Basic Radiation Physics

بناماكانى فيزياى تيشكى

مبادىء الفيزياء الشعاعية

Radiology Department – First Stage

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RADIATION AND ATOM

1.1 The Atom

Q/ Define the atom? Atoms are far too small to see directly, even with the most powerful optical microscopes.

Q/ How atoms reveal their internal structures in amazingly fine detail? Atoms do interact with and under some circumstances emit light in ways that reveal their internal structures in amazingly fine detail.

Q/ Through what language we can communicate with the world of the atom? It is through the "language of light" that we communicate with the world of the atom.

1.1.1 Fundamental Particles

Q/ Enumerate the radiations that used for diagnostic imaging? X-ray, gamma ray, radiofrequency and sound wave - to which the body is partly but not completely transparent, and it exploits the special properties of a number of elements and compounds.

Q/ Why we need to discussing the structure of the atom and the production of X-rays? Because ionizing radiations (**X-rays** and **gamma rays**) are used most.

Q/ An **atom** consists mainly of empty space. Its mass is concentrated in a **central nucleus** which contains a number **A** of nucleons, where A is called the **mass number.**

Q/ The **nucleons** comprise Z protons, where Z is the **atomic number** of the element, and so **(A-Z)** neutrons.

Q/ A nuclide is a species of nucleus characterized by the two numbers Z and A. The **atomic number** is synonymous with the name of the element.

Q/ Write the expression for the electron limit per shell? $2n^2$ where ***n*** is the shell number.

Q/ In each atom, the outermost or valence shell is concerned with what? concerned with the **chemical**, **thermal**, **optical** and **electrical** properties of the element.

NOTE: X-rays involve the **inner shells**, and **radioactivity** concerns the **nucleus.**

1.1.3 Binding Energy

Q/ Define binding energy? Binding energy, amount of energy required to separate a particle from a system of particles or to disperse all the particles of the system.

Q/ Define nuclear binding energy? Nuclear binding energy is the energy required to separate an atomic nucleus completely into its constituent protons and neutrons, or, equivalently, the energy that would be liberated by combining individual protons and neutrons into a single nucleus.

Q/ The hydrogen-2 nucleus, for example, composed of **one proton** and **one neutron**, can be separated completely by supplying **2.23 million electron volts (MeV)** of energy. Conversely, when a slowly moving **neutron** and **proton** combine to form a hydrogen-2 nucleus, **2.23 MeV** are liberated in the form of **gamma radiation.**

Q/ Write the expression of Einstein's mass–energy equation? The total mass of the bound particles is less than the sum of the masses of the separate particles by an amount equivalent to the binding energy.

Q/ What's called electron binding energy? It's called ionization potential.

Q/ Define ionization potential? Is the energy required to remove an electron from an atom, a molecule, or an ion.

Q/ In general, the binding energy of a single **proton** or **neutron** in a nucleus is approximately a **million times** greater than the binding energy of a single **electron** in an atom.

Q/ An atom is said to be ionized when one of its electrons has been completely **removed**. The detached electron is **negative ion** and the remnant atom a **positive ion**. Together they form an **ion pair.**

Q/ The binding energy depends on what? The binding energy depends on the shell $(E_K > E_L > E_M \cdots)$, and on the element, increasing as the atomic number increases.

Q/ An atom is **excited** when an electron is raised from one shell to another farther out.

1.2 Wave-Particle Duality

Q/ There are two aspects for Electromagnetic radiation can be regarded as a **stream of 'packets'** or **quanta** of energy, called ***photon***, traveling in straight lines.

Q/ The photon is the smallest possible packet (*quantum*) of light; it has **zero mass** but a **definite** energy.

Q/ **<u>Einstein</u>** is most famous for saying "mass is related to energy".

Q/ Write the equation of wave-particle duality of light that the *energy* of a wave can be related to the wave's *frequency?*

$$E = h \times f$$

Energy (Joules)	planck's Constant (6.626×10^{-34} J.s)	Frequency (Hz or s^{-1})

Q/ Enumerate the three measurable properties of wave motion? *amplitude*, *wavelength*, and *frequency*

Q/ Define a frequency? The number of vibrations per second.

Q/ Write the equation that describe the relation between the wavelength (λ), frequency of a wave (ν) and the propagation velocity (^{v})? $v = \lambda * \nu$

or **Velocity = Wavelength * Frequency**

NOTE: This relation is true of all kinds of wave motion, including sound; although the velocity of sound is million times less.

Q/ Show that the energy of the x-ray and gamma ray more than blue light?

$$E \text{ (in keV)} = \mathbf{1.24/\lambda} \text{ (in nm)}$$

Blue light	λ=400 nm	E=3 eV
Typical X- and gamma rays	λ=0.1 nm	E=140 keV

Q/ Define the following terms?

1- Amplitude (A): The peak field strength is called the amplitude (A).

2- **Period (T):** The interval between successive crests of the wave is called the period (T).

3- **The frequency (ν)**: Is the number of crests passing a point in a second, and **(ν = 1/ T).**

4- Wavelength (λ): The distance between successive crests of the wave is called the wavelength (λ).

Q/ When the energy is less than **1 keV** the radiation is usually described in terms of its frequency, except that **<u>visible light</u>** is usually described in terms of its wavelength.

Q/ It is curious that only radiations at the ends of the spectrum, radio waves and X-Ray or gamma rays, **penetrate** the human body sufficiently to be used in **transmission imaging.**

1.3 Radiation

Q/ Define a radiation? Radiation is energy moving in the form of waves or streams of particles.

Q/ How can you understand a radiation? Understanding radiation requires basic knowledge of atomic structure, energy and how radiation may damage cells in the human body.

Q/ When people hear the word radiation, they often think about each type of radiation? When people hear the word radiation, they often think of **atomic energy**, **nuclear power** and **radioactivity**, but radiation has many other forms.

Q/ What are the familiar types of radiation? Sound and **visible light** are familiar forms of radiation; other types include **ultraviolet radiation** (that produces a suntan), **infrared radiation** (a form of heat energy), **radio** and **television** signals.

Q/ Electromagnetic energy is the term given to energy traveling across empty space and used to describe all the different kinds of energies released into space by stars such as the Sun.

Q/ All forms of electromagnetic radiation (which includes radio waves, light, cosmic rays, etc.) moves through empty space with the same **velocity** at the speed of (very close to 3×10^{8} ms^{-1}) and not significantly less in air.

Q/ Enumerate kind of energies? Radio Waves. **TV waves**. **Radar waves**. **Heat** (infrared radiation). **Light**. **Ultraviolet Light** (This is what causes Sunburns). **X-rays** (emitted by X-ray tubes)**. Short waves. Microwaves,** like in a microwave oven. **Gamma Rays** (emitted by radioactive nuclei) have essentially the same properties of X-rays and differ only in their origin.

Q/ How all electromagnetic waves do different things, but they have some things in common? All these waves do **different things** (for example, **light waves make things visible to the human eye**, while **heat waves make molecules move and warm up, and x rays can pass through a person and land on film, allowing us to take a picture inside someone's body)** but they have **some things in common**. They all travel **in waves.**

Q/ Where all kinds of electromagnetic radiation are come to us? All kinds of electromagnetic radiation are released from the Sun.

Q/ What is the benefit of atmosphere? Our atmosphere stops some kinds from getting to us. For example, **the ozone layer stops a lot of harmful ultraviolet radiation from getting to us**, and that's why people are so concerned about the hole in it.

Q/ How many forms of radiation? There are two forms of radiation: **non-ionizing** radiation and **ionizing** radiation.

1.3.1 Non-Ionizing Radiation

Q/ Define non- ionizing radiation? Non-ionizing radiation is the radiation that has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons. That mean it does not possess enough energy to produce ions.

Q/ Enumerate the non- ionizing radiation in the part of electromagnetic spectrum? Which includes **radio waves**, **microwaves**, **infra-red**, **visible and ultraviolet light, together with sound and ultrasound**. **Cellular telephones**, **television stations**, **FM** and **AM radio**, and **cordless phones** use non-ionizing radiation.

Other forms include **the earth's magnetic field**, as well as magnetic field exposure from proximity to **transmission lines**, **household wiring** and **electric appliances**. These are defined as **Extremely Low-Frequency (ELF)** waves and are not considered to pose a health risk.

Q/ Enumerate the ionizing radiation in the electromagnetic spectrum? The ionizing radiation in the electromagnetic spectrum includes (**X-ray** and **Gamma ray**).

1.3.2 Ionizing Radiation

Q/ Define ionizing radiation? Ionizing radiation is a special type of radiation (in the form of either particles or waves) that has enough energy to remove tightly bound electrons out of their orbits around atoms, thus creating ions.

Q/ Define ionization process? Ionizing radiation is any kind of radiation capable of removing an orbital electron from an atom with which it interacts, the atom is said to be ionized. This process is called ionization.

Q/ Where ionization radiation come to us or originate? Ionizing radiation includes the radiation that comes from both **natural** and **man-made radioactive materials**.

Q/ What is the difference between gamma radiation and x-ray radiation? Gamma radiation consists of photons that originate from within the nucleus, and X-ray radiation consists of photons that originate from outside the nucleus, and are typically lower in energy than gamma radiation.

Q/ What are the advantages of properties for both gamma ray and x-ray? We take advantage of its properties in **diagnostic imaging**, to **kill cancer cells**, and in many **manufacturing processes**.

Q/ Ionization is the process by which a stable atom or a molecule **loses** or **gains** an electron(s), thereby **acquiring** an electric charge or **changing** an existing charge.

Q/ An atom or molecule with an electric charge is called an **ion**, which may behave differently, **electrically** and **chemically**, from a stable atom or molecule.

Q/ *Ionizing radiation* can occur in one of two forms: **particulate** or **electromagnetic**.

Q/ Particulate ionizing radiation is emitted when components of the structure of an atom are ejected, **artificially** or **naturally**.

Q/ Ionizing radiation includes the radiation that comes from both **natural** and **man-made radioactive** materials.

1.4 Types of Ionizing Radiation

Q/ How the intensity of photon radiation reduces? Photon radiation can only be reduced in intensity by materials that are quite dense, such as lead or steel.

Q/ In general, photon radiation can travel much greater **distances** than **alpha** or **beta** radiation, and it can **penetrate** bodily tissues and organs when the radiation source is **outside** the body.

Q/ Photon radiation can also be hazardous if photon-emitting **nuclear substances** are taken into the body.

Q/ Give an example of a nuclear substance that undergoes photon emission? Cobalt-60, which decays to Nickel-60.

1.4.1 Particle Radiation

Q/ Define particle radiation? Particle radiation consists of a stream of charged or neutral particles, both charged ions and subatomic elementary particles.

Q/ Give some examples of subatomic elementary particles? This includes solar wind, cosmic radiation, and neutron flux in nuclear reactors.

1.4.1.1 Alpha Particles

Q/ Define alpha particles (α)? Alpha particles (α), helium nuclei, are the least penetrating. Some unstable atoms emit alpha particles. Alpha particles are positively charged and made up of two protons and two neutrons from the atom's nucleus.

Q/ Alpha particle comes from the decay of each kind of materials? Alpha particles come from the decay of the **heaviest** radioactive elements, such as **uranium**, **radium** and **polonium**.

Q/ How even very energetic alpha particles can be stopped? Even very energetic alpha particles can be **stopped by a single sheet of paper**. They are **so heavy** that they use up their energy over **short distances** and are **unable** to travel **very far** from the atom.

Q/ The health effect from exposure to alpha particles depends greatly on what? The health effect from exposure to alpha particles depends greatly on **how a person is exposed**.

Q/ Why if alpha particle exposure the body from outside is not a major concern? Because alpha particles lack the energy to penetrate even the outer layer of skin.

Q/ Why if alpha particle exposure the body from inside can be very harmful? Because if alpha-emitters are inhaled, swallowed, or get into the body through a cut, the alpha particles can damage sensitive living tissue.

Q/ The way these large, **heavy particles** because damage makes them more **dangerous** than other types of radiation. The ionizations they cause are very close together they can **release** all their energy in a **few** cells. This results in more **severe** damage to cells and **DNA**.

1.4.1.2 Beta Particles (β)

Q/ Define beta particle? Beta particles (β) are fast-moving particles with a negative electrical charge. Beta particles (electrons) are emitted from an atom's nucleus during radioactive decay with more penetrating, but still can be absorbed by a few millimeters of aluminum.

Q/ However, in cases where **high energy** beta particles are emitted shielding must be accomplished with **low density** materials, *e.g.*, **plastic**, **wood**, **water** or **acrylic glass** (Plexiglas, Lucite). They travel **farther** in air than alpha particles, but can be stopped by a layer of **clothing** or by a **thin** layer of a substance such as **aluminum**.

Q/ In the case of **beta+ radiation** (**positrons**), the gamma radiation from the **electron-positron annihilation** reaction poses additional concern. These particles are emitted by certain unstable atoms such as **hydrogen-3 (tritium)**, **carbon-14** and **strontium-90**.

Q/ Why beta particle are more penetrating than alpha particle but are less damaging to living tissue and DNA? because the ionizations they produce are more widely spaced.

Q/ Some beta particles are capable of penetrating the skin and causing damage such as **skin burns**, however, as with alpha-emitters, beta-emitters are **most hazardous** when they are **inhaled** or **swallowed**.

1.4.1.3 Neutron Radiation

Q/ What is a neutron radiation? Neutron radiation is not as readily absorbed as charged particle radiation, which makes this type highly penetrating.

Q/ How neutron radiation absorbed? Neutrons are absorbed by nuclei of atoms in a nuclear reaction.

Q/ What is the only natural source of neutrons? Apart from cosmic radiation, spontaneous fission is the only natural source of neutrons.

Q/ What is a common source of neutrons? A common source of neutrons is the **nuclear reactor**, in which the splitting of a uranium or plutonium nucleus is accompanied by the emission of neutrons.

Q/ What is the principle of production nuclear power? The neutrons emitted from one fission event can strike the nucleus of an adjacent atom and cause another fission event, inducing a chain reaction.

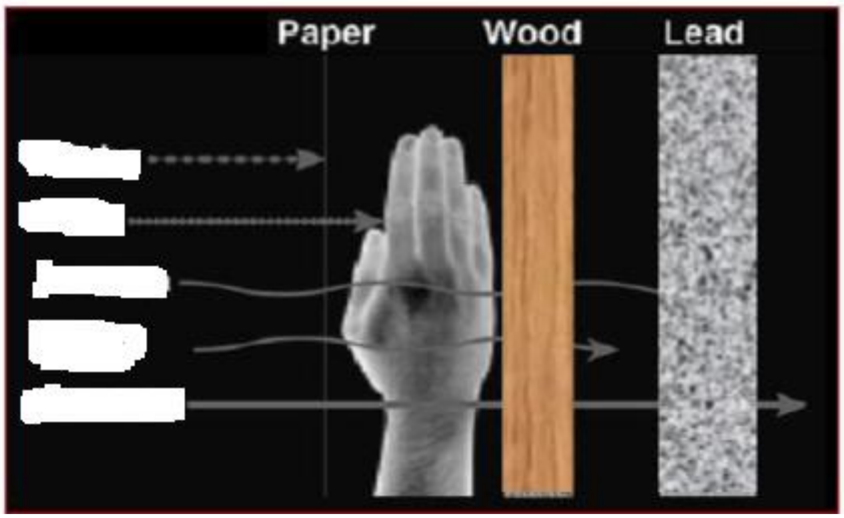
Q/ Neutrons are able to **penetrate** tissues and organs of the human body when the radiation source is **outside** the body.

Q/ Neutrons can also be **hazardous** if neutron-emitting nuclear substances are deposited **inside** the body.

Q/ What is the best shielding or absorbing material of neutron radiation? Neutron radiation is best shielded or absorbed by materials that contain **hydrogen** atoms, such as **paraffin wax** and **plastics**.

Q/ Why neutron radiation is best shielded or absorbed by paraffin wax and plastics? This is because **neutrons** and **hydrogen** atoms **have similar atomic weights** and readily undergo collisions between each other.

Q/ Complete the following figure, that types of radiation from higher-energy ionizing radiation to lower-energy non-ionizing radiation. Each radiation source differs in its ability to penetrate various materials, such as paper, skin, wood and lead.



1.4.2 Types of Electromagnetic Ionizing Radiation

Q/ In general, electromagnetic radiation consists of emissions of electromagnetic waves, the properties of which depend on the **wavelength**.

Q/ If Ionizing radiation has more energy than non-ionizing radiation such that it can cause what? It can cause chemical changes by interacting with an atom to remove tightly bound electrons from the orbit of the atom, causing the atom to become charged or ionized.

1.4.2.1 Gamma Rays

Q/ Define Gamma Rays: Gamma rays (γ) are weightless packets of energy called photons. Gamma-rays have the smallest wavelengths and but have much higher energy of any other wave in the electromagnetic spectrum.

Q/ Gamma rays unlike alpha and beta particles, which have both **energy** and **mass**, gamma rays are pure energy.

Q/ Gamma rays are often emitted along with alpha or beta particles during **radioactive decay** and in **nuclear explosions**.

Q/ Write the properties of gamma rays? Gamma rays are **1-** a radiation hazard for the entire body. **2-** They can easily penetrate barriers, such as skin and clothing that can stop alpha and beta particles. **3-** Gamma rays have so much penetrating power that several inches of a dense material like lead or even a few feet of concrete may be required to stop them. **4-** Gamma rays can pass completely through the human body easily.

Q/ What is the advantages of the ionization of gamma ray? As they pass through, the body they can cause ionizations, that damage tissue and DNA or kill living cells, a fact which medicine uses to its advantage, using gamma-rays to kill cancerous cells.

1.4.2.2 X-Rays

Q/ Why almost everybody has heard of x-rays? Because of their use in medicine.

Q/ What is the similarity and difference between x-rays and gamma rays? X-rays are similar to gamma rays in that they are photons of pure energy. X-rays and gamma rays have the same basic properties but come from different parts of the atom. X-rays are emitted from processes outside the nucleus, but gamma rays originate inside the nucleus. They also are generally lower in energy and, therefore, less penetrating than gamma rays but have higher energy than ultraviolet waves.

Q/ As the wavelengths of light decrease, they increase in **energy**.

Q/ Why We usually talk about X-rays in terms of their energy rather than wavelength? This is partially because **1-** X-rays have very small wavelengths **2-** X-ray light tends to act more like a particle than a wave.

Q/ X-rays can be produced naturally or artificially by machines using **electricity**.

Q/ Enumerate the x-ray machines are used daily in medicine? Computerized tomography, commonly known as CT or CAT scans, uses special x-ray equipment to make detailed images of bones and soft tissue in the body. Medical x-rays are the single largest source of man-made radiation exposure. X-rays are also used in industry for inspections and process controls.

1.4.2.3 Ultraviolet

Q/ What is called the dividing line between ionizing and non-ionizing radiation in the electromagnetic spectrum? falls in the ultraviolet portion of the spectrum and while most UV is classified as non-ionizing radiation, the shorter wavelengths from about 150 nm (UV-C or 'Far' UV) are ionizing.

Q/ Which type of ultraviolet is ionization and how it absorbed? The type UV-C is ionization part, it is all absorbed by the ozone layer.

1.5 Inverse Square Law for Radiation

Q/ What obey inverse square law? Point sources of **gravitational force**, **electric field**, **light**, **sound or radiation** obey the inverse square law. Any point source which spreads its influence equally in all directions without a limit to its range will obey the inverse square law. This comes from strictly geometrical considerations.

Q/ Define inverse square law? The intensity of the influence at any given radius is the source strength divided by the area of the sphere. Being strictly geometric in its origin, the inverse square law applies to diverse phenomena.

Q/ When light is emitted from a source such as the sun or a light bulb, the **intensity** decreases rapidly with the **distance** from the source.

Q/ X-rays exhibit precisely the same property. The intensity of the radiation is **inversely** proportional to the **square** of the distance from a point source.

Q/ Write the mathematical expression of inverse square law? As intensity is the power per unit area.

$$\text{Intensity} = \text{Power}/\text{Area} \quad (P/m^2)$$

It naturally decreases with the square of the distance, as the size of the radiative spherical wave front increases with distance (r).

So, the luminous intensity on a spherical surface a distance from a source radiating a total power P is:

Area of spherical shape is 3/4 πr^2 **so:**

$$I = \frac{3}{4}\frac{P}{\pi r^2}$$

As **P** and **π** remain constant, the luminous intensity is proportional to the inverse of distance:

$$\text{Intensity} \propto \frac{1}{(\text{distance})^2} \quad \textbf{Or} \quad I \propto 1/r^2$$

Q/ Prove that $\text{Intensity} \propto \frac{1}{(\text{distance})^2}$ **or** $I \propto 1/r^2$ **?**

$$\text{Intensity} = \text{Power}/\text{Area} \quad (P/m^2)$$

the luminous intensity on a spherical surface a distance from a source radiating a total power P is:

Area of spherical shape is 3/4 $\boldsymbol{\pi r^2}$ **so:**

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As **P** and **π** remain constant, the luminous intensity is proportional to the inverse of distance:

$$\text{Intensity} \propto \frac{1}{(\text{distance})^2} \quad \textbf{or} \quad I \propto 1/r^2$$

Q/ Write the mathematical expression of inverse square law if I double the distance to a light source the observed intensity is decreased to of its $(1/2)^2 = 1/4$ **original value. Generally, the ratio of intensities at distances** d_1 **and** d_2 **are:**

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2}$$

1.6 Properties Considered When Ionizing Radiation Measured

Q/ Write the considered properties of measuring ionizing radiation?

1- The strength or radioactivity of the radiation source, **2-** the energy of the radiation, **3-** the level of radiation in the environment, and **4-** the radiation dose or the amount of radiation energy absorbed by the human body.

Q/ From the point of view of the occupational exposure, the **radiation dose** is the most important measure.

Q/ The risk of radiation-induced diseases depends on the total radiation dose that a person receives over **time**.

1.7 Radiologic Units