regulations describe quality control tests and the frequency with which they must be performed to ensure that the eluate from the radionuclide generator is suitable for use. Moly generators yield a number of possible contaminates, mainly breakthrough of Mo-99 and aluminum ion. End users must check for these two before using any generator.

2. Write in detail about the construction and working of Linear accelerator with neat diagram?(May 2018, Sep 2020)

Linear accelerator, also called Linac, type of particle accelerator (*q.v.*) that imparts a series of relatively small increases in energy to subatomic particles as they pass through a sequence of alternating electric fields set up in a linear structure. The small accelerations add together to give the particles a greater energy than could be achieved by the voltage used in one section alone.

Construction and Working:

It will be consist of following components:

- ❖ The design of the source depends on the particle that is being moved. Electrons are generated by a cold cathode, the hot cathode and photocathode, or radio frequency ion sources. Protons are generated in an ion source, which can have many different designs. If the heavier particles are to be accelerated, e.g. uranium ions and the specialized ion source are needed.
- ❖ A high voltage source for the initial injection of particles.
- ❖ A hollow pipe vacuum chamber. The length will vary with the application. If the device is used for the production of X-rays for inspection or therapy the pipe may be only 0.5 to 1.5 meters long. If the device is to be an injector for a synchrotron it may be about 10 meters long. If the device is used as the primary accelerator for nuclear particle investigations, it may be several thousand meters long.
- ❖ Within the chamber, electrically isolated cylindrical electrodes are placed, whose length varies with the distance along the pipe. The length of each electrode is determined by the frequency and power of the driving power source and the nature of the particle to be accelerated, with shorter segments near the source and longer segments near the target. The mass of the particle has a large effect on the length of the cylindrical electrodes; for e.g. An electron is considerably lighter than a proton and so will

generally require a much smaller section of cylindrical electrodes as it accelerates very quickly think about a boulder versus a ping pong ball; it is easier to accelerate the ping pong ball.

- Likewise, because its mass is so small, even compared to the nucleus of an atom, electrons have much less kinetic energy than protons at the same speed. Because of the possibility of electron emissions from highly charged surfaces, the voltages used in the accelerator have an upper limit, so this cannot be as simple as just increasing voltage to match increased mass.
- One or more sources of radio frequency energy used to energize the cylindrical electrodes. The very high power accelerator will use one source for each electrode. The sources must operate at precise power, frequency and phase appropriate to the particle type to be accelerated to obtain maximum device power Quadrupole magnets surrounding the linac of the Australian Synchrotron are used to help focus the electron beam.
- An appropriate target the electrons are accelerated to produce X-rays then water cooled tungsten target is used. Various target materials are used when protons or other nuclei are accelerated, depending upon the specific investigation. For particle-to-particle collision investigations the beam may be directed to a pair of storage rings, with the particles kept within the ring by magnetic fields.
- The beams may then be extracted from the storage rings to create head on particle collisions. As the particle bunch passes through the tube it is unaffected while the frequency of the driving signal and the spacing of the gaps between electrodes are designed so that the maximum voltage differential appears as the particle crosses the gap.
- This accelerates the particle, imparting energy to it in the form of increased velocity. At speeds near the speed of light, the incremental velocity increase will be small, with the energy appearing as an increase in the mass of the particles. In portions of the accelerator where this occurs, the tubular electrode lengths will be almost constant.
- The additional magnetic or electrostatic lens elements may be included to ensure that the beam remains in the center of the pipe and its electrodes.
- The very long accelerators may maintain a precise alignment of their components through the use of servo systems guided by a laser beam.

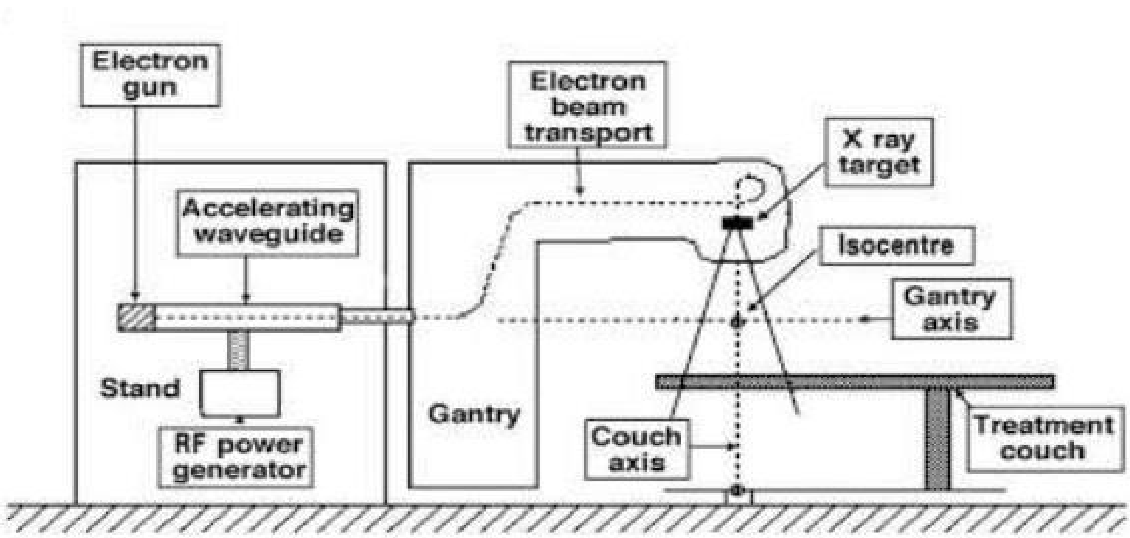
Working:

A linear accelerator works on the principle of electric attraction and repulsion. A charged particle such as an electron or a proton is injected into a tube with a similar charge (negative for electrons, positive for protons).Just beyond that tube is another tube with an opposite charge.

The particle gets attracted by the far tube, so it moves towards the next tube. Recall that inside a conductor, the electric field is zero therefore the charge of the tube it's in doesn't affect it. But when it's in the space between the tubes, it experiences an electric field which drives it forward. Just as it hits the next tube, its polarity switches so now it's the same as the particle.

A third tube, just beyond the second one, gets charged with the opposite polarity, and the same thing happens. This continues on, tube after tube. The particle gets a kick of energy each time it sees a new field, and the electric potential gets converted into kinetic energy. As the particle gets faster, the tubes have to get longer; the particle spends the same amount of time in each tube. Obviously, the geometry of the tubes and the frequency with which they're switched needs to be calculated precisely.

Linear accelerators of this type can be many miles long; they're often long enough that the curvature of the earth needs to be accounted for during their construction. But they can accelerate particles to a significant fraction of the speed of light.



Applications of LINAC:

The LINAC System highly efficient accelerators are ideally suited to many applications in industry, medicine, and research.

- LINAC Synchrotron Injector is serving as the perfect first stage to other higher energy accelerators.
- Semiconductor Processing.
- Boron Neutron Capture Therapy (BNCT) conventionally uses a nuclear reactor as the neutron source. Our LINAC-based neutron source provides a better controlled neutron energy spectrum, at lower cost, without the concern of radioactive waste associated with a reactor.
- Isotope Production Our LINACs are ideally suited for isotope production, such as the PET isotopes.
- Neutron Radiography.
- Neutron Activation Analysis.
- Surface Science.
- Particle-Induced X-ray Emission (PIXE).
- Pulsed Neutron Applications is LINAC-based neutron source allows for pulsed neutron beams for applications such as time-of-flight measurements.

Uses:

- A linear accelerator (LINAC) is most commonly used for external beam radiation patients with cancer.
- It delivers a uniform dose of high-energy x-ray to the region of the patient for tumor.
- These x-rays can destroy the cancer cells, while sparing the surrounding normal tissue.

3. Discuss the methods of producing artificial radioisotopes in medicine. (May 2017)

- Radioactive isotopes, or radioisotopes, are species of chemical elements that are produced through the natural decay of atoms.
- Exposure to radiation generally is considered harmful to the human body, but radioisotopes are highly valuable in medicine, particularly in the diagnosis and treatment of disease.
- Nuclear medicine uses radioactive isotopes in a variety of ways. One of the more common uses is as a tracer in which a radioisotope, such as technetium-99m, is taken orally or is injected or is inhaled into the body.

- ❖ The radioisotope then circulates through the body or is taken up only by certain tissues. Its distribution can be tracked according to the radiation it gives off.
- ❖ The emitted radiation can be captured by various imaging techniques, such as single photon emission computed tomography (SPECT) or positron emission tomography (PET), depending on the radioisotope used.
- ❖ Through such imaging, physicians are able to examine blood flow to specific organs and assess organ function or bone growth.
- ❖ Radioisotopes typically have short half-lives and typically decay before their emitted radioactivity can cause damage to the patient's body.
- ❖ Therapeutic applications of radioisotopes typically are intended to destroy the targeted cells.
- ❖ This approach forms the basis of radiotherapy, which is commonly used to treat cancer and other conditions involving abnormal tissue growth, such as hyperthyroidism.
- ❖ In radiation therapy for cancer, the patient's tumor is bombarded with ionizing radiation, typically in the form of beams of subatomic particles, such as protons, neutrons, or alpha or beta particles, which directly disrupt the atomic or molecular structure of the targeted tissue.
- ❖ Ionizing radiation introduces breaks in the double-stranded DNA molecule, causing the cancer cells to die and thereby preventing their replication.
- ❖ While radiotherapy is associated with unpleasant side effects, it generally is effective in slowing cancer progression or, in some cases, even prompting the regression of malignant disease
- ❖ The use of radioisotopes in the fields of nuclear medicine and radiotherapy has advanced significantly since the discovery of artificial radioisotopes in the first decades of the 1900s.
- ❖ Artificial radioisotopes are produced from stable elements that are bombarded with neutrons.
- ❖ Following that discovery, researchers began to investigate potential medical applications of artificial radioisotopes, work that laid the foundation for nuclear medicine.
- ❖ Today diagnostic and therapeutic procedures using radioactive isotopes are routine.

4. Illustrate the working of a cyclotron with neat diagram. (Nov 2016, Nov 2018, Nov 2019)

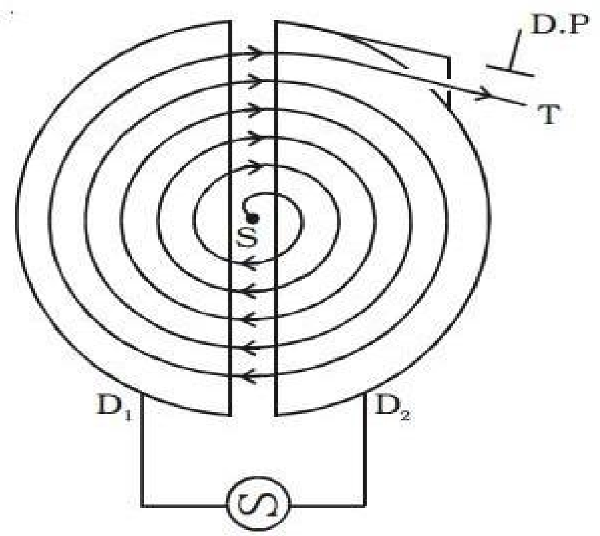
Cyclotron:

Cyclotron is a device used to accelerate charged particles to high energies. It was devised by Lawrence.

Principle:

Cyclotron works on the principle that a charged particle moving normal to a magnetic field experiences magnetic lorentz force due to which the particle moves in a circular path.

Construction



❖ It consists of a hollow metal cylinder divided into two sections D1 and D2 called Dees, enclosed in an evacuated chamber.

❖ The Dees are kept separated and a source of ions is placed at the centre in the gap between the Dees.

❖ They are placed between the pole pieces of a strong electromagnet.

❖ The magnetic field acts perpendicular to the plane of the Dees.

❖ The Dees are connected to a high frequency oscillator.

Working

❖ When a positive ion of charge q and mass m is emitted from the source, it is accelerated towards the Dee having a negative potential at that instant of time.

❖ Due to the normal magnetic field, the ion experiences magnetic lorentz force and moves in a circular path.

❖ By the time the ion arrives at the gap between the Dees, the polarity of the Dees gets reversed.

❖ Hence the particle is once again accelerated and moves into the other Dee with a greater velocity along a circle of greater radius.

- Thus the particle moves in a spiral path of increasing radius and when it comes near the edge, it is taken out with the help of a deflector plate (D.P).
- The particle with high energy is now allowed to hit the target T.
- When the particle moves along a circle of radius r with a velocity v, the magnetic Lorentz force provides the necessary centripetal force.

$$Bqv = (vm2\ ) / r$$

$$v / r = Bq / m = \text{constant} \quad ...(1)$$

The time taken to describe a semi-circle

$$t = \pi r / v \qquad (2)$$

Substituting equation (1) in (2),

$$t = \pi m / Bq \qquad ..\ (3)$$

It is clear from equation (3) that the time taken by the ion to describe a semi-circle is independent of

(i) the radius (r) of the path and (ii) the velocity (v) of the particle

Hence, period of rotation T = 2t

$$T = 2\pi m / Bq = \text{constant} \quad ...(4)$$

So, in a uniform magnetic field, the ion traverses all the circles in exactly the same time.

The frequency of rotation of the particle,

$$v = 1 / T = Bq / 2\pi m \qquad ..\ (5)$$

If the high frequency oscillator is adjusted to produce oscillations of frequency as given in equation (5), resonance occurs.

Cyclotron is used to accelerate protons, deutrons and α - particles.

$$Bq\upsilon = \frac{m\upsilon^2}{r}$$

$$\frac{\upsilon}{r} = \frac{Bq}{m} = \text{constant} \qquad ...(1)$$

$$t = \frac{\pi r}{\upsilon} \qquad ...(2)$$

$$t = \frac{\pi m}{Bq} \qquad ...(3)$$

$$T = \frac{2\pi m}{Bq} = \text{constant} \qquad ...(4)$$

$$\upsilon = \frac{1}{T} = \frac{Bq}{2\pi m} \qquad ...(5)$$

Limitations

❖ Maintaining a uniform magnetic field over a large area of the Dees is difficult.

❖ At high velocities, relativistic variation of mass of the particle upsets the resonance condition.

❖ At high frequencies, relativistic variation of mass of the electron is appreciable and hence electrons cannot be accelerated by cyclotron.

5. Explain in detail about various types of Radioactive decay and its application? (May 2015, May 2016, Nov 2017, May 2018, May 2019,Nov 2018, Dec 2017, Sep 2020)

The early work on natural radioactivity associated with uranium and thorium ores identified two distinct types of radioactivity: alpha and beta decay.

ALPHA DECAY:

❖ In alpha decay, an energetic helium ion (alpha particle) is ejected, leaving a daughter nucleus of atomic number two less than the parent and of atomic mass number four less than the parent

❖ An example is the decay (symbolized by an arrow) of the abundant isotope of uranium, 238U, to a thorium daughter plus an alpha particle:

$$^{238}_{92}\mathrm{U} \longrightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He} \qquad Q_\alpha = 4.268 \text{ MeV} \qquad t_{1/2} = 4.51 \times 10^9 \text{ years}$$

- Given for this and subsequent reactions are the energy released (Q) in millions of electron volts (MeV) and the half-life (t1⁄2).
- It should be noted that in alpha decays the charges, or number of protons, shown in subscript are in balance on both sides of the arrow, as are the atomic masses, shown in superscript.

BETA DECAY:

Beta minus decay:

- In beta-minus decay, an energetic negative electron is emitted, producing a daughter nucleus of one higher atomic number and the same mass number.
- An example is the decay of the uranium daughter product thorium-234 into protactinium-234:

$$^{234}_{90}\mathrm{Th} \longrightarrow {}^{234}_{91}\mathrm{Pa} + e^- + \bar{\nu} \qquad Q_{\beta^+} = .263 \text{ MeV} \qquad t_{1/2} = 24.1 \text{ days}$$

- In the above reaction for beta decay, ν represents the antineutrino.
- Here, the number of protons is increased by one in the reaction, but the total charge remains the same, because an electron, with negative charge, is also created.

Beta plus decay:

- During the 1930s new types of radioactivity were found among the artificial products of nuclear reactions: beta-plus decay, or positron emission, and electron capture.
- In beta-plus decay an energetic positron is created and emitted, along with a neutrino, and the nucleus transforms to a daughter, lower by one in atomic number and the same in mass number.
- For instance, carbon-11 (Z = 6) decays to boron-11 (Z = 5), plus one positron and one neutrino:

$$^{11}_{6}\mathrm{C} \longrightarrow {}^{11}_{5}\mathrm{B} + e^+ + \nu \qquad Q_{\beta^+} = 0.97 \text{ MeV} \qquad t_{1/2} = 20.4 \text{ min}$$

GAMMA DECAY:

- A third type of radiation, gamma radiation, usually accompanies alpha or beta decay. Gamma rays are photons and are without rest mass or charge.
- Alpha or beta decay may simply proceed directly to the ground (lowest energy) state of the daughter nucleus without gamma emission, but the decay may also proceed wholly or partly to higher energy states (excited states) of the daughter.
- In the latter case, gamma emission may occur as the excited states transform to lower energy states of the same nucleus. (Alternatively to gamma emission, an excited nucleus may transform to a lower energy state by ejecting an electron from the cloud surrounding the nucleus.
- This orbital electron ejection is known as internal conversion and gives rise to an energetic electron and often an X-ray as the atomic cloud fills in the empty orbital of the ejected electron.
- The ratio of internal conversion to the alternative gamma emission is called the internal-conversion coefficient.

MEDICAL APPLICATION:

The uses of radiation in diagnosis and treatment have multiplied so rapidly in recent years that one or another form of radiation is now indispensable in virtually every branch of medicine. The many forms of radiation that are used include electromagnetic waves of widely differing wavelengths (e.g., radio waves, visible light, ultraviolet radiation, X rays, and gamma rays), as well as particulate radiations of various types (e.g., electrons, fast neutrons, protons, alpha particles, and pi-mesons).

Imaging techniques

- Advances in techniques for obtaining images of the body's interior have greatly improved medical diagnosis.
- New imaging methods include various X-ray systems, positron emission tomography, and nuclear magnetic resonance imaging.

X-ray systems:

- In all such systems, a beam of X radiation is shot through the patient's body, and the rays that pass through are recorded by a detection device.

- An image is produced by the differential absorption of the X-ray photons by the various structures of the body.

- For example, the bones absorb more photons than soft tissues; they thus cast the sharpest shadows, with the other body components (organs, muscles, etc.) producing shadows of varying intensity.

- The conventional X-ray system produces an image of all structures in the path of the X-ray beam, so that a radiograph of, say, the lungs shows the ribs located in front and as well as in back.

- Such extraneous details often make it difficult for the physician examining the X-ray image to identify tumours or other abnormalities on the lungs.

- This problem has been largely eliminated by computerized tomographic (CT) scanning, which provides a cross-sectional image of the body part being scrutinized.

- Since its introduction in the 1970s, CT scanning, also called computerized axial tomography (CAT), has come to play a key role in the diagnosis and monitoring of many kinds of diseases and abnormalities.

- In CT scanning a narrow beam of X rays is rotated around the patient, who is surrounded by several hundred X-ray photon detectors that measure the strength of the penetrating photons from many different angles.

- The X-ray data are analyzed, integrated, and reconstructed by a computer to produce images of plane sections through the body onto the screen of a television-like monitor. Computerized tomography enables more precise and rapid visualization and location of anatomic structures than has been possible with ordinary X-ray techniques. In many cases, lesions can be detected without resorting to exploratory surgery.

Positron emission tomography (PET):

- This imaging technique permits physicians to determine patterns of blood flow, blood volume, oxygen perfusion, and various other physiological, metabolic, and immunologic parameters.

- It is used increasingly in diagnosis and research, especially of brain and heart functions.

- PET involves the use of chemical compounds "labeled" with short-lived positron-emitting isotopes such as carbon-11 and nitrogen-13, positron cameras consisting of photomultiplier-scintillator detectors, and computerized tomographic reconstruction techniques.

- After an appropriately labeled compound has been injected into the body, quantitative measurements of its activity are made throughout the sections of the body being scanned by the detectors.

- As the radioisotope disintegrates, positrons are annihilated by electrons, giving rise to gamma rays that are detected simultaneously by the photo multiplier-scintillator combinations positioned on opposite sides of the patient.

6. Write a note on spontaneous emission of radionuclide?(Nov 2015, Nov 2019)

- Spontaneous emission is an energy conversion process in which an excited electron or molecule decays to an available lower energy level and in the process gives off a photon.
- This process occurs naturally and does not involve interaction of other photons. The average time for decay by spontaneous emission is called the spontaneous emission lifetime.
- For some excited energy levels this spontaneous decay occurs on average within nanoseconds while in other materials it occurs within a few seconds.
- As with absorption, this process can occur in isolated atoms, ionic compounds, molecules, and other types of materials, and it can occur in solids, liquids, and gases.
- Energy is conserved when the electron decays to the lower level, and that energy must go somewhere.

❖ The energy may be converted to heat, mechanical vibrations, or electromagnetic photons.

❖ If it is converted to photons, the process is called spontaneous emission, and the energy of the photon produced is equal to the energy dierence between the electron energy levels involved.

❖ The emitted photon may have any direction, phase, and electromagnetic polarization. There are many ways in which an electron can be excited to a higher energy level.

❖ Spontaneous emission processes may be classified based on the source of energy which excites the electrons, and these classes .

❖ If the initial source of energy for spontaneous emission is supplied optically, the process is called photo luminescence.

❖ Glow in the dark materials emit light by this process. If the initial form of energy is supplied by a chemical reaction, the process is called chemiluminescence.

❖ Glow sticks produce spontaneous emission by chemiluminescence. If the initial form of energy is supplied by a voltage, the process is called electroluminescence.

❖ LEDs emit light by electro luminescence. If the initial form of energy is caused by sound waves, the process is called sonoluminescence.

❖ If the initial form of energy is due to accelerated electrons hitting a target, this process is called cathodeluminescence.

❖ If spontaneous emission occurs in a living organism, such a firefly, the process is called bioluminescence.

❖ At temperatures above absolute zero, some electrons in atoms are thermally excited to energy levels above the ground state.

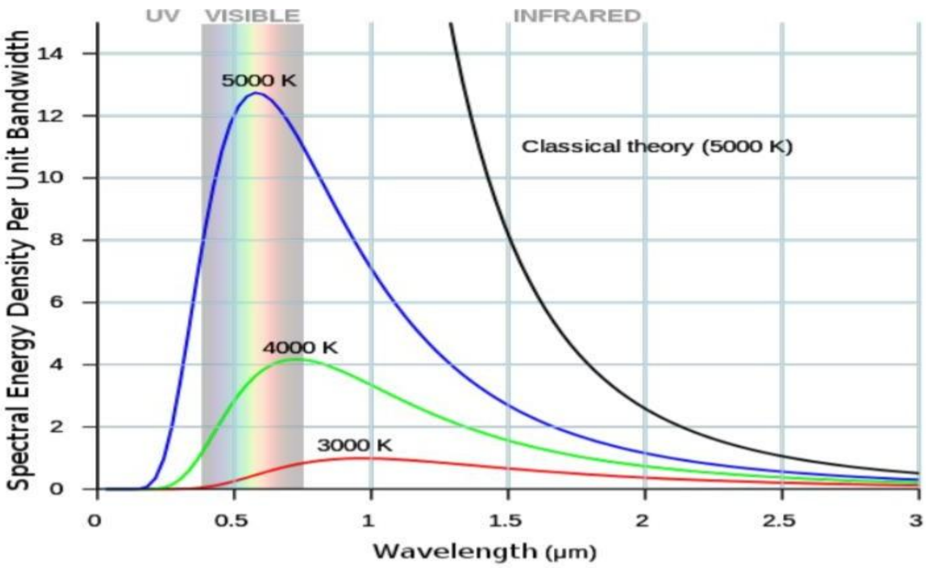
❖ These electrons decay and emit a photon by spontaneous emission. Any object at a temperature above absolute zero naturally emits photons by spontaneous emission, and this process is called blackbody radiation.

❖ Max Planck derived a formula for the energy density per unit bandwidth of a blackbody radiator by making the assumption that only discrete energies are allowed

❖ . His work agreed with known experimental data, and it is one of the fundamental ideas of quantum mechanics. More specifically, the spectral energy density per unit bandwidth, u in units.

$$u = \frac{8\pi f^2}{c^3} \cdot \frac{hf}{e^{(hf/k_B T) - 1}}.$$

- It includes a number of constants including cc the speed of light in free space, hh the Planck constant, and k_B the Boltzmann constant.
- Additionally, ff is frequency in Hz, and TT is temperature in kelvins. The first term represents the number of modes per unit frequency per unit volume while the second term represents the average energy per mode.
- The expression can be written as a function of wavelength instead of frequency with the substitution f=cλ.
- Photons emitted by a blackbody radiator have a relatively wide range of wavelengths, and this bandwidth depends on temperature, plots the energy density per unit bandwidth for blackbody radiators as a function of wavelength at temperatures 3000, 4000, and 5000 K.
- Room temperature corresponds to around 300 K. Visible photons have wavelengths between 400 nm <λ<<λ< 650 nm.
- From the figure, we can see that black body radiators at higher temperatures emit both more photons and have a larger fraction of photons emitted fall in the visible range.



BM T43 – MEDICAL PHYSICS

UNIT-4

2 MARKS

1. **What is tidal and residual volume? (May 2015)**

Tidal volume is the amount of air that moves in or out of the lungs with each respiratory cycle. It measures around 500 mL in an average healthy adult male and approximately 400 mL in a healthy female.

Residual Volume is the volume of air remaining in the lungs after maximal exhalation. Normal adult value is averaged at 1200ml(20-25 ml/kg) . It is indirectly measured from summation of FRC and ERV.

2. **Define Reynolds's number (May 2015, Nov 2018)**

The Reynolds number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities. A region where these forces change behavior is known as a boundary layer, such as the bounding surface in the interior of a pipe

$$Re=\rho VD/\mu$$

Where,

- R_e is the Reynolds number
- ρ is the density of the fluid
- V is the velocity of flow
- D is the pipe diameter
- μ is the viscosity of the fluid

3. **What is alveolar ventilation? (Nov 2015, May 2019)**

Alveolar ventilation is the exchange of gas between the alveoli and the external environment. Although alveolar ventilation is usually defined as the volume of fresh air entering the alveoli per minute, a similar volume of alveolar air leaving the body per minute.

4. Define vital capacity. (Nov 2015)

Vital capacity (VC) is the maximum amount of air a person can expel from the lungs after a maximum inhalation. It is equal to the sum of inspiratory reserve volume, tidal volume, and expiratory reserve volume. A normal adult has a vital capacity between 3 and 5 litres

5. Write a short note on physics of alveoli. (Nov 2017)

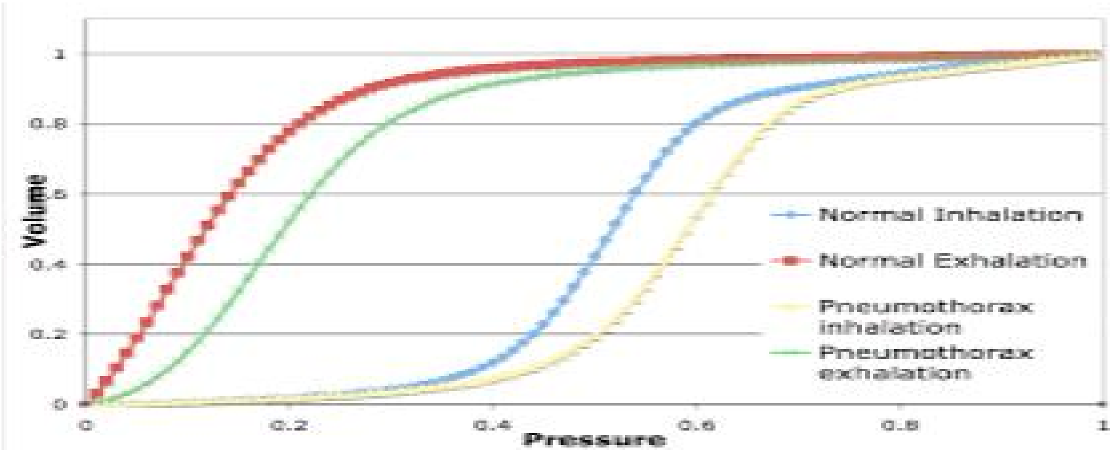
Alveoli are tiny air sacs in your lungs that take up the oxygen you breathe in and keep your body going. Although they're microscopic, alveoli are the workhorses of your respiratory system. You have about 480 million alveoli, located at the end of bronchial tubes. The alveoli are where the lungs and the blood exchange oxygen and carbon dioxide during the process of breathing in and breathing out. Oxygen breathed in from the air passes through the alveoli and into the blood and travels to the tissues throughout the body.

6. List out the difference between blood flow and turbulent. (Nov 2017, May 2019, May 2017)

BASIS OF COMPARISON	**LAMINA FLOW**	**TURBULENT FLOW**
Description	In lamina flow of a fluid, the various layers of the fluid slide parallel to each other without any disturbance, interference or intermixing. Lamina flow can also be referred to as streamline flow.	Turbulent flow is turbulent and chaotic in nature. The adjacent layers of the fluid get mixed with each other and there is a large amount of friction between the boundaries of these layers.
Fluid Layer Movement	The fluid layers move in straight line or is considered to be moving in layers or laminae.	The fluid layers do not move in straight line. They move randomly in zigzag manner.
Occurrence	Occurs in the fluid flowing with low velocity.	Occurs in the fluid flowing with high velocity.

Shear Stress	Shear stress in laminar flow depends only on the viscosity of the fluid and independent of the density.	Shear stress in the turbulent flow depends upon the density of the fluid.
Velocity Of The Flow	Occurs in the small diameter pipes in which fluid flows with low velocity.	Occurs in large diameter pipes in which fluid flows with high velocity.
Fluid Flow	The fluid flow is regular i.e there is no mixing of adjacent layers of the fluid and they move parallel to each other also with the walls of the pipe. The flow appears to be smooth without any mixing on a macroscopic scale between adjacent layers, even though mixing on molecular scale may exist.	The fluid flow is irregular i.e there is mixing of adjacent layers of the fluid with each other and they do not move parallel to each other and also with the walls of the pipe.
Reynolds Number	The fluid is laminar when the value of Reynolds number (Re) is less than 200.	The fluid flow is turbulent when the value of Reynolds number (Re) is greater than 4000.
Example	The flow of any liquid within a pipe or tube with small diameter, flow of honey or thick syrup from a bottle.	Ocean currents and waves, oil transport in pipelines, blood flow in arteries, lava flow, flow through pumps and turbines, flow in boat wakes and around aircraft-wings etc.
Common Feature	Characterized by the absence of cross currents, eddies and swirls.	Characterized by the presence of eddies, tiny whirlpools, swirls and waves.

7. Draw the three different P-V curves for different breathing rates. (Nov 2016)



8. State Bernoulli's principle. (May 2016, Nov 2016, May 2018,Sep 2020)

Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in static pressure or a decrease in the fluid's potential energy

$$p + 12\, \rho\, v^2 + \rho gh = \text{constant}$$

Where,

- p is the pressure exerted by the fluid
- v is the velocity of the fluid
- ρ is the density of the fluid
- h is the height of the container

9. What happens to the lung tissues during respiration? (May 2017, May 2016)

When you breathe in, or inhale, your diaphragm contracts and moves downward. This increases the space in your chest cavity, and your lungs expand into it. The muscles between your ribs also help enlarge the chest cavity. They contract to pull your rib cage both upward and outward when you inhale

10. Give the importance of surfactant in alveoli. (May 2018)

It is established that pulmonary surfactant reduces surface tension at the air–water interface in the alveoli, thereby preventing collapse of these structures at end-expiration. In this manner, surfactant reduces the work associated with breathing

11. Define minute volume. (Nov 2018)

Minute volume is the amount of gas inhaled or exhaled from a person's lungs in one **minute**.

Minute ventilation = VE = TV x f At rest, a normal person moves ~450 ml/breath x 10 breath/min = 4500 ml/min.

12. List the major components of cardiovascular system. (Nov 2019)

The cardiovascular system can be thought of as the transport system of the body. This system has main components: the heart, the blood vessel and the blood itself. The heart is the system's pump and the blood vessels are like the delivery routes.

13. How is Residual volume measure? (Nov 2019)

Residual volume is measured by: A gas dilution test. A person breathes from a container containing a documented amount of a gas (either 100% oxygen or a certain amount of helium in air). This test measures the total amount of air the lungs can hold (total lung volume).

14. Give the importance of surfactant in alveoli? (Sep 2020)

It is established that pulmonary surfactant reduces surface tension at the air–water interface in the alveoli, thereby preventing collapse of these structures at end-expiration. In this manner, surfactant reduces the work associated with breathing.

11 MARKS

1. Explain in detail about the breathing mechanism of a human system. (May 2015, May 2016, Nov 2016, May 2018, May 2019,Sep 2020)

Pathway of air: nasal cavities (or oral cavity) > pharynx > trachea > primary bronchi (right & left) > secondary bronchi > tertiary bronchi > bronchioles > alveoli (site of gas exchange)

Human respiratory system, the system in humans that takes up oxygen and expels carbon dioxide

The nose

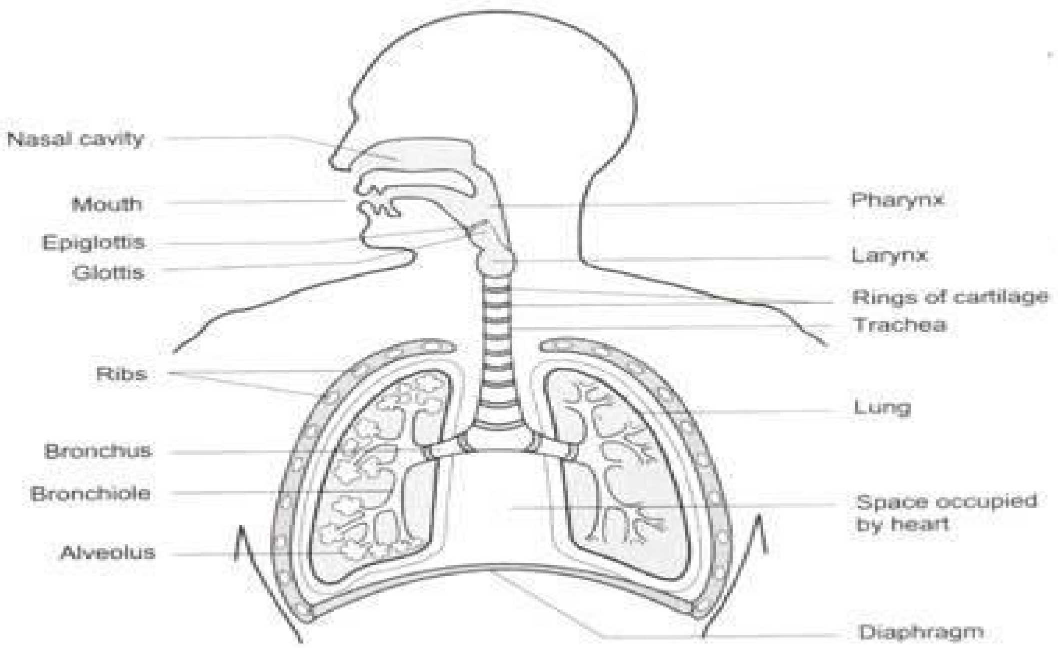
The nose detects odor molecules and helps filter and warm the air we inhale. The upper respiratory system, or upper respiratory tract, consists of the nose and nasal cavity, the pharynx, and the larynx. These structures allow us to breathe and speak.

The pharynx

The pharynx acts as a passageway for food on its way to the stomach and for air en route to the lungs. The mucosal epithelium in the pharynx is thicker than elsewhere in the respiratory tract as it has to protect the tissues from any abrasive and chemical trauma caused by food

The larynx

Larynx, also called voice box, a hollow, tubular **structure** connected to the top of the windpipe (trachea); air passes through the larynx on its way to the lungs. The larynx also produces vocal sounds and prevents the passage of food and other foreign particles into the lower respiratory tracts



Human respiratory system

The trachea

The trachea is composed of about 20 rings of tough cartilage. The back part of each ring is made of muscle and connective tissue. Moist, smooth tissue called mucosa lines the inside of the trachea. The trachea widens and lengthens slightly with each breath in, returning to its resting size with each breath out.

The bronchi

The Bronchi Are Passageways That Bring Air In and Out of the Lungs. The tubes of the primary bronchi branch off from the bottom of the trachea. These branches subdivide further into secondary and tertiary bronchi and then into the bronchioles.

The bronchioles

The respiratory bronchioles deliver air to the exchange surfaces of the lungs. They are interrupted by alveoli which are thin walled evaginations. Alveolar ducts are distal continuations of the respiratory bronchioles

The alveoli

The alveoli are where the lungs and the blood exchange oxygen and carbon dioxide during the process of breathing in and breathing out. Oxygen breathed in from the air passes through the alveoli and into the blood and travels to the tissues throughout the body**.**

Process of Inspiration

- Inspiration is the phase of ventilation in which air enters the lungs. It is initiated by contraction of the inspiratory muscles:
- Diaphragm – flattens, extending the superior/inferior dimension of the thoracic cavity.
- External intercostal muscles – elevates the ribs and sternum, extending the anterior/posterior dimension of the thoracic cavity.
- The action of the inspiratory muscles results in an increase in the volume of the thoracic cavity. As the lungs are held against the inner thoracic wall by the pleural seal, they also undergo an increase in volume.
- As per Boyle's law, an increase in lung volume results in a decrease in the pressure within the lungs. The pressure of the environment external to the lungs is

now greater than the environment within the lungs, meaning air moves into the lungs down the pressure gradient.

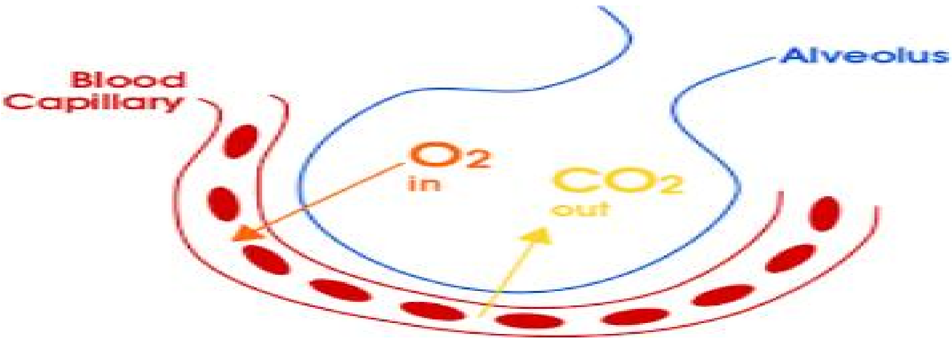
Process of Passive Expiration

Expiration is the phase of ventilation in which air is expelled from the lungs. It is initiated by relaxation of the inspiratory muscles:

- **Diaphragm** – relaxes to return to its resting position, reducing the superior/inferior dimension of the thoracic cavity.
- **External intercostal muscles** – relax to depress the ribs and sternum, reducing the anterior/posterior dimension of the thoracic cavity.
- The relaxation of the inspiratory muscles results in a decrease in the volume of the thoracic cavity. The elastic recoil of the previously expanded lung tissue allows them to return to their original size.
- As per Boyle's law, a decrease in lung volume results in an increase in the pressure within the lungs. The pressure inside the lungs is now greater than in the external environment, meaning air moves out of the lungs down the pressure gradient.

Exchange and Transport of Gases in Lungs

Gas exchange is the process that occurs between oxygen and carbon dioxide. Oxygen is passed from the lungs to the bloodstream and carbon dioxide is eliminated from the bloodstream to the lungs. Exchange of Gas takes place in lungs between the alveoli and capillaries which are tiny blood vessels, placed at the walls of alveoli. The rate of diffusion depends on the thickness of the biological membrane which forms the boundary between the external environment and organisms.



2. Derive the Bernoulli's and Poisseuille's equation blood flow in a CVS. (May 2015, Nov 2017, May 2017, May 2019)

Bernoulli's equation blood flow in a CVS

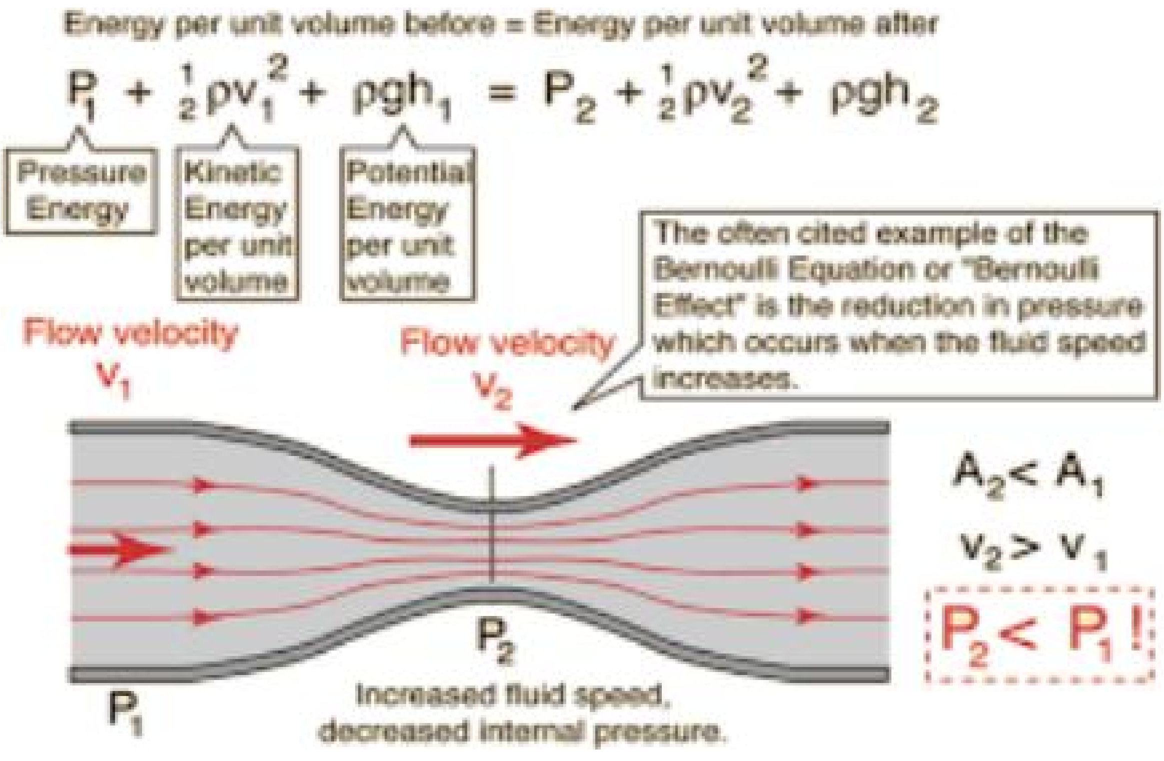
- It is because flowing blood has mass and velocity it has **kinetic energy** (KE). This KE is proportionate to the mean velocity squared (V^2; from $KE = \frac{1}{2} mV^2$).
- Furthermore, as the blood flows inside a vessel, pressure is exerted laterally against the walls of the vessel; this pressure represents the **potential or pressure energy** (PE).
- The total energy (E) of the blood flowing within the vessel, therefore, is the sum ofthe kinetic and potential energies (assuming no gravitational effects)

$$\mathbf{E = KE + PE} \quad \textit{(where } KE \propto V^2\textit{) Therefore, } \mathbf{E \propto V^2 + PE}$$

- Blood flow is driven by the difference in total energy between two points.
- Although pressure is normally considered as the driving force for blood flow, in reality it is the total energy that drives flow between two points (e.g., longitudinally along a blood vessel or across a heart valve).
- Throughout most of the cardiovascular system, KE is relatively low, so for practical purposes, it is stated that the pressure energy (PE) difference drives flow.
- When KE is high, however, adding KE to the PE significantly increases the total energy, E.
- To illustrate this, consider the flow across the aortic valve during cardiac ejection. Late during ejection, the intraventricular pressure (PE) falls slightly below the aortic pressure (PE), nevertheless, flow continues to be ejected into the aorta.
- The reason for this is that the KE of the blood as it moves across the valve at a very high velocity ensures that the total energy (E) in the blood crossing the valve is higher than the total energy of the blood more distal in the aorta.
- Kinetic energy and pressure energy can be interconverted so that total energy remains unchanged. This is the basis of Bernoulli's Principle.
- This principle can be illustrated by a blood vessel that is suddenly narrowed then returned to its normal diameter.
- In the narrowed region (stenosis), the velocity increases as the diameter decreases. Quantitatively, $V \propto 1/D^2$ because flow (F) is the product of mean velocity (V) and vessel cross-sectional area (A) ($F = V \times A$), and A is directly related to diameter (D) (or

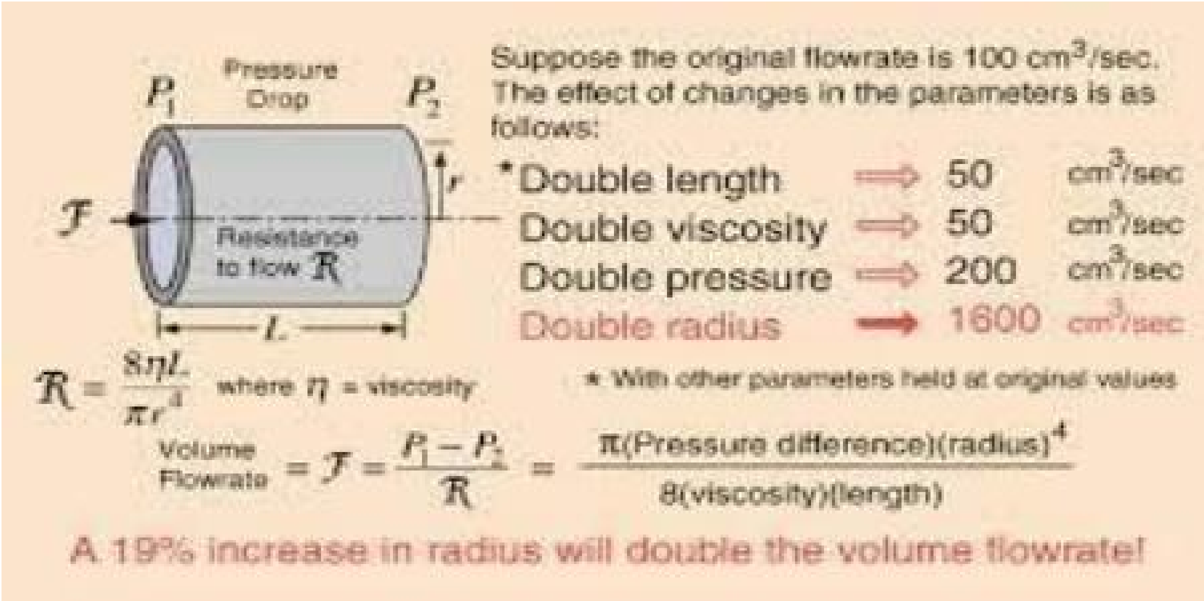
radius, r) squared (from $A = \pi r^2$). If the diameter is reduced by one-half in the region of the stenosis, the velocity increases 4-fold. Because KE $\propto V^2$, the KE increases 16-fold.

- ❖ Assuming that the total energy is conserved within the stenosis (E actually decreases because of resistance as shown in the figure), then the 16-fold increase in KE must result in a reciprocal decrease in in the magnitude of PE.
- ❖ The fall in PE represents a decrease in the lateral pressure against the vessel walls.
- ❖ Therefore, an increase in velocity leads to a decrease in lateral pressure, which is the basis for the Venturi effect.
- ❖ Once past the narrowed segment, KE will revert back to its pre-stenosis value because the post-stenosis diameter is the same as the pre-stenosis diameter and flow (and therefore, velocity) is conserved.
- ❖ Because of the resistance of the stenosis, and the turbulence the likely occurs, the post-stenosis PE and E will both fall.
- ❖ To summarize this concept, blood flowing at higher velocities has a higher ratio of kinetic energy to potential (pressure) energy.



Poisseuille's equation blood flow in a CVS.

- There are three primary factors that determine the resistance to blood flow within a single vessel: vessel diameter (or radius), vessel length, and viscosity of the blood. Of these three factors, the most important quantitatively and physiologically is vessel diameter.
- The reason for this is that vessel diameter changes because of contraction and relaxation of the vascular smooth muscle in the wall of the blood vessel.
- Furthermore, as described below, very small changes in vessel diameter lead to large changes in resistance.
- Vessel length does not change significantly and blood viscosity normally stays within a small range (except when hematocrit changes).



- Vessel resistance (R) is directly proportional to the length (L) of the vessel and the viscosity (η) of the blood, and inversely proportional to the radius to the fourth power (r^4).
- Because changes in diameter and radius are directly proportional to each other ($D = 2r$; therefore $D \propto r$), diameter can be substituted for radius in the following expression.
- Therefore, a vessel having twice the length of another vessel (and each having the same radius) will have twice the resistance to flow.
- Similarly, if the viscosity of the blood increases 2-fold, the resistance to flow will increase 2-fold. In contrast, an increase in radius will reduce resistance. Furthermore, the change in radius alters resistance to the fourth power of the change in radius.

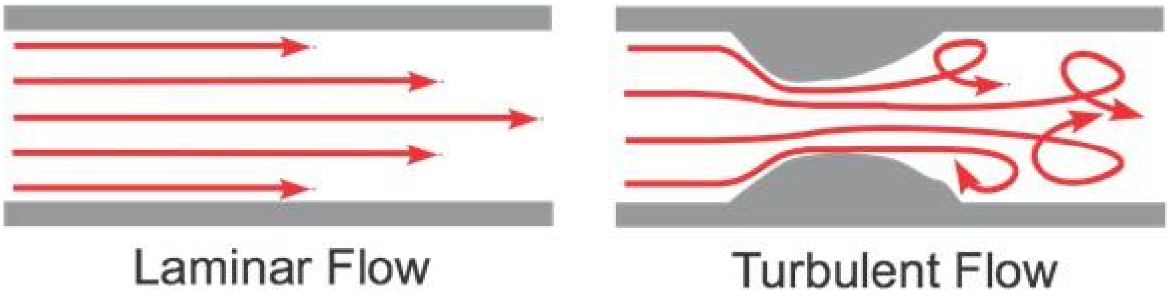
- The relationship between flow and vessel radius to the fourth power (assuming constant ΔP, L, η and laminar flow conditions) is illustrated in the figure to the right. This figure shows how very small decreases in radius dramatically reduces flow.
- Vessel length does not change appreciably in vivo and, therefore, can generally be considered constant.
- Blood viscosity normally does not change very much; however, it can be significantly altered by changes in hematocrit, temperature, and by low flow states.
- If the above expression for resistance is combined with the equation describing the relationship between flow, pressure and resistance (F=ΔP/R), then

F= r^4 ΔP / n L

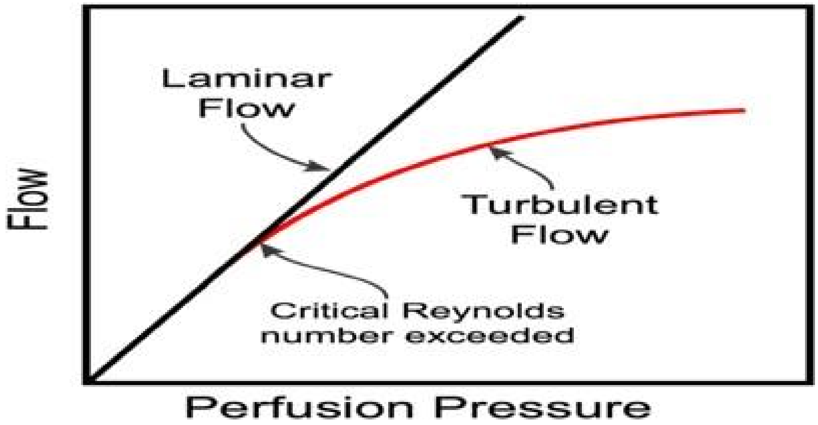
- This relationship (**Poiseuille's equation**) was first described by the 19th century French physician Poiseuille.
- It is a description of how flow is related to perfusion pressure, radius, length, and viscosity.
- The full equation contains a constant of integration and pi, which are not included in the above proportionality.
- In the body, however, flow does not conform exactly to this relationship because this relationship assumes long, straight tubes (blood vessels), a Newtonian fluid (e.g., water, not blood which is non-Newtonian), and steady, laminar flow conditions.
- Nevertheless, the relationship clearly shows the dominant influence of vessel radius on resistance and flow and therefore serves as an important concept to understand how physiological (e.g., vascular tone) and pathological (e.g., vascular stenosis) changes in vessel radius affect pressure and flow, and how changes in heart valve orifice size (e.g., in valvular stenosis) affect flow and pressure gradients across heart valves.
- Although the above discussion is directed toward blood vessels, the factors that determine resistance across a heart valve are the same as described above except that length becomes insignificant because path of blood flow across a valve is extremely short compared to a blood vessel. Therefore, when resistance to flow is described for heart valves, the primary factors considered are radius and blood viscosity.

3. Describe the laminar and turbulent blood flow and name two physiological conditions under which turbulent flow might arise in the body? (May 2016)

- Generally in the body, blood flow is laminar. However, under conditions of high flow, particularly in the ascending aorta, laminar flow can be disrupted and become turbulent.
- When this occurs, blood does not flow linearly and smoothly in adjacent layers, but instead the flow can be described as being chaotic.
- Turbulent flow also occurs in large arteries at branch points, in diseased and narrowed (stenotic or partially obstructed) arteries (see figure below), and across stenotic heart valves.



- Turbulence increases the energy required to drive blood flow because turbulence increases the loss of energy in the form of friction, which generates heat.
- When plotting a pressure-flow relationship (see figure to right), turbulence increases the perfusion pressure required to drive a given flow.
- Alternatively, at a given perfusion pressure, turbulence leads to a decrease in flow.



- Turbulence does not begin to occur until the velocity of flow becomes high enough that the flow lamina break apart.
- Therefore, as blood flow velocity increases in a blood vessel or across a heart valve, there is not a gradual increase in turbulence. Instead, turbulence occurs when a critical Reynolds number (Re) is exceeded.
- Reynolds number is a way to predict under ideal conditions when turbulence will occur. The equation for Reynolds number is:

$$Re = \frac{(\overline{V} \cdot D \cdot \rho)}{\eta}$$

Where V = mean velocity, D = vessel diameter, ρ = blood density, and η = blood viscosity

- As can be seen in this equation, Re increases as velocity increases, and decreases as viscosity increases.
- Therefore, high velocities and low blood viscosity (as occurs with anemia due to reduced hematocrit) are more likely to cause turbulence.
- An increase in diameter without a change in velocity also increases Re and the likelihood of turbulence; however, the velocity in vessels ordinarily decreases disproportionately as diameter increases.
- The reason for this is that flow (F) equals the product of mean velocity (V) times cross-sectional area (A), and area is proportionate to radius squared; therefore, the velocity at constant flow is inversely related to radius (or diameter) squared.

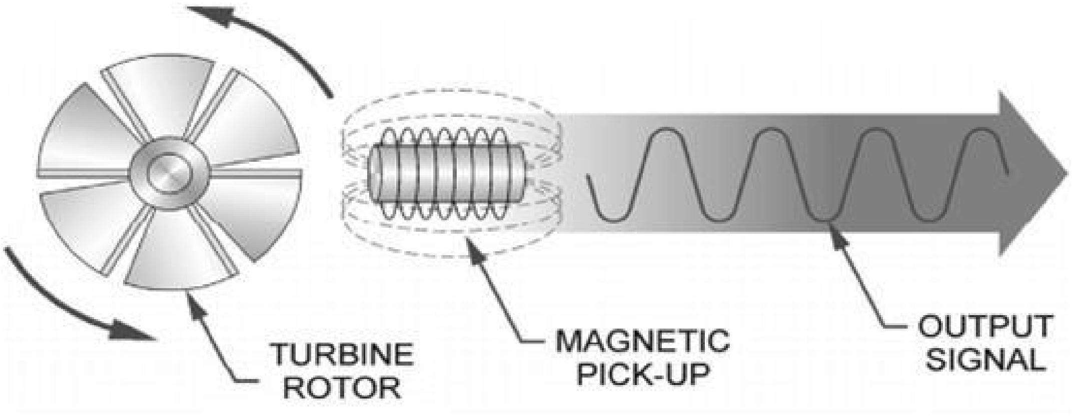
- For example, if radius (or diameter) is doubled, the velocity decreases to one-fourth its normal value, and Re decreases by one-half.
- Under ideal conditions (e.g., long, straight, smooth blood vessels), the critical Re is relatively high.
- However, in branching vessels, or in vessels with atherosclerotic plaques protruding into the lumen, the critical Re is much lower so that there can be turbulence even at normal physiological flow velocities.
- Turbulence generates sound waves (e.g., ejection murmurs, carotid bruits) that can be heard with a stethoscope.
- Because higher velocities enhance turbulence, murmurs intensify as flow increases.
- Elevated cardiac outputs, even across anatomically normal aortic valves, can cause physiological murmurs because of turbulence.
- This sometimes occurs in pregnant women who have elevated cardiac output and who may also have anemia, which decreases blood viscosity.
- Both factors increase the Reynolds number, which increases the likelihood of turbulence.

4. Explain in detail about principle and mechanism of turbine type volume transducer. (Nov 2015)

- **Turbine Flow Meter** is a volumetric measuring turbine type. The flowing fluid engages the rotor causing it to rotate at an angular velocity proportional to the fluid flow rate.
- The angular velocity of the rotor results in the generation of an electrical signal (AC sine wave type) in the pickup. The summation of the pulsing electrical signal is related directly to total flow.

- The frequency of the signal relates directly to flow rate. The vaned rotor is the only moving part of the flow meter.

Turbine Flow Meter



- The Turbine flow meter (axial turbine) was invented by Reinhard Woltman and is an accurate and reliable flow meter for liquids and gases.
- It consists of a flow tube with end connections and a magnetic multi bladed free spinning rotor (impeller) mounted inside; in line with the flow.
- The rotor is supported by a shaft that rests on internally mounted supports.
- The Supports in Process Automatics Turbine Flow Meters are designed to also act as flow straighteners, stabilizing the flow and minimizing negative effects of turbulence.
- The Supports also house the unique open bearings; allowing for the measured media to lubricate the bushes – prolonging the flow meters life span.
- The Supports are fastened by locking rings (circlips) on each end.
- The rotor sits on a shaft ,which in turn is suspended in the flow by the two supports. As the media flows, a force is applied on the rotor wings.
- The angle and shape of the wings transform the horizontal force to a perpendicular force, creating rotation. Therefore, the rotation of the rotor is proportional to the applied force of the flow.
- Because of this, the rotor will immediately rotate as soon as the media induces a forward force.
- As the rotor cannot turn thru the media on its own, it will stop as soon as the media stops.
- This ensures an extremely fast response time, making the Turbine Flow Meter ideal for batching applications
- A pick-up sensor is mounted above the rotor.

- ❖ When the magnetic blades pass by the pickup sensor, a signal is generated for each passing blade.
- ❖ This provides a pulsed signal proportional to the speed of the rotor and represents pulses per volumetric unit.; and as such the flow rate too.

Applications

In order of magnitude from largest to smallest,

- these are used in oil and gas,
- water and waste water,
- gas utility,
- chemical,
- power, food and beverage,
- aerospace, pharmaceutical,
- metals and mining, and pulp and paper.

Cautions for Turbine Flow meters

- ❖ **Turbine meters** are less accurate at low flow rates due to rotor/bearing drag that slows the rotor.
- ❖ Make sure to operate these flow meters above approximately 5 percent of maximum flow.
- ❖ Turbine flow meters should not be operated at high velocity because premature bearing wear and/or damage can occur.
- ❖ Be careful when measuring fluids that are non-lubricating because bearing wear can cause the flow meter become inaccurate and fail. In some applications, bearing replacement may need to be performed routinely and increase maintenance costs.

- ❖ Application in dirty fluids should generally be avoided so as to reduce the possibility of flow meter wear and bearing damage. In summary, turbine flow meters have moving parts that are subject to degradation with time and use.

- ❖ Abrupt transitions from gas flow to liquid flow should be avoided because they can mechanically stress the flow meter, degrade accuracy, and/or damage the flow meter.
- ❖ These conditions generally occur when filling the pipe and under slug flow conditions.
- ❖ Two-phase flow conditions can also cause turbine flow meters to measure inaccurately.

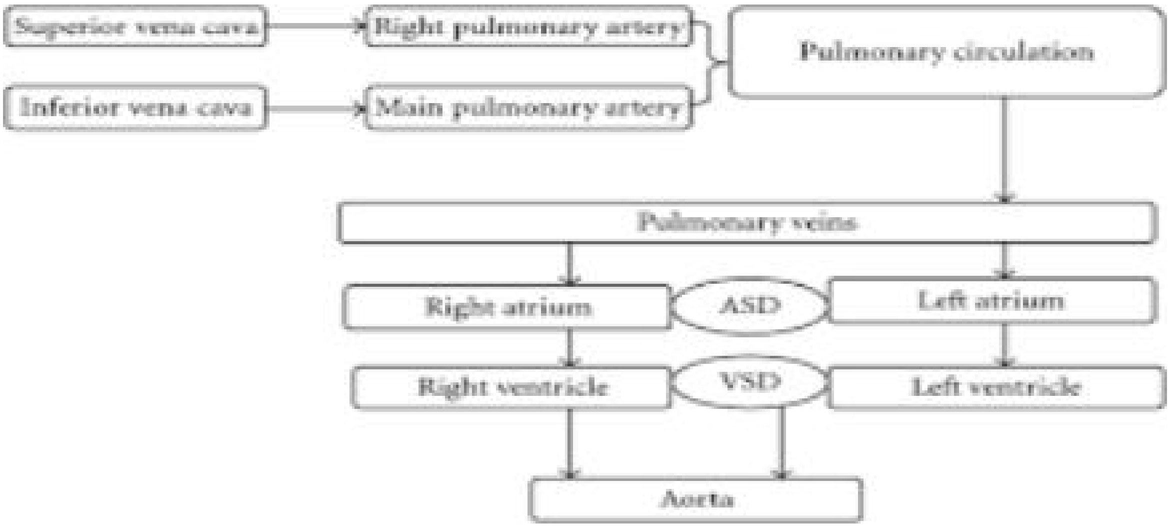
Turbine Meter Advantages

- Wide flow range ability including low flow rates
- Turndown ratio is up to 35:1
- Good level of accuracy at an economic price
- Simple, durable construction
- Easy to install and maintain
- Flexible connection to flow instruments for flow control
- Wide variety of process connections
- Turbine meters can operate over a wide range of temperatures and pressures
- Low pressure drop across the turbine
- Provides a convenient signal output

Turbine Meter Limitations

- Requires constant backpressure to prevent cavitations.
- Accuracy adversely affected by bubbles in liquids
- Turbine meters can be used with clean liquids and gases only (may need to install a strainer upstream to prevent damage from particulates)
- Not applicable for measuring corrosive fluids
- Requires a turbulent flow profile (consistent fluid velocity across the pipe diameter) for accuracy
- Sensitive to changes in fluid viscosity
- Require a straight run of pipe before and after the turbine meter to allow swirl patterns in the flow stream to dissipate
- May not function properly with high viscosity fluids where the flow profile is laminar.

5. **Write a detailed note on O2 and CO2 exchange in capillary system.. (Nov 2015, May 2018,Nov 2019,Sep 2020)**



- The primary function of the respiratory system is to take in oxygen and eliminate carbon dioxide. Inhaled oxygen enters the lungs and reaches the alveoli.
- The layers of cells lining the alveoli and the surrounding capillaries are each only one cell thick and are in very close contact with each other.
- This barrier between air and blood averages about 1 micron ($^1/_{10,000}$ of a centimeter, or 0.000039 inch) in thickness.
- Oxygen passes quickly through this air-blood barrier into the blood in the capillaries. Similarly, carbon dioxide passes from the blood into the alveoli and is then exhaled.
- Oxygenated blood travels from the lungs through the pulmonary veins and into the left side of the heart, which pumps the blood to the rest of the body (see Function of the Heart).
- Oxygen-deficient, carbon dioxide-rich blood returns to the right side of the heart through two large veins, the superior vena cava and the inferior vena cava.
- Then the blood is pumped through the pulmonary artery to the lungs, where it picks up oxygen and releases carbon dioxide.
- To support the absorption of oxygen and release of carbon dioxide, about 5 to 8 liters (about 1.3 to 2.1 gallons) of air per minute are brought in and out of the lungs, and about three tenths of a liter (about three tenths of a quart) of oxygen is transferred from the alveoli to the blood each minute, even when the person is at rest. At the same time, a similar volume of carbon dioxide moves from the blood to the alveoli and is exhaled.

- During exercise, it is possible to breathe in and out more than 100 liters (about 26 gallons) of air per minute and extract 3 liters (a little less than 1 gallon) of oxygen from this air per minute.
- The rate at which oxygen is used by the body is one measure of the rate of energy expended by the body. Breathing in and out is accomplished by respiratory muscles.

Three processes are essential for the transfer of oxygen from the outside air to the blood flowing through the lungs: ventilation, diffusion, and perfusion.

- Ventilation is the process by which air moves in and out of the lungs.
- Diffusion is the spontaneous movement of gases, without the use of any energy or effort by the body, between the alveoli and the capillaries in the lungs.
- Perfusion is the process by which the cardiovascular system pumps blood throughout the lungs.

- The body's circulation is an essential link between the atmosphere, which contains oxygen, and the cells of the body, which consume oxygen.
- For example, the delivery of oxygen to the muscle cells throughout the body depends not only on the lungs but also on the ability of the blood to carry oxygen and on the ability of the circulation to transport blood to muscle.
- In addition, a small fraction of the blood pumped from the heart enters the bronchial arteries and nourishes the airways.

6. Write a note on measurement of lung volume with suitable illustration. (Nov 2017, Nov 2018, Nov 2019, May 2017)

- Lung volumes are also known as respiratory volumes.
- It refers to the volume of gas in the lungs at a given time during the respiratory cycle.
- Lung capacities are derived from a summation of different lung volumes.
- The average total lung capacity of an adult human male is about 6 litres of air.
- Lung volumes measurement is an integral part of pulmonary function test.

- These volumes tend to vary, depending on the depth of respiration, ethnicity, gender, age, body composition and in certain respiratory diseases.
- A number of the lung volumes can be measured by Spirometry- Tidal volume, Inspiratory reserve volume, and Expiratory reserve volume.
- However, measurement of Residual volume, Functional residual capacity, and Total lung capacity is through body plethysmography, nitrogen washout and helium dilution technique.

Lung Volumes

Tidal Volume (TV)

- It is the amount of air that can be inhaled or exhaled during one respiratory cycle.
- This depicts the functions of the respiratory centres, respiratory muscles and the mechanics of the lung and chest wall.
- The normal adult value is 10% of vital capacity (VC), approximately 300 -500ml (6·8 ml/kg); but can increase up to 50% of VC on exercise

Inspiratory Reserve Volume (IRV)

- It is the amount of air that can be forcibly inhaled after a normal tidal volume.
- IRV is usually kept in reserve, but is used during deep breathing.
- The normal adult value is 1900-3300ml.

Expiratory Reserve Volume (ERV)

- It is the volume of air that can be exhaled forcibly after exhalation of normal tidal volume.
- The normal adult value is 700-1200ml. ERV is reduced with obesity, ascites or after upper abdominal surgery

Residual Volume (RV)

- It is the volume of air remaining in the lungs after maximal exhalation.
- Normal adult value is averaged at 1200ml(20·25 ml/kg) .

- It is indirectly measured from summation of FRC and ERV and cannot be measured by spirometry.
- In obstructive lung diseases with features of incomplete emptying of the lungs and air trapping, RV may be significantly high.
- The RV can also be expressed as a percentage of total lung capacity and values in excess of 140% significantly increase the risks of barotrauma, pneumothorax, infection and reduced venous return due to high intra thoracic pressures as noticed in patients with high RV who require surgery and mechanical ventilation thus needs high peri-operative inflation pressures.

Lung capacities

Inspiratory capacity(IC)

- It is the maximum volume of air that can be inhaled following a resting state.
- It is calculated from the sum of inspiratory reserve volume and tidal volume.
- IC = IRV+TV

Total Lung Capacity(TLC)

- It is the maximum volume of air the lungs can accommodate or sum of all volume compartments or volume of air in lungs after maximum inspiration.
- The normal value is about 6,000mL(4·6 L).
- TLC is calculated by summation of the four primary lung volumes (TV, IRV, ERV, RV).
- TLC may be increased in patients with obstructive defects such as emphysema and decreased in patients with restrictive abnormalities including chest wall abnormalities and kyphoscoliosis.

Vital Capacity(VC)

- It is the total amount of air exhaled after maximal inhalation.
- The value is about 4800mL and it varies according to age and body size.

- It is calculated by summing tidal volume, inspiratory reserve volume, and expiratory reserve volume. VC = TV+IRV+ERV.
- VC indicates ability to breathe deeply and cough, reflecting inspiratory and expiratory muscle strength.
- VC should be 3 times greater than TV for effective cough.
- VC is sometimes reduced in obstructive disorders and always in restrictive disorders

Function Residual Capacity(FRC)

- It is the amount of air remaining in the lungs at the end of a normal exhalation.
- It is calculated by adding together residual and expiratory reserve volumes.
- The normal value is about 1800 – 2200 mL. FRC = RV+ERV.
- FRC does not rely on effort and highlights the resting position when inner and outer elastic recoils are balanced. FRC is reduced in restrictive disorders.
- The ratio of FRC to TLC is an index of hyperinflation.
- In COPD, FRC is upto 80% of TLC

Measurement of Lung Volumes

Measurements of lung volume are important for a correct physiological diagnosis, however, its role in the assessment of disease severity, functional disability, the course of disease and response to treatment remains controversial. Measurement can be done using Spirometry Body plethysmography, Nitrogen washout and Helium dilution with the latter three techniques used in measuring static lung volumes

Spirometer

- A **spirometer** is an apparatus for measuring the volume of air inspired and expired by the lungs.

- A spirometer measures ventilation, the movement of air into and out of the lungs.

- The spirogram will identify two different types of abnormal ventilation patterns, obstructive and restrictive.

- There are various types of spirometers that use a number of different methods for measurement (pressure transducers, ultrasonic, water gauge).

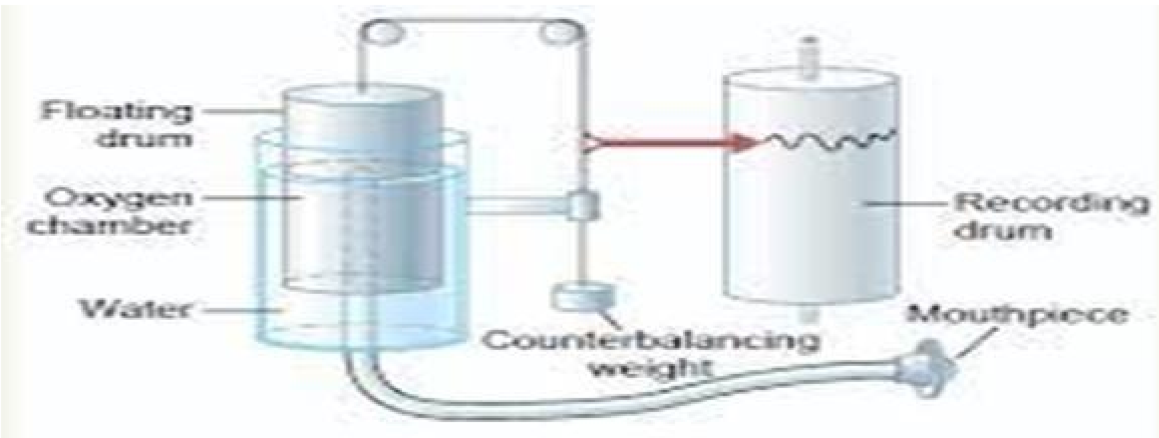
- Spirometry measures key aspects of pulmonary (lung) function.

- The test can play an important role in diagnosing and managing many lung problems.

- It can help distinguish between diseases with similar symptoms and determine whether the condition is obstructive (in which exhalation is impaired) and/or restrictive (in which inhalation is impaired).

- Spirometry is rarely used alone to diagnose a lung condition.

- It is typically combined with other findings, such as a physical exam, medical history review, and imaging tests, to reach a diagnosis.



As part of a panel of PFTs, spirometry may be used to help diagnose:

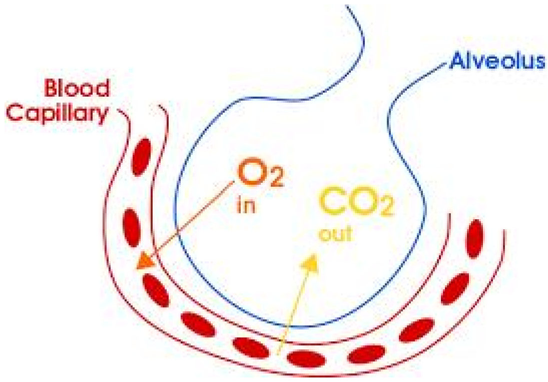
- Chronic obstructive pulmonary disease (COPD)
- Emphysema (a type of COPD)
- Bronchiectasis (a type of COPD)
- Chronic bronchitis (a type of COPD)

- Asthma
- Pulmonary fibrosis, including idiopathic pulmonary fibrosis
- Cystic fibrosis

❖ Spirometry is also useful for evaluating disease progression (namely, whether it is getting better, worse, or staying the same).

❖ This can help determine if a treatment is working or needs to be modified.

❖ Spirometry may also be used before lung cancer surgery to predict how well a patient will tolerate the operation and manage once a portion or lobe of a lung is removed.



6. Explain the major components of cardiovascular systems. (Nov 2016, Nov 2018)

Arteries – largest **vessels** – carry **blood** from the heart.

Arterioles- smaller version of. arteries, carry **blood** to the capillaries.

Capillaries – smallest **vessels**, one. cell thick, transfer materials to and.

Venules – small version of veins, carry **blood** from capillaries to veins.

Veins – carry **blood** back to heart,

Components of the Cardiovascular System

❖ It consists of the heart plus all the blood vessels

❖ Transports blood to all parts of the body in two 'circulations': pulmonary (lungs) & systemic (the rest of the body)

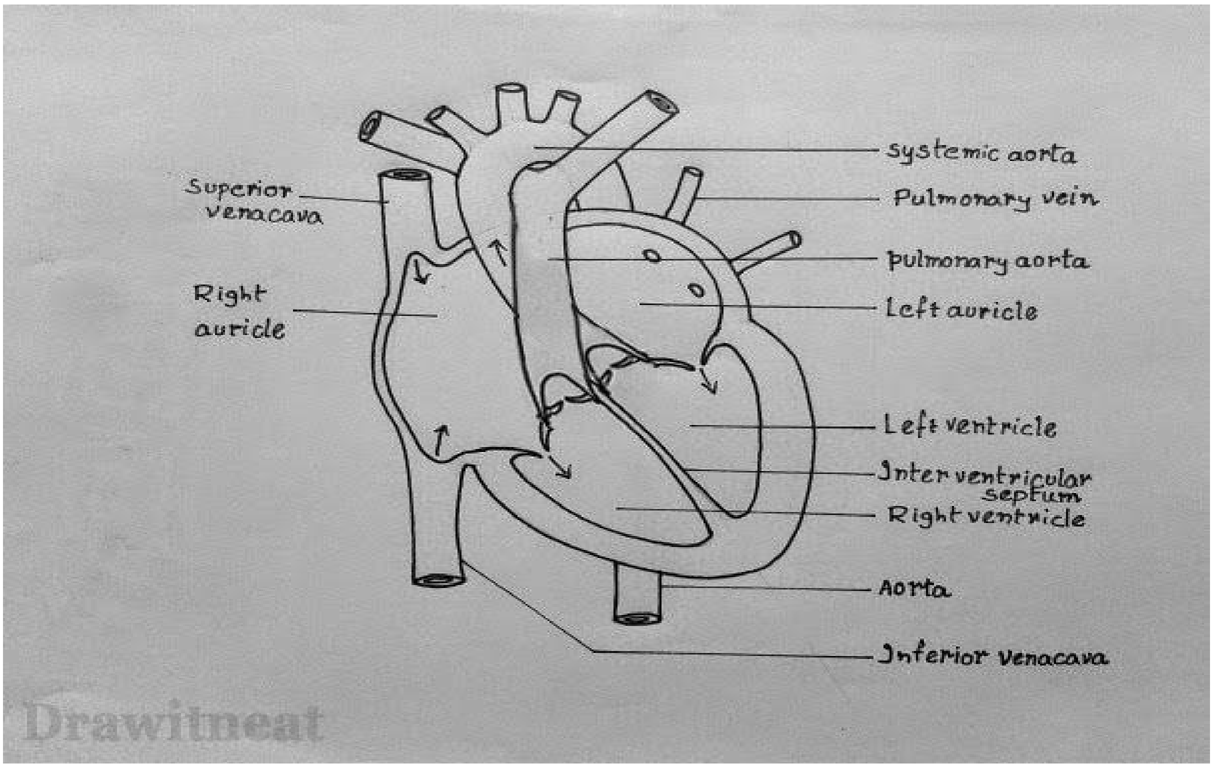
❖ Responsible for the flow of blood, nutrients, oxygen and other gases, and hormones to and from cells · about 2,000 gallons (7,572 liters) of blood travel daily through about 60,000 miles (96,560 kilometers) of blood vessels

❖ Average adult has 5 to 6 quarts (4.7 to 5.6 liters) of blood, which is made up of plasma, red blood cells, white blood cells and platelets

- In addition to blood, it moves lymph, which is a clear fluid that helps rid the body of unwanted material
- Right Atrium: It collects deoxygenated blood returning from the body (through the vena cava) and then forces it into the right ventricle through the tricuspid valve.
- Left Atrium: It collects oxygenated blood returning from the lungs and then forces it into the left ventricle through the mitral valve.
- The atrioventricular (AV) valves (Mitral & Tricuspid Valves) prevent flow from the ventricles back into the atria.
- Right Ventricle: It collects deoxygenated blood from the right atrium and then forces it into the lungs through the pulmonary valve.
- Left Ventricle: It is the largest and the strongest chamber in the heart. It pushes blood through the aortic valve and into the body.
- The pulmonary and aortic valves prevent back flow from the pulmonary trunk into the right ventricle and from the aorta into the left ventricle.
- Cardiac muscle cells are joined by gap junctions that permit action potentials to be conducted from cell to cell.
- The myocardium also contains specialized muscle cells that constitute the conducting system of the heart, initiating the cardiac action potentials and speeding their spread through the heart.
- Aorta: It is the largest artery and carries oxygenated blood from the heart to the rest of the body.
- Superior Vena Cava: Deoxygenated blood from the upper parts of the body returns to the heart through the superior vena cava.
- Inferior Vena Cava: Deoxygenated blood from the lower parts of the body returns to the heart through the inferior vena cava.
- Pulmonary Veins: They carry oxygenated blood from the lungs back to the heart.
- Pulmonary Arteries: They carry blood from the heart to the lungs to pick up oxygen.
- Mechanical Events of the Cardiac Cycle
- The cardiac cycle is divided into systole (ventricular contraction) and diastole (ventricular relaxation).
- At the onset of systole, ventricular pressure rapidly exceeds atrial pressure, and the AV valves close. The aortic and pulmonary valves are not yet open, however, and so no ejection occurs during this isovolumetric ventricular contraction.

- ❖ When ventricular pressures exceed aortic and pulmonary trunk pressures, the aortic and pulmonary valves open, and ventricular ejection of blood occurs.
- ❖ When the ventricles relax at the beginning of diastole, the ventricular pressures fall significantly below those in the aorta and pulmonary trunk, and the aortic and pulmonary valves close. Because AV valves are also still closed, no change in ventricular volume occurs during this isovolumetric ventricular relaxation.
- ❖ When ventricular pressures fall below the pressures in the right and the left atria, the AV valves open, and the ventricular filling phase of diastole begins.
- ❖ Filling occurs very rapidly at first so that atrial contraction, which occurs at the very end of diastole, usually adds only a small amount of additional blood to the ventricles.
- ❖ The amount of blood in the ventricles just before systole is the end diastolic volume.
- ❖ The volume remaining after ejection is the end-systolic volume, and the volume ejected is the stroke volume.
- ❖ Pressure changes in the systemic and pulmonary circulations have similar patterns but the pulmonary pressures are much lower.
- ❖ The first heart sound is due to the closing of the AV valves, and the second to the closing of the aortic and pulmonary valves.

Diagram of a Human Heart



The Cardiac Output

The cardiac output is the volume of blood pumped by each ventricle and equals the product of heart rate and stroke volume.

1. Heart rate is increased by stimulation of the sympathetic nerves to the heart and by epinephrine; it is decreased by stimulation of the parasympathetic nerves to the heart.

2. Stroke volume is increased by an increase in end-diastolic volume (the Frank-Starling mechanism) and by an increase in contractility due to sympathetic-nerve stimulation or to epinephrine. Inherent rates for each of the three pacemaker sites Sinus Node 60 to 100 beats per minute AV Junction 40 to 60 beats per minute Ventricles 20 to 40 beats per minute

Flow of Blood through the Body:

vena cava → right atrium → tricuspid valve → right ventricle → pulmonary valve → pulmonary artery → pulmonary capillary bed → pulmonary veins → left atrium → bicuspid (mitrial valve) → left ventricle → aortic valve → aorta → arteries → arterioles → tissue capillaries → venules → veins → vena cava

PRESSURE, FLOW, & RESISTANCE

- The cardiovascular system consists of two circuits: the pulmonary circulation, from the right ventricle to the lungs and then to the left atrium; and the systemic circulation, from the left ventricle to all peripheral organs and tissues and then to the right atrium.
- Arteries carry blood away from the heart, and veins carry blood toward the heart · In the systemic circuit, the large artery leaving the left heart is the aorta, and the large veins emptying into the right heart are the superior vena cava and inferior vena cava.
- The analogous vessels in the pulmonary circulation are the pulmonary trunk and the four pulmonary veins.
- The microcirculation consists of the vessels between arteries and veins: the arterioles, capillaries, and venules.
- Flow between two points in the cardiovascular system is directly proportional to the pressure difference between the points and inversely proportional to the resistance:

$$F = P/R$$

- Resistance is directly proportional to the viscosity of a fluid and to the length of the tube.
- It is inversely proportional to the fourth power of the tube's radius, which is the major variable controlling changes in resistance.

BM T42 – MEDICAL PHYSICS

UNIT 5

2 MARKS

1. What is ALARA? (May 2015)

ALARA stands for "as low as reasonably achievable". This principle means that even if it is a small dose, if receiving that dose has no direct benefit, you should try to avoid it. To do this, you can use three basic protective measures in radiation safety: time, distance, and shielding.

2. What are somatic and genetic effects? (May 2015,May 2017)

SOMATIC EFFECTS

- Somatic mutation, genetic alteration acquired by a cell that can be passed to the progeny of the mutated cell in the course of cell division.
- Somatic mutations differ from germ line mutations, which are inherited genetic alterations that occur in the germ cells (i.e., sperm and eggs).
- Somatic mutations are frequently caused by environmental factors, such as exposure to ultraviolet radiation or to certain chemicals.

GENETIC EFFECTS

- Single-gene disorders, where a mutation affects one gene. Sickle cell anemia is an example.
- Chromosomal disorders, where chromosomes (or parts of chromosomes) are missing or changed.
- Complex disorders, where there are mutations in two or more genes.

3. How should an LD50 value be used? (May 2016)

LD50 values have been used to compare relative acute hazards of industrial chemicals, especially when no other toxicology data are available for the chemicals. However, many important observations of toxicity are not represented by LD50 values or by slopes of dose-response curves for lethality.

4. What are the long term effect of radiation? (May 2016)

Radiation exposure increases the risk of cancer throughout life, so continued follow-up of survivors is essential. Overall, survivors have a clear radiation-related excess risk of cancer, and people exposed as children have a higher risk of radiation-induced cancer than those exposed at older ages.

5. What is LD50? Explain (Nov 2015, Nov 2017,Nov 2016,May 2017,Nov 2018,May 2018,May 2019,Nov 2019,Sep 2020)

The median lethal dose (or LD50) is defined as the dose of a test substance that is lethal for 50% of the animals in a dose group. LD50 values have been used to compare relative acute hazards of industrial chemicals, especially when no other toxicology data are available for the chemicals.

6. What is the required condition or acute Radiation Syndrome (ARS)? (Nov 2016,Nov 2017)

The required conditions for Acute Radiation Syndrome (ARS) are: The radiation dose must be large (i.e., greater than 0.7 Gray (Gy)1, 2 or 70 rads). Mild symptoms may be observed with doses as low as 0.3 Gy or 30 rads.

7. List out the adverse effects of radiation? (Nov 2015,May 2018,May 2019,Sep 2020)

Exposure to very high levels of radiation, such as being close to an atomic blast, can cause acute health effects such as skin burns and acute radiation syndrome (“radiation sickness"). It can also result in long-term health effects such as cancer and cardiovascular disease.

8. What are stochastic effect? (Nov 2018)

Effects that occur by chance, generally occurring without a threshold level of dose, whose probability is proportional to the dose and whose severity is independent of the dose. In the context of radiation protection, the main stochastic effects are cancer and genetic effects.

9. State bernoulli"s law and give its experssion? (Nov 2019)

The total mechanical energy of the moving fluid comprising the gravitational potential energy of elevation, the energy associated with the fluid pressure and the kinetic energy of the fluid motion, remains constant.

Bernoulli's equation formula is a relation between pressure, kinetic energy, and gravitational potential energy of a fluid in a container.

The formula for Bernoulli's principle is given as:

$p + 12\ \rho\ v2 + \rho gh$ =constant

11 MARKS

1. How does radiation affect the human system as example explain? (May 2015,May 2019)

Radiation Affect Humans

- ❖ Radiation may come from either an external source, such as an x-ray machine, or an internal source, such as an injected radioisotope.
- ❖ The impact of radiation on living tissue is complicated by the type of radiation and the variety of tissues.
- ❖ In addition, the effects of radiation are not always easy to separate from other factors, making it a challenge at times for scientists to isolate them.
- ❖ An overview may help explain not only the effects of radiation but also the motivation for studying them, which led to much of the research examined by the Advisory Committee.

Effect can ionizing radiation have on chemical bonds

- ❖ The functions of living tissue are carried out by molecules, that is, combinations of different types of atoms united by chemical bonds.
- ❖ Some of these molecules can be quite large. The proper functioning of these molecules depends upon their composition and also their structure (shape).
- ❖ Altering chemical bonds may change composition or structure. Ionizing radiation is powerful enough to do this. For example, a typical ionization releases six to seven times the energy needed to break the chemical bond between two carbon atoms.

- This ability to disrupt chemical bonds means that ionizing radiation focuses its impact in a very small but crucial area, a bit like a karate master focusing energy to break a brick.
- The same amount of raw energy, distributed more broadly in non ionizing form, would have much less effect. For example, the amount of energy in a lethal dose of ionizing radiation is roughly equal to the amount of thermal energy in a single sip of hot coffee.
- The crucial difference is that the coffee's energy is broadly distributed in the form of non ionizing heat, while the radiation's energy is concentrated in a form that can ionize.

DNA

- Of all the molecules in the body, the most crucial is DNA (deoxyribose nucleic acid), the fundamental blueprint for all of the body's structures. The DNA blueprint is encoded in each cell as a long sequence of small molecules, linked together into a chain, much like the letters in a telegram.
- DNA molecules are enormously long chains of atoms wound around proteins and packed into structures called chromosomes within the cell nucleus.
- When unwound, the DNA in a single human cell would be more than 2 meters long. It normally exists as twenty-three pairs of chromosomes packed within the cell nucleus, which itself has a diameter of only 10 micrometers (0.00001 meter).
- Only a small part of this DNA needs to be read at any one time to build a specific molecule. Each cell is continually reading various parts of its own DNA as it constructs fresh molecules to perform a variety of tasks.
- It is worth remembering that the structure of DNA was not solved until 1953, nine years after the beginning of the period studied by the Advisory Committee. We now have a much clearer picture of what happens within a cell than did the scientists of 1944.

Effect can ionizing radiation have on DNA

- Ionizing radiation, by definition, "ionizes," that is, it pushes an electron out of its orbit around an atomic nucleus, causing the formation of electrical charges on atoms or molecules.
- If this electron comes from the DNA itself or from a neighboring molecule and directly strikes and disrupts the DNA molecule, the effect is called direct action. This initial ionization takes place very quickly, in about 0.000000000000001 of a second. However,

today it is estimated that about two-thirds of the damage caused by x rays is due to indirect action.

- This occurs when the liberated electron does not directly strike the DNA, but instead strikes an ordinary water molecule. This ionizes the water molecule, eventually producing what is known as a free radical.
- A free radical reacts very strongly with other molecules as it seeks to restore a stable configuration of electrons. A free radical may drift about up to 10,000,000,000 times longer than the time needed for the initial ionization (this is still a very short time, about 0.00001 of a second), increasing the chance of it disrupting the crucial DNA molecule. This also increases the possibility that other substances could be introduced that would neutralize free radicals before they do damage.
- Neutrons act quite differently. A fast neutron will bypass orbiting electrons and occasionally crash directly into an atomic nucleus, knocking out large particles such as alpha particles, protons, or larger fragments of the nucleus.
- The most common collisions are with carbon or oxygen nuclei. The particles created will themselves then set about ionizing nearby electrons.
- A slow neutron will not have the energy to knock out large particles when it strikes a nucleus. Instead, the neutron and the nucleus will bounce off each other, like billiard balls. In so doing, the neutron will slow down, and the nucleus will gain speed. The most common collision is with a hydrogen nucleus, a proton that can excite or ionize electrons in nearby atoms.

<u>Effects can ionizing radiation have on living cells</u>

- All of these collisions and ionizations take place very quickly, in less than a second. It takes much longer for the biological effects to become apparent. If the damage is sufficient to kill the cell, the effect may become noticeable in hours or days. Cell "death" can be of two types.
- First, the cell may no longer perform its function due to internal ionization; this requires a dose to the cell of about 100 gray (10,000 rad). (For a definition of gray and rad, see the section below titled "How Do We Measure the Biological Effects of Radiation?") Second, "reproductive death" (mitotic inhibition) may occur when a cell can no longer reproduce, but still performs its other functions.

- This requires a dose of 2 gray (200 rad), which will cause reproductive death in half the cells irradiated (hence such a quantity is called a "mean lethal dose.").
- Today we still lack enough information to choose among the various models proposed to explain cell death in terms of what happens at the level of atoms and molecules inside a cell.
- If enough crucial cells within the body totally cease to function, the effect is fatal. Death may also result if cell reproduction ceases in parts of the body where cells are continuously being replaced at a high rate (such as the blood cell-forming tissues and the lining of the intestinal tract).
- A very high dose of 100 gray (10,000 rad) to the entire body causes death within twenty-four to forty-eight hours; a whole-body dose of 2.5 to 5 gray (250 to 500 rad) may produce death within several weeks.
- At lower or more localized doses, the effect will not be death, but specific symptoms due to the loss of a large number of cells. These effects were once called nonstochastic; they are now called deterministic. A beta burn is an example of a deterministic effect.

Long-term effects of radiation

- The effect of the radiation may not be to kill the cell, but to alter its DNA code in a way that leaves the cell alive but with an error in the DNA blueprint.
- The effect of this mutation will depend on the nature of the error and when it is read. Since this is a random process, such effects are now called stochastic.
- Two important stochastic effects of radiation are cancer, which results from mutations in nongerm cells (termed somatic cells), and heritable changes, which result from mutations in germ cells (eggs and sperm).

Ionizing radiation cause cancer

- Cancer is produced if radiation does not kill the cell but creates an error in the DNA blueprint that contributes to eventual loss of control of cell division, and the cell begins dividing uncontrollably.
- This effect might not appear for many years. Cancers induced by radiation do not differ from cancers due to other causes, so there is no simple way to measure the rate of cancer due to radiation.

- During the period studied by the Advisory Committee, great effort was devoted to studies of irradiated animals and exposed groups of people to develop better estimates of the risk of cancer due to radiation. This type of research is complicated by the variety of cancers, which vary in radiosensitivity. For example, bone marrow is more sensitive than skin cells to radiation-induced cancer.
- Large doses of radiation to large numbers of people are needed in order to cause measurable increases in the number of cancers and thus determine the differences in the sensitivity of different organs to radiation.
- Because the cancers can occur anytime in the exposed person's lifetime, these studies can take seventy years or more to complete. For example, the largest and scientifically most valuable epidemiologic study of radiation effects has been the ongoing study of the Japanese atomic bomb survivors.
- Other important studies include studies of large groups exposed to radiation as a consequence of their occupation (such as uranium miners) or as a consequence of medical treatment. These types of studies are discussed in greater detail in the section titled "How Do Scientists Determine the Long-Term Risks from Radiation?"

Ionizing radiation produce genetic mutations

- Radiation may alter the DNA within any cell. Cell damage and death that result from mutations in somatic cells occur only in the organism in which the mutation occurred and are therefore termed somatic or nonheritable effects.
- Cancer is the most notable long-term somatic effect. In contrast, mutations that occur in germ cells (sperm and ova) can be transmitted to future generations and are therefore called genetic or heritable effects.
- Genetic effects may not appear until many generations later. The genetic effects of radiation were first demonstrated in fruit flies in the 1920s. Genetic mutation due to radiation does not produce the visible monstrosities of science fiction; it simply produces a greater frequency of the same mutations that occur continuously and spontaneously in nature.
- Like cancers, the genetic effects of radiation are impossible to distinguish from mutations due to other causes. Today at least 1,300 diseases are known to be caused by a mutation.
- Some mutations may be beneficial; random mutation is the driving force in evolution. During the period studied by the Advisory Committee, there was considerable debate

among the scientific community over both the extent and the consequences of radiation-induced mutations.

- ❖ In contrast to estimates of cancer risk, which are based in part on studies of human populations, estimates of heritable risk are based for the most part upon animal studies plus studies of Japanese survivors of the atomic bombs.
- ❖ The risk of genetic mutation is expressed in terms of the doubling dose: the amount of radiation that would cause additional mutations equal in number to those that already occur naturally from all causes, thereby doubling the naturally occurring rate of mutation.
- ❖ It is generally believed that mutation rates depend linearly on dose and that there is no threshold below which mutation rates would not be increased. Spontaneous mutation (unrelated to radiation) occurs naturally at a rate of approximately 1/10,000 to 1/1,000,000 cell divisions per gene, with wide variation from one gene to another.
- ❖ Attempts have been made to estimate the contribution of ionizing radiation to human mutation rates by studying offspring of both exposed and nonexposed Japanese atomic bomb survivors.
- ❖ These estimates are based on comparisons of the rate of various congenital defects and cancer between exposed and nonexposed survivors, as well as on direct counting of mutations at a small number of genes. For all these endpoints, no excess has been observed among descendants of the exposed survivors.
- ❖ Given this lack of direct evidence of any increase in human heritable (genetic) effects resulting from radiation exposure, the estimates of genetic risks in humans have been compared with experimental data obtained with laboratory animals.
- ❖ However, estimates of human genetic risks vary greatly from animal data. For example, fruit flies have very large chromosomes that appear to be uniquely susceptible to radiation.
- ❖ Humans may be less vulnerable than previously thought. Statistical lower limits on the doubling dose have been calculated that are compatible with the observed human data. Based on our inability to demonstrate an effect in humans, the lower limit for the genetic doubling dose is thought to be less than 100 rem.

2. Write notes on LD50? (May 2015,May 2018,Sep 2020)

- ❖ LD50 is the amount of a material, given all at once, which causes the death of 50% (one half) of a group of test animals.

- The LD50 is one way to measure the short-term poisoning potential (acute toxicity) of a material.
- Toxicologists can use many kinds of animals but most often testing is done with rats and mice.
- LD stands for "Lethal Dose”, it figures a substance's acute toxicity.
- Median Lethal Dose is quantity of the chemical that is estimated to be fatal to 50% of the organisms.

Importance

- Different chemicals cause different toxic effects, comparing the toxicity of one with another is hard.
- To compare the toxic potency or intensity of different chemicals, researchers must measure the same effect.
- One way is to carry out lethality testing (the LD50 tests) by measuring how much of a chemical is required to cause death.
- Significance As an aid in developing emergency procedures in case of a major spill or accident.
- To help develop guidelines for the use of appropriate safety clothing and equipment.
- For the development of transportation regulations.
- As an aid in establishing occupational exposure limits.
- The smaller the LD50 value, the more toxic is the chemical and larger the ld50 value, lower is the toxicity of that particular chemical.
- LD50 gives a measure of the immediate or acute toxicity of a chemical in the strain, sex, and age group of a particular animal species being tested.
- Two most common scales used are the
    - Hodge and Sterner Scale
    - Gosselin, Smith and Hodge Scale

Design of acute toxicity (LD50) study

- Performed usually on mice first.
- Test compound was administered at various doses to groups of 5-10 mice of both sexes amd equal in number.
- The number of every group should be more than the number of groups to avoid calculation error.

3. **Describe in detail the Late deterministic effect in different organs and tissues? (May 2016,May 2017)**

- Deterministic effects describe a cause and effect relationship between ionising radiation and certain side-effects.
- They are also known as non-stochastic effects to contrast them with chance-like stochastic effects (e.g. cancer induction).
- These effects depend on dose, dose rate, dose fractionation, irradiated volume and type of radiation (linear energy transfer (LET).
- Deterministic effects have a threshold below which the effect does not occur. The threshold may be very low and may vary from person to person.
- However, once the threshold has been exceeded, the severity of an effect increases with dose.
- There are practical threshold doses below which no significant changes are apparent and these thresholds should never be reached occupationally if sensible procedures are upheld.
- Examples of deterministic effects (doses are given as absorbed doses and expressed in grays (Gy)):
    - Skin erythema: 2-5 Gy
    - irreversible skin damage: 20-40 Gy
    - hair loss: 2-5 Gy
    - sterility: 2-3 Gy
    - cataracts: 0.5 Gy (NB: a significantly lowered threshold of 5Gy to 0.5Gy in the latest ICRP 118 1)
    - lethality (whole body): 3-5 Gy
    - fetal abnormality: 0.1-0.5 Gy

Radiation Effects on Tissues

- Most information on radiation effects on normal tissues and organs comes from observations during and after radiation therapy treatments.
- This is because the doses and effects during radiation cancer treatments are carefully monitored.

- Cancer treatments with radiation began within a few years of Roentgen's discovery. Radiation treatment of cancer is based on the fact that rapidly dividing cells are more sensitive to radiation.
- Cancer is made up of rapidly dividing cells, so the cancer cells are expected to be more sensitive to radiation than normal tissue.
- The major challenge in radiation therapy is to eradicate the cancer without unduly damaging surrounding normal tissues.
- Even today, the amount of radiation delivered to the tumor is limited by the collateral damage to nearby normal tissues.
- Radiation oncologists have been observing radiation injuries to normal tissues since the birth of the field.
- Early treatments were limited by the poor penetrating ability of the radiation, so skin reactions limited the dose that could be safely delivered to deeper lying tumors.
- In the 1950s and 1960s, higher-energy radiation beams became available and data on radiation effects to internal tissues and organs became available.
- In radiation oncology, the damage to organs is reported in terms of a tumor dose (TD) that produces complications in normal tissues with 5% probability within 5 years following the end of radiation treatment.
- This is termed the normal tissue complication probability (NTCP) TD 5/5. Another term used in radiation oncology is NTCP TD 50/5, which is the tumor dose that produces a 50% NTCP in 5 years.
- These terms are normally not used outside the field of radiation therapy because other medical doses are so much smaller than those used in radiation therapy.
- Some important organs, their TD 5/5 and 50/5 values, and the effects of radiation on the tissues are presented here in alphabetical order.

Bladder

- The doses for serious complications are 65 Gy TD for NTCP of 5% in 5 years and 80 Gy TD for NTCP of 50% in 5 years.
- The complications are bladder contraction, volume loss, and difficulty in completely emptying or leaking from the bladder.
- These are extremely high-radiation doses and will be encountered only in radiation oncology cancer treatments or very serious radiation accidents.

Blood and Blood Vessels

- After a significant (>1 Gy) radiation dose from exposure to the whole body, all blood elements are adversely affected.
- Increases in dose result in an increased effect, and the effects are seen earlier. In the case of a whole body exposure from a radiation accident, the loss of white blood cells means the body's defenses against infection are diminished.
- Damage to the skin and intestine make the body particularly vulnerable to bacterial infection during the first few weeks following exposures greater than 1 Gy.
- A person exposed to 1 Gy has their lymphocyte cell count reduced. He or she will be more susceptible to infection.
- Early symptoms of such exposures mimic the flu, that is, loss of appetite, nausea, diarrhea, and vomiting.
- The chapter on whole body radiation treats the effects of decreased white blood cells following radiation exposure more completely.
- Most of the long term, late effects on tissues and organs are the result of injury to blood vessels, especially to those making up the micro vasculature.
- Damage to the capillaries bringing oxygen and nutrients to the cells of an organ will inevitably affect its function.
- The interior surface of blood and lymphatic vessels is lined with a thin layer of endothelial cells which form a barrier between the circulating blood or lymph inside the vessel and the vessel wall.
- Damage to the endothelial cells allows white blood cells and fluids to pass through the vessel.
- Radiation at lower doses can cause damage to the capillary vessels. Such changes can include less flexibility and greater vessel stiffness leading to decreased perfusion.
- This is especially important in the blood vessels, brain, and skin.
- scanning electron microscope image of a blood platelet on interior surface of a damaged blood vessel.
- The blood platelet illustrated is ready to start the formation of a blood clot.

Bone

- The doses for serious complications of bone are 52 Gy TD for NTCP of 5% in 5 years and 65 Gy TD for NTCP of 50% in 5 years.
- The complications are necrosis and pathologic fractures without any external trauma.

Brain

- Because brain cells do not reproduce, they are not significantly damaged unless their blood supply is compromised.
- The doses for major complications of the brain are 45 Gy TD for NTCP of 5% in 5 years and 60 Gy TD for NTCP of 50% in 5 years.
- Complications are necrosis and an infarction.
- An infarction is a group of tissue that dies because of a lack of oxygen caused by an obstruction of the tissue's blood supply.
- There are reports of decrease in IQ scores of about one IQ point per 4 mSv.

Breast

- Radiation treatment for breast cancer is usually spread out over 6 weeks with five 2-Gy treatments per week. This results in a total dose of approximately 60 Gy.
- Late side effects from breast irradiation usually appear one or more years after treatment.
- The two major long-term complications of breast radiation treatments are fibrosis and lymphedema.
- Fibrosis is a hardening or stiffening of the tissues due to loss of elasticity due to a diffuse scarring.
- Lymphedema is a swelling due to localized fluid retention caused by damage to the lymphatic system.
- The complications are the result of blood vessel and connective tissue damage that were in the radiation field.
- Studies have shown that there is no increase in thyroid cancer following radiation treatment for breast cancer.

Esophagus

- The doses for major complications of the esophagus are 55 Gy TD for NTCP of 5% in 5 years and 68 Gy TD for NTCP of 50% in 5 years.
- These are extremely high-radiation doses and will be encountered only in radiation oncology cancer treatments or very serious radiation accidents.
- Major complications include necrosis of the lining of the esophagus.
- The esophagus, the tube leading from the mouth to the stomach, is located between the lungs in the chest.
- During radiation to lungs to treat lung cancer, the esophagus is often included in the radiation field.

- Pain or difficulty with swallowing, heartburn, and a sensation of a lump in the throat are side effects of the radiation.
- Symptoms usually occur 2–3 weeks into therapy and subside a few weeks after completing treatments.

Eye

- Eye doses for complications due to radiation exposure to the eye are 50 Gy TD for NTCP of 5% in 5 years and 65 Gy TD for NTCP of 50% in 5 years.
- These extremely high doses can lead to blindness.

Cataract Formation

- The major complication of radiation to the eye is cataract formation, which is classified as a tissue reaction/deterministic effect with a threshold.
- Radiation cataracts begin as an opacity near the posterior pole of the eye and progress forward.
- For many years, the threshold for cataract induction was believed to be about 2 Gy from chronic exposures over many years.
- Fractionated doses can cause the formation of cataracts after a latent period of 2 years or more depending on the age of the individual and the time period of exposure.
- Recent studies however have shown that the threshold for cataract formation may be significantly lower.
- Interventional physicians with exposures spread over many years have shown cataract formation at cumulative doses as low as 0.8 Gy.

4. Describe in detail about the bone marrow syndrome due to radiation exposure? (May 2016,Nov 2017,May 2019)

- Bone marrow is the spongy tissue inside some of the bones in the body, including the hip and thigh bones. Bone marrow contains immature cells, called stem cells.
- Many people with blood cancers, such as leukemia and lymphoma, sickle cell anemia, and other life-threatening diseases, rely on bone marrow or cord blood transplants to survive.
- Healthy bone marrow and blood cells are needed in order to live.
- When disease affects bone marrow so that it can no longer function effectively, a marrow or cord blood transplant could be the best treatment option; for some patients it is the only potential cure.

- Bone marrow is soft, gelatinous tissue that fills the medullary cavities, the centers of bones. The two types of bone marrow are red bone marrow, known as myeloid tissue, and yellow bone marrow, or fatty tissue.
- Both types of bone marrow are enriched with blood vessels and capillaries.
- Bone marrow makes more than 200 billion new blood cells every day.Most blood cells in the body develop from cells in the bone marrow
- Bone marrow stem cells
- The bone marrow contains two types of stem cells, mesenchymal and hematopoietic.
- Red bone marrow consists of a delicate, highly vascular fibrous tissue containing hematopoietic stem cells. These are blood-forming stem cells.
- Yellow bone marrow contains mesenchymal stem cells, also known as marrow stromal cells. These produce fat, cartilage, and bone.4
- Stem cells are immature cells that can turn into a number of different types of cell.
- Hematopoietic stem cells in the bone marrow give rise to two main types of cells: myeloid and lymphoid lineages. These include monocytes, macrophages, neutrophils, basophils, eosinophils, erythrocytes, dendritic cells, and megakaryocytes or platelets, as well as T cells, B cells, and natural killer cells.
- The different types of hematopoietic stem cells vary in their regenerative capacity and potency.
- Some are multipotent, oligopotent or unipotent as determined by how many types of cell they reate.
- Pluripotent hematopoietic stem cells have the following properties:
- Renewal: They can reproduce another cell identical to themselves.
- Differentiation: They can generate one or more subsets of more mature cells.
- The process of development of different blood cells from these pluripotent stem cells is known as hematopoiesis.
- It is these stem cells that are needed in bone marrow transplant.
- Stem cells constantly divide and produce new cells. Some new cells remain as stem cells and others go through a series of maturing stages, as precursor or blast cells, before becoming formed, or mature, blood cells. Stem cells rapidly multiply to make millions of blood cells each day.10
- Blood cells have a limited life span. This is around 100-120 days for red blood cells. They are constantly being replaced. The production of healthy stem cells is vital.12

- The blood vessels act as a barrier to prevent immature blood cells from leaving the bone marrow.
- Only mature blood cells contain the membrane proteins required to attach to and pass through
- the blood vessel endothelium. Hematopoietic stem cells can cross the bone marrow barrier, however. These may be harvested from peripheral, or circulating, blood.15
- The blood-forming stem cells in red bone marrow can multiply and mature into three significant types of blood cells, each with their own job:
- Red blood cells (erythrocytes) transport oxygen around the body
- White blood cells (leukocytes) help fight infection and disease. White blood cells include lymphocytes – the cornerstone of the immune system – and myeloid cells which include granulocytes: neutrophils, monocytes, eosinophils, and basophils
- Platelets (thrombocytes) help with clotting after injury. Platelets are fragments of the cytoplasm of megakaryocytes, another bone marrow cell.
- Once mature, these blood cells move from the marrow into the bloodstream, where they perform important functions required to keep the body alive and healthy.7
- Mesenchymal stem cells are found in the bone marrow cavity. They differentiate into a number of stromal lineages, such as:
  - chondrocytes (cartilage generation)
  - osteoblasts (bone formation)
  - Osteoclasts
  - adipocytes (adipose tissue)
  - myocytes (muscle)
  - Macrophages
  - endothelial cells
- fibroblasts.

Red bone marrow

- Red bone marrow produces all red blood cells and platelets in human adults and around 60 to 70 percent of lymphocytes. Other lymphocytes begin life in the red bone marrow and become fully formed in the lymphatic tissues, including the thymus, spleen, and lymph nodes.1
- Together with the liver and spleen, red bone marrow also plays a role in getting rid of old red blood cells.

Yellow bone marrow

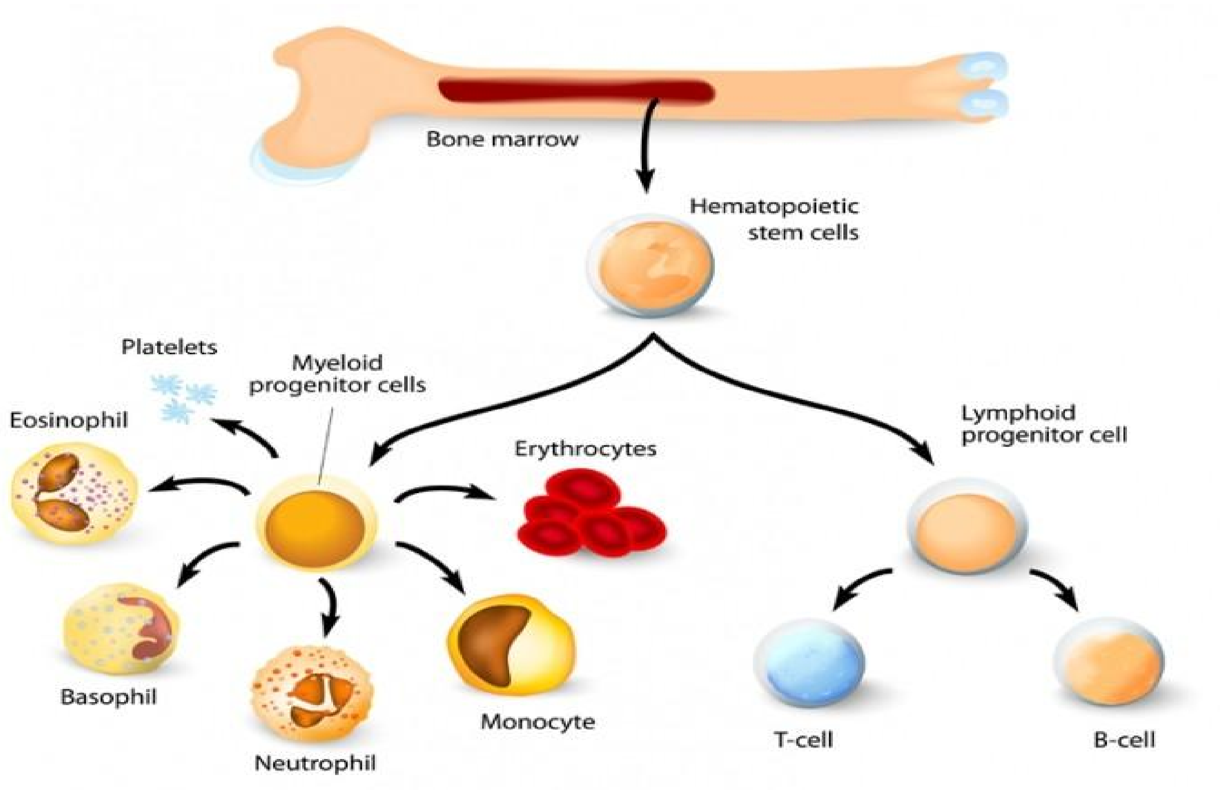
- Yellow bone marrow mainly acts as a store for fats. It helps to provide sustenance and maintain the correct environment for the bone to function. However, under particular conditions, such as severe blood loss or fever, the yellow marrow may revert to red marrow.
- Yellow marrow tends to be located in the central cavities of long bones, and is generally surrounded by a layer of red marrow with long trabeculae (beam-like structures) within a sponge-like reticular framework.

Bone marrow timeline

- Before birth, bone marrow first develops in the clavicle toward the end of fetal development. It becomes active about 3 weeks later. Bone marrow takes over from the liver as the major hematopoietic organ at 32 to 36 weeks' gestation.
- Bone marrow remains red until around the age of 7 years, as the need for new continuous blood formation is high. As the body ages, the red marrow is gradually replaced by yellow fat tissue. Adults have an average of about 2.6 kg (5.7 lbs) of bone marrow, about half of which is red.3
- In adults, the highest concentration of red marrow is in the bones of the vertebrae, hips (ilium), breastbone (sternum), ribs, skull and at the metaphyseal and epiphyseal ends of the long bones of the arm (humerus) and leg (femur and tibia). All other cancellous, or spongy, bones and central cavities of the long bones are filled with yellow marrow.

Function

- Blood cell formation from differentiation of hematopoietic stem cells in red bone marrow.
- Most red blood cells, platelets, and most of the white blood cells are formed in the red marrow. Yellow bone marrow produces fat, cartilage, and bone.
- White blood cells survive from a few hours to a few days, platelets for about 10 days, and red blood cells for about 120 days. These cells must be constantly replaced by the bone marrow, as each blood cell has a set life expectancy.
- Certain conditions may trigger additional production of blood cells. This may happen when the oxygen content of body tissues is low, if there is loss of blood or anemia, or if the number of red blood cells decreases. If these happen, the kidneys produce and release erythropoietin, a hormone that stimulates the bone marrow to produce more red blood cells.



- The bone marrow also produces and releases more white blood cells in response to infections, and more platelets in response to bleeding. If a person experiences serious blood loss, yellow bone marrow can be activated and transformed into red bone marrow.
- Healthy bone marrow is important for a range of systems and activities.

Circulatory system

- The circulatory system touches every organ and system in the body. It involves a number of different cells with a variety of functions.
- Red blood cells transport oxygen to cells and tissues, platelets are carried in the blood to help blood clot after injury, and white blood cells are transported to sites of infection or injury.

Hemoglobin

- Hemoglobin is the protein in red blood cells that gives them their color.
- Hemoglobin collects oxygen in the lungs, transports it in the red blood cells, and releases oxygen to tissues such as the heart, muscles, and brain.
- Carbon dioxide (CO_2), a waste product of respiration, is also removed by hemoglobin and sent back to the lungs to be exhaled.

Iron

- Iron is an important nutrient for human physiology.

- It combines with protein to make the hemoglobin in red blood cells and is essential in the production of red blood cells (erythropoiesis).
- The body stores iron in the liver, spleen, and bone marrow. Most of the iron needed each day for making hemoglobin comes from the recycling of old red blood cells.

Red blood cells

- The production of red blood cells is called erythropoiesis. It takes about 7 days for a committed stem cell to mature into a fully functional red blood cell. As red blood cells age, they become less active and more fragile.
- Aging red cells are removed or eaten up by a type of white blood cell, or macrophage, in a process known as phagocytosis. The contents of these cells are released into the blood. The iron released in this process is carried to either the bone marrow for production of new red blood cells or to the liver or other tissues for storage.
- Normally, around 1 percent of the body's total red blood cells are replaced every day. In a healthy person, around 200 billion red blood cells are produced each day.

White blood cells

- The bone marrow produces many types of white blood cells. These are necessary for a healthy immune system. They prevent and fight infections.
- The main types of white blood cell, or leukocyte, are:

Lymphocytes

- Lymphocytes are produced in bone marrow. They make natural antibodies to fight infection caused by viruses that enter the body through the nose, mouth or other mucous membrane, or through cuts and grazes. Specific cells recognize the presence of foreign invaders (antigens) that enter the body and send a signal to other cells to attack the antigens.
- The number of lymphocytes increases in response to these invasions. There are two major types of lymphocyte: B- and T-lymphocytes.

Monocytes

- Monocytes are produced in the bone marrow.
- Mature monocytes have a life expectancy in the blood of only 3 to 8 hours, but when they move into the tissues, they mature into larger cells called macrophages.
- Macrophages can survive in the tissues for long periods of time where they engulf and destroy bacteria, some fungi, dead cells, and other material foreign to the body.

Granulocytes

- Granulocyte is the family or collective name given to three types of white blood cells: neutrophils, eosinophils and basophils. The development of a granulocyte may take two weeks, but this time is shortened when there is an increased threat, such as a bacterial infection.
- Bone marrow stores a large reserve of mature granulocytes. For every granulocyte circulating within the blood, there may be 50 to 100 cells waiting in the marrow to be released into the blood stream. As a result, half the granulocytes in the blood stream can be available to actively fight an infection in the body within 7 hours of detecting an infection.
- Once a granulocyte has left the blood, it does not normally return. A granulocyte may survive in the tissues for up to 4 to 5 days, depending on the conditions, but it only survives for a few hours in the circulation.

Neutrophils

Neutrophils are the most common granulocyte. They can attack and destroy bacteria and viruses.

Eosinophils

Eosinophils are involved in the fight against many types of parasitic infections and against the larvae of parasitic worms and other organisms. They are also involved in some allergic reactions.

Basophils

- Basophils are the least common of the white blood cells and respond to various allergens that cause the release of histamines, heparin, and other substances.
- Heparin is an anticoagulant. It prevents blood from clotting. Histamines are vasodilators that cause irritation and inflammation. Releasing these substances makes a pathogen more permeable, and allows for white blood cells and proteins to enter tissues to engage the pathogen.
- The irritation and inflammation in tissues affected by an allergen is part of the reaction seen in hay fever, some forms of asthma, hives, and in its most serious form, anaphylactic shock.

Platelets

- Bone marrow produces platelets in a process known as thrombopoiesis. Platelets are needed for blood to coagulate and for clots to form, to stop bleeding.

- Sudden blood loss triggers platelet activity at the site of an injury or wound. Here, the platelets clump together and combine with other substances to form fibrin. Fibrin has a thread-like structure and forms an external scab or clot.
- Platelet deficiency causes the body to bruise and bleed more easily. Blood may not clot well at an open wound, and there may be a greater risk for internal bleeding if the platelet count is very low.

Lymphatic system

- The lymphatic system consists of lymphatic organs such as bone marrow, the tonsils, the thymus, the spleen and lymph nodes.
- All lymphocytes develop in the bone marrow from immature cells called stem cells. Lymphocytes that mature in the thymus gland (behind the breastbone) are called T-cells. Those that mature in the bone marrow or lymphatic organs are called B-cells.14

5. Describe the types of ARS syndrome?(Nov 2016)

The three ARS syndromes, each of which occurs depending on the absorbed doses. The three syndromes are hematopoietic syndrome (or bone marrow syndrome), gastrointestinal syndrome, and the neurovascular syndrome (or cardiovascular/central nervous system syndrome), which are listed in ascending order of absorbed doses.

BONE NARROW SYNDROME

With bone marrow disease, there are problems with the stem cells or how they develop: In leukemia, a cancer of the blood, the bone marrow makes abnormal white blood cells. In aplastic anemia, the bone marrow doesn't make red blood cells. In myeloproliferative disorders, the bone marrow makes too many white blood cells.

Symptoms of bone marrow cancer

- weakness and fatigue due to shortage of red blood cells (anemia)
- bleeding and bruising due to low blood platelets (thrombocytopenia)
- infections due to shortage of normal white blood cells (leukopenia)
- extreme thirst.
- frequent urination.
- dehydration.
- abdominal pain.
- loss of appetite.

GASTROINTESTINAL TRACT

- The gastrointestinal tract, (GI tract, GIT, digestive tract, digestion tract, alimentary canal) is the tract from the mouth to the anus which includes all the organs of the digestive system in humans and other animals.
- Food taken in through the mouth is digested to extract nutrients and absorb energy, and the waste expelled as feces.
- The mouth, esophagus, stomach and intestines are all part of the gastrointestinal tract.
- Gastrointestinal is an adjective meaning of or pertaining to the stomach and intestines.
- A tract is a collection of related anatomic structures or a series of connected body organs.
- All vertebrates and most invertebrates have a digestive tract.
- The sponges, cnidarians, and ctenophores are the early invertebrates with an incomplete digestive tract having just one opening instead of two, where food is taken in and waste expelled.
- The human gastrointestinal tract consists of the esophagus, stomach, and intestines, and is divided into the upper and lower gastrointestinal tracts.
- The GI tract includes all structures between the mouth and the anus, forming a continuous passageway that includes the main organs of digestion, namely, the stomach, small intestine, and large intestine. However, the complete human digestive system is made up of the gastrointestinal tract plus the accessory organs of digestion (the tongue, salivary glands, pancreas, liver and gallbladder
- The tract may also be divided into foregut, midgut, and hindgut, reflecting the embryological origin of each segment.
- The whole human GI tract is about nine metres (30 feet) long at autopsy.
- It is considerably shorter in the living body because the intestines, which are tubes of smooth muscle tissue, maintain constant muscle tone in a halfway-tense state but can relax in spots to allow for local distention and peristalsis.

- ❖ The gastrointestinal tract contains trillions of microbes, with some 4,000 different strains of bacteria having diverse roles in maintenance of immune health and metabolism.
- ❖ Cells of the GI tract release hormones to help regulate the digestive process. These digestive hormones, including gastrin, secretin, cholecystokinin, and ghrelin, are mediated through either intracrine or autocrine mechanisms, indicating that the cells releasing these hormones are conserved structures throughout evolution

NEURO VASCULAR SYSTEM

Neurovascular compression syndromes are a form of vascular compression disorders where there is usually compression or distortion of a cranial nerve due to a redundant or aberrant vascular structure.

6. Discuss the stochastic and deterministic effects?(Nov 2016,Nov 2018,May 2019)

Deterministic effects are threshold health effects, that are related directly to the absorbed radiation dose and the severity of the effect increases as the dose increases.

Stochastic effects occur by chance, generally occurring without a threshold level of dose. Probability of occurrence of stochastic effects is proportional to the dose but the severity of the effect is independent of the dose received.

Deterministic Effects

- ❖ Deterministic effects (or non-stochastic health effects) are health effects, that are related directly to the absorbed radiation dose and the severity of the effect increases as the dose increases.
- ❖ Deterministic effects have a threshold below which no detectable clinical effects do occur.
- ❖ The threshold may be very low (of the order of magnitude of 0.1 Gy or higher) and may vary from person to person.
- ❖ For doses between 0.25 Gy and 0.5 Gy slight blood changes may be detected by medical evaluations and for doses between 0.5 Gy and 1.5 Gy blood changes will be noted and symptoms of nausea, fatigue, vomiting occur.
- ❖ Once the threshold has been exceeded, the severity of an effect increases with dose.

- The reason for the presence of this threshold dose is that radiation damage (serious malfunction or death) of a critical population of cells (high doses tend to kill cells) in a given tissue needs to be sustained before injury is expressed in a clinically relevant form.
- Therefore, deterministic effects are also termed tissue reaction.
- They are also called non-stochastic effects to contrast with chance-like stochastic effects (e.g. cancer induction).
- Deterministic effects are not necessarily more or less serious than stochastic effects.
- High doses can cause visually dramatic radiation burns, and/or rapid fatality through acute radiation syndrome.
- Acute doses below 250 mGy are unlikely to have any observable effects.
- Acute doses of about 3 to 5 Gy have a 50% chance of killing a person some weeks after the exposure, if a person receives no medical treatment.
- Deterministic effects can ultimately lead to a temporary nuisance or also to a fatality.
- Examples of deterministic effects are:

Acute radiation syndrome, by acute whole-body radiation

Radiation burns, from radiation to a particular body surface

Radiation-induced thyroiditis, a potential side effect from radiation treatment against **hyperthyroidism**

Chronic radiation syndrome, from long-term radiation.

Radiation-induced lung injury, from for example radiation therapy to the lungs

Stochastic Effects

- Stochastic effects of ionizing radiation occur by chance, generally occurring without a threshold level of dose.
- Probability of occurrence of stochastic effects is proportional to the dose but the severity of the effect is independent of the dose received.
- The biological effects of radiation on people can be grouped into somatic and hereditary effects.
- Somatic effects are those suffered by the exposed person.
- Hereditary effects are those suffered by the offspring of the individual exposed.
- Cancer risk is usually mentioned as the main stochastic effect of ionizing radiation, but also hereditary disorders are stochastic effects.

According to ICRP:

- On the basis of these calculations the Commission proposes nominal probability coefficients for detriment-adjusted cancer risk as 5.5 x 10-2 Sv-1 for the whole population and 4.1 x 10-2 Sv-1 for adult workers.
- For heritable effects, the detriment-adjusted nominal risk in the whole population is estimated as 0.2 x 10-2 Sv-1 and in adult workers as 0.1 x 10-2 Sv-1 .

Biological Effects and Dose Limits

- In radiation protection, dose limits are set to limit stochastic effects to an acceptable level, and to prevent deterministic effects completely.
- Note that, stochastic effects are those arising from chance: the greater the dose, the more likely the effect.
- Deterministic effects are those which normally have a threshold: above this, the severity of the effect increases with the dose.
- Dose limits are a fundamental component of radiation protection, and breaching these limits is against radiation regulation in most countries.
- Note that, the dose limits described in this article apply to routine operations.
- They do not apply to an emergency situation when human life is endangered.
- They do not apply in emergency exposure situations where an individual is attempting to prevent a catastrophic situation.
- The limits are split into two groups, the public, and occupationally exposed workers.
- According to ICRP, occupational exposure refers to all exposure incurred by workers in the course of their work, with the exception of excluded exposures and exposures from exempt activities involving radiation or exempt sources any medical exposure the normal local natural background radiation.

Type of limit	Occupational	Public
Stochastic limits **Effective dose:**	20 mSv per year, averaged over defined periods of 5 years	1 mSv in a year
Deterministic limits **Annual equivalent dose in:**		
Lens of the eye	150 mSv	15 mSv
Skin	500 mSv	50 mSv
Hands and feet	500 mSv	-

Table of dose limits for occupationally exposed workers and for the public.

7. Discuss about radiation syndrome in gastro intestinal system?(May 2017,Nov 2017,Nov 2018,May 2018,May 2019,Sep 2020)

- The gastrointestinal tract, (GI tract, GIT, digestive tract, digestion tract, alimentary canal) is the tract from the mouth to the anus which includes all the organs of the digestive system in humans and other animals.
- Food taken in through the mouth is digested to extract nutrients and absorb energy, and the waste expelled as feces.
- The mouth, esophagus, stomach and intestines are all part of the gastrointestinal tract.
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- The tract may also be divided into foregut, midgut, and hindgut, reflecting the embryological origin of each segment.
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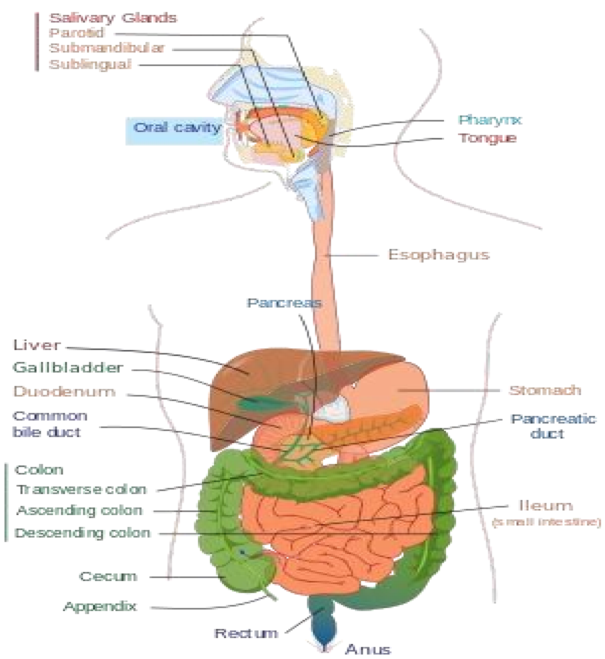
- The gastrointestinal tract contains trillions of microbes, with some 4,000 different strains of bacteria having diverse roles in maintenance of immune health and metabolism.

- Cells of the GI tract release hormones to help regulate the digestive process. These digestive hormones, including gastrin, secretin, cholecystokinin, and ghrelin, are mediated through either intracrine or autocrine mechanisms, indicating that the cells releasing these hormones are conserved structures throughout evolution

Structure



Upper and lower human gastrointestinal tract

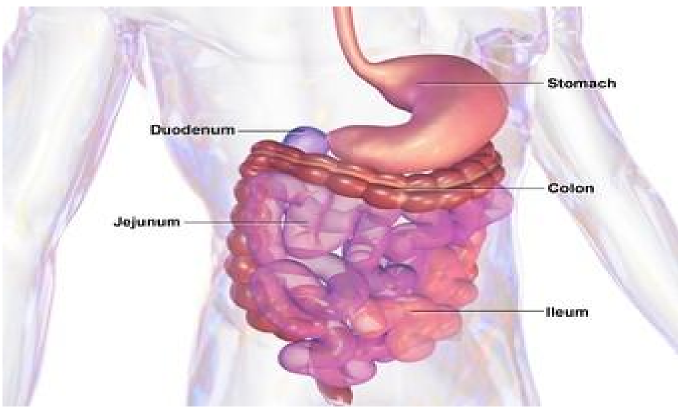


Illustration of human gastrointestinal tract

The structure and function can be described both as gross anatomy and as microscopic anatomy or histology. The tract itself is divided into upper and lower tracts, and the intestines small and large parts.

Upper gastrointestinal tract

- The upper gastrointestinal tract consists of the mouth, pharynx, esophagus, stomach, and duodenum.
- The exact demarcation between the upper and lower tracts is the suspensory muscle of the duodenum.
- This differentiates the embryonic borders between the foregut and midgut, and is also the division commonly used by clinicians to describe gastrointestinal bleeding as being of either "upper" or "lower" origin.
- Upon dissection, the duodenum may appear to be a unified organ, but it is divided into four segments based upon function, location, and internal anatomy.
- The four segments of the duodenum are as follows (starting at the stomach, and moving toward the jejunum): bulb, descending, horizontal, and ascending.
- The suspensory muscle attaches the superior border of the ascending duodenum to the diaphragm.
- The suspensory muscle is an important anatomical landmark which shows the formal division between the duodenum and the jejunum, the first and second parts of the small intestine, respectively.
- This is a thin muscle which is derived from the embryonic mesoderm.

Lower gastrointestinal tract

- The lower gastrointestinal tract includes most of the small intestine and all of the large intestine.

- In human anatomy, the intestine (bowel, or gut. Greek: éntera) is the segment of the gastrointestinal tract extending from the pyloric sphincter of the stomach to the anus and as in other mammals, consists of two segments, the small intestine and the large intestine.
- In humans, the small intestine is further subdivided into the duodenum, jejunum and ileum while the large intestine is subdivided into the cecum, ascending, transverse, descending and sigmoid colon, rectum, and anal canal.

Small intestine

- The small intestine begins at the duodenum and is a tubular structure, usually between 6 and 7 m long.
- Its mucosal area in an adult human is about 30 m2 (320 sq ft).[19] The combination of the circular folds, the villi, and the microvilli increases the absorptive area of the mucosa about 600-fold, making a total area of about 250 m2 (2,700 sq ft) for the entire small intestine.
- Its main function is to absorb the products of digestion (including carbohydrates, proteins, lipids, and vitamins) into the bloodstream.

There are three major divisions:

Duodenum: A short structure (about 20–25 cm long) which receives chyme from the stomach, together with pancreatic juice containing digestive enzymes and bile from the gall bladder. The digestive enzymes break down proteins, and bile emulsifies fats into micelles. The duodenum contains Brunner's glands which produce a mucus-rich alkaline secretion containing bicarbonate. These secretions, in combination with bicarbonate from the pancreas, neutralize the stomach acids contained in the chyme.

Jejunum: This is the midsection of the small intestine, connecting the duodenum to the ileum. It is about 2.5 m (8.2 ft) long and contains the circular folds also known as plicae circulares and villi that increase its surface area. Products of digestion (sugars, amino acids, and fatty acids) are absorbed into the bloodstream here.

Ileum: The final section of the small intestine. It is about 3 m long, and contains villi similar to the jejunum. It absorbs mainly vitamin B12 and bile acids, as well as any other remaining nutrients.

Large intestine

- The large intestine also called the colon, consists of the cecum, rectum, and anal canal. It also includes the appendix, which is attached to the cecum.
- The colon is further divided into:

1. Cecum (first portion of the colon) and appendix
2. Ascending colon (ascending in the back wall of the abdomen)
3. Right colic flexure (flexed portion of the ascending and transverse colon apparent to the liver)
4. Transverse colon (passing below the diaphragm)
5. Left colic flexure (flexed portion of the transverse and descending colon apparent to the spleen)
6. Descending colon (descending down the left side of the abdomen)
7. Sigmoid colon (a loop of the colon closest to the rectum)
8. Rectum
9. Anus