Ministry of Higher Education
and Scientific Research
Al-Mustaqbal University
Department of Medical Physics

Introduction to the physics of diagnostic radiology

Lecture 1

By

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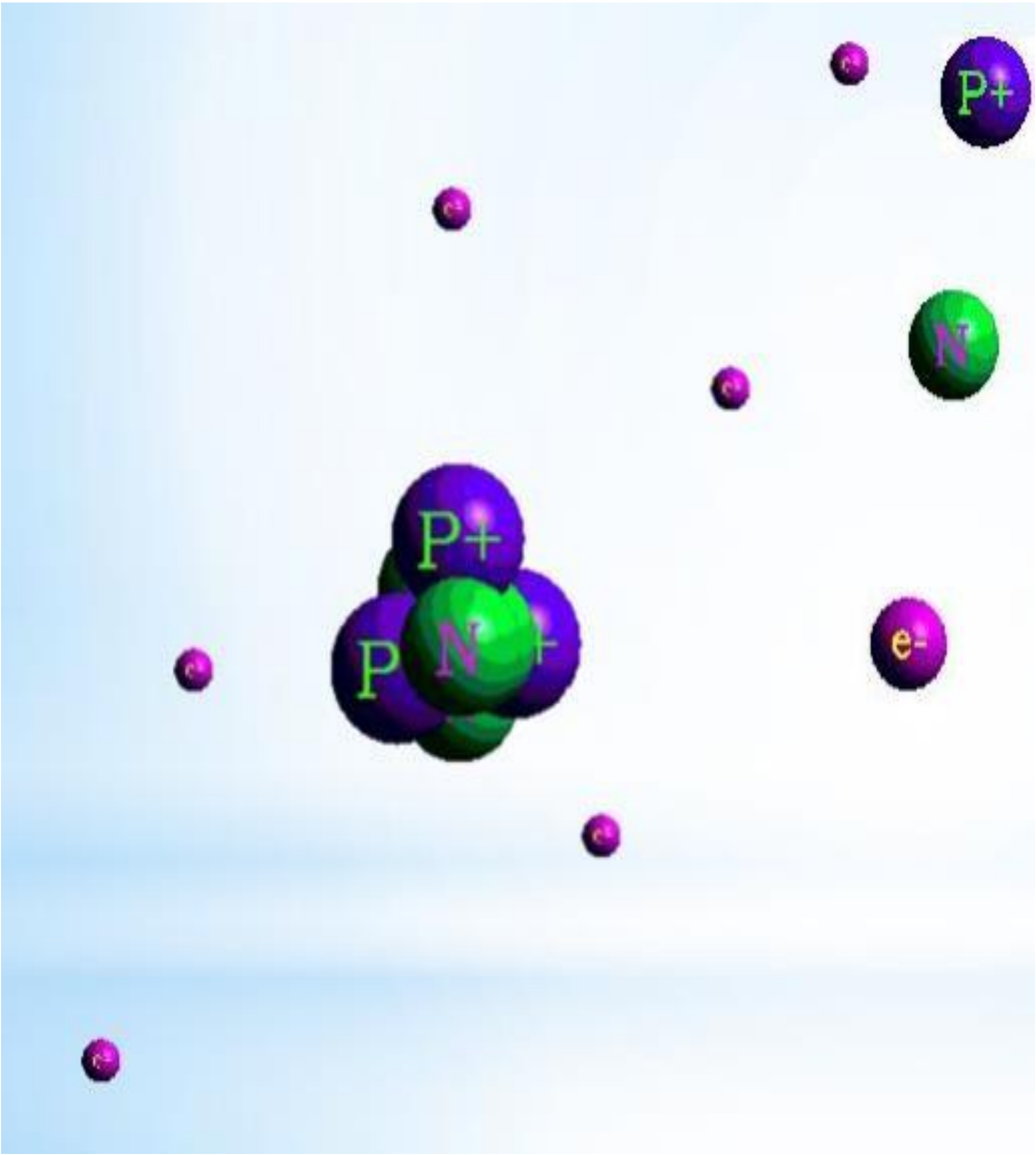
Atomic structure

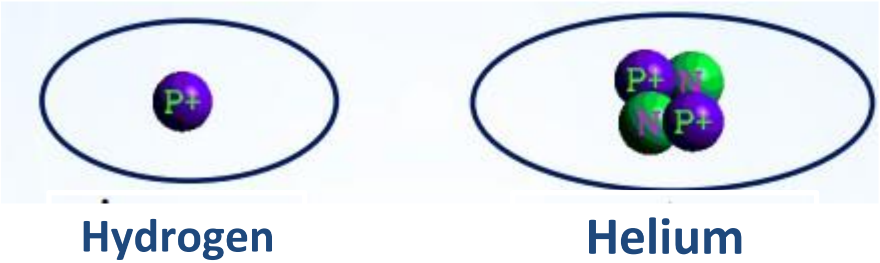


Protons (positive)

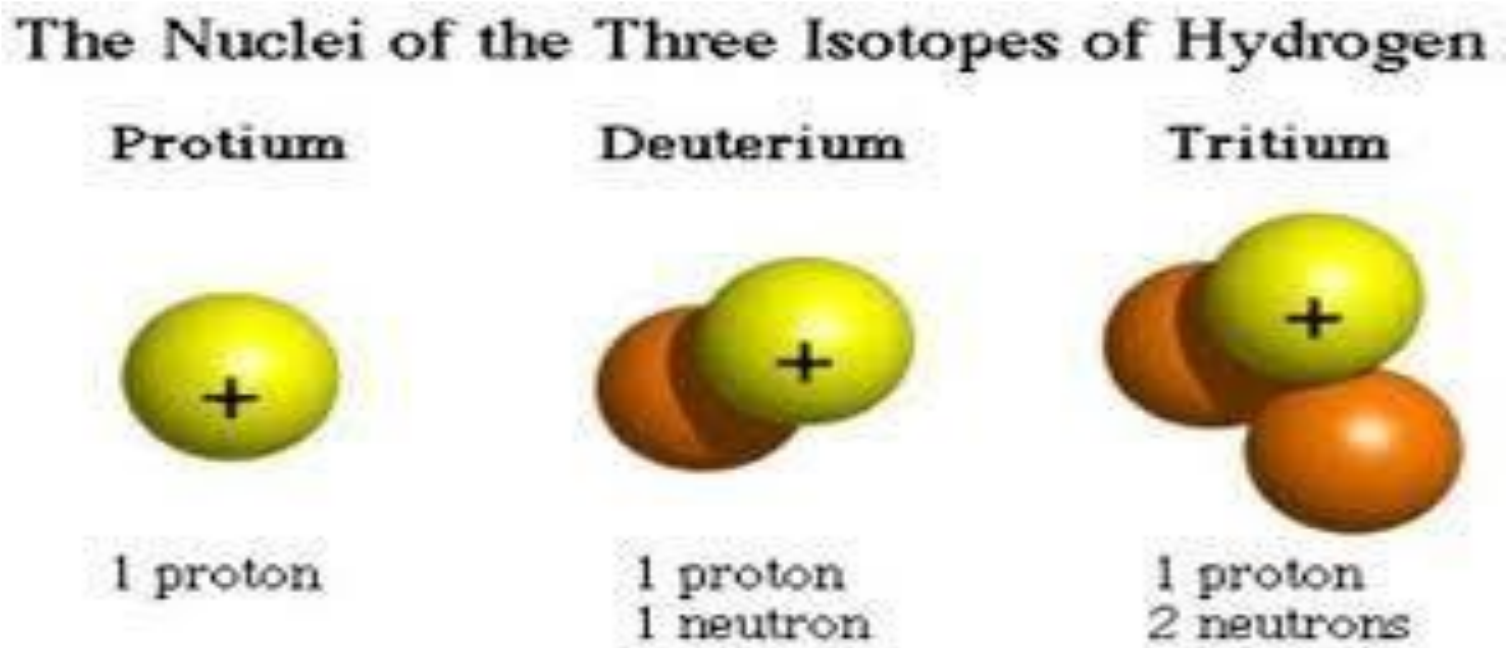
Neutrons (neutral)

Electrons (negative)

Elements: identified by number of protons

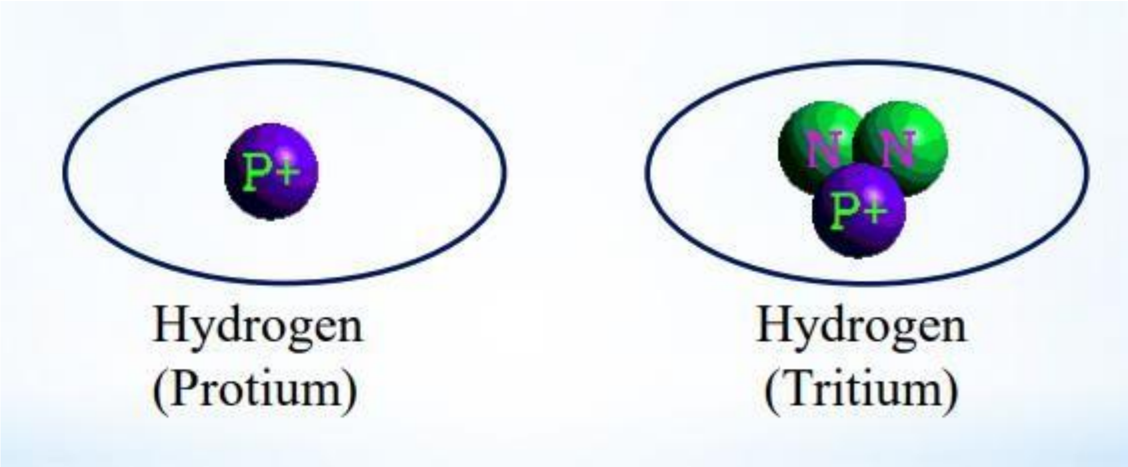


Nuclides that have the same number of protons but different numbers of neutrons are known as **isotopes**



Nuclear Stability and Instability

- If a large number of protons were forced together in a nucleus they would immediately explode due to electrostatic repulsion. Very short-range attractive forces are therefore required within the nucleus for stability, and these are provided by neutrons, uncharged particles with a mass almost identical to that of the proton.



Stability
Non-radioactive

Instability
Radioactive

1. Atomic and nuclear structure

1.1. Basic definitions

The atom is composed of a central nucleus surrounded by a cloud of negatively charged electrons. Most of the mass of the atom is concentrated in the atomic nucleus, which consists of Z protons and (A minus Z) neutrons, where Z is known as the atomic number and A the atomic mass number of the nucleus. the proton and neutron have nearly identical rest masses; the proton has a positive charge identical in magnitude to the negative electron charge, and the neutron has no charge. in a non-ionized atom, the number of electrons and number of protons are equal. the radius of an atom is about 0.1 nm, whereas the radius of the nucleus is much smaller, about 10^{-5} nm. Protons and neutrons are commonly referred to as nucleons; they have identical strong attractive interactions, and are bound in the nucleus with the strong force. in contrast to electrostatic and gravitational forces that are inversely proportional to the square of the distance between two particles, the strong force between two nucleons is a very short range force, active only at distances of the order of a few femtometres. At these short distances, the strong force is the predominant force, exceeding other forces by several orders of magnitude.

Some basic definitions and descriptions are as follows:

- Atomic number Z: number of protons and number of electrons in an atom.
- Atomic mass number A: number of protons Z plus number of neutrons N in an atom (A = Z + N).

The total number of protons and neutrons, collectively referred to as nucleons, within the nucleus is called the *mass number* , usually given the symbol A.

Each particular combination of Z and A defines a *nuclide*. The number of protons Z and element X.

1.2. Atomic structure

The modern quantum mechanical model of the atom is built on the work of many physicists. the idea of a dense central nucleus surrounded by orbiting electrons was first proposed by Rutherford in 1911. his model, however, being based on classical physics, had a number of unsatisfactory features. for example, it could not explain the observed emission spectra of the elements. bohr elaborated Rutherford's atomic model in 1913, based on classical, non-relativistic mechanics, by adding the concept of angular momentum quantization. his model is based on four postulates:

(i) electrons revolve about the Rutherford nucleus in well defined, allowed orbits (shells), the central attractive coulomb force of attraction between the electrons and the positively charged nucleus being balanced by the centripetal force arising from the orbital motion.

(ii) While in orbit, the electron does not lose any energy in spite of being constantly accelerated (this postulate is in contravention of classical physics, which predicts that an accelerated charged particle will lose energy in the form of radiation).

(iii) the angular momentum of the electron in an allowed orbit is quantized and only takes values of $n\hbar$, where n is an integer and $\hbar = h/(2\pi)$, where h is Planck's constant.

(iv) an atom or ion emits radiation when an electron makes a transition from an initial orbit with quantum number n_i to a final orbit with quantum number n_f for $n_i > n_f$. While the work of bohr was a major breakthrough, successfully explaining aspects of the behaviour of the hydrogen atom, the singly ionized helium atom and the doubly ionized lithium atom, etc., the story did not stop there. through the work of heisenberg, schrödinger, Dirac, Pauli and others, the theory of quantum mechanics was developed. in this theory, the electrons occupy individual energy states defined by four quantum numbers, as follows

● the principal quantum number, *n*, which can take integer values and specifies the main energy shell;

● the azimuthal quantum number, *l*, which can take integer values between 0 and n–1, and which specifies the total rotational angular momentum for the electron;

● the magnetic quantum number, *m*, which can take integer values between –l and +l and which specifies a component of the angular momentum;

● the spin quantum number, *s*, which takes values *–½ or +½* and specifies a component of the spin angular momentum of the electron. according to the Pauli exclusion principle, no two electrons can occupy the same state and it follows that the number of electron states that can share the same principal quantum number, n, is equal to $2n^2$

1.3 Radioactive Decay Processes

Three types of radioactive decay that result in the emission of charged particles will be considered at this stage.

1- **β– Decay**

A negative β particle is an electron. Its emission is actually a very complex process but it will suffice here to think of a change in the nucleus in which a neutron is converted into a proton. The particles are emitted with a range of energies. Note that although the process results in emission of electrons, it is a nuclear process and has nothing to do with the orbiting electrons. The mass of the nucleus remains unchanged but its charge increases by one, thus this change is favored by nuclides which have too many neutrons.

2- **β+ Decay**

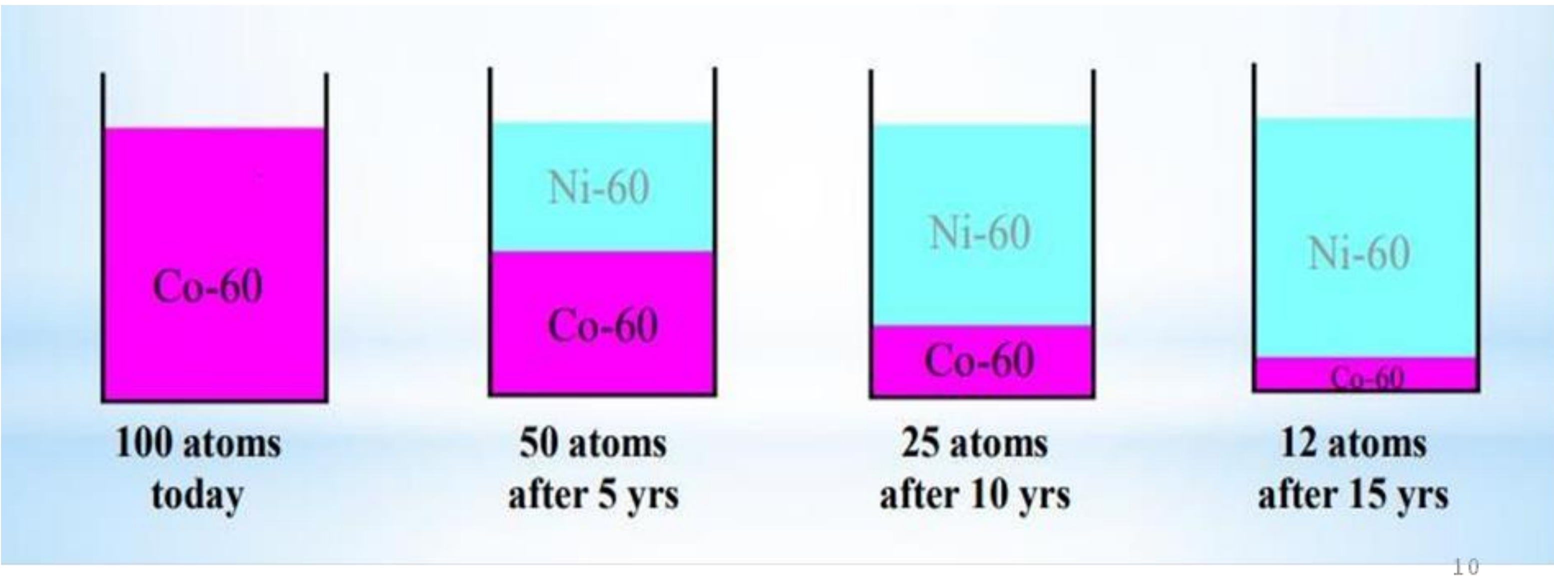
A positive β particle, or positron, is the anti- particle to an electron, having the same mass and an equal but opposite charge. Again, its precise mode of production is complex but it can be thought of as being released when a proton in the nucleus is converted to a neutron. Note that a positron can only exist while it has kinetic energy. When it comes to rest it spontaneously combines with an electron. The mass of the nucleus again remains unchanged but its charge decreases by one, thus this change is favoured by nuclides which have too many protons.

3- **α Decay**

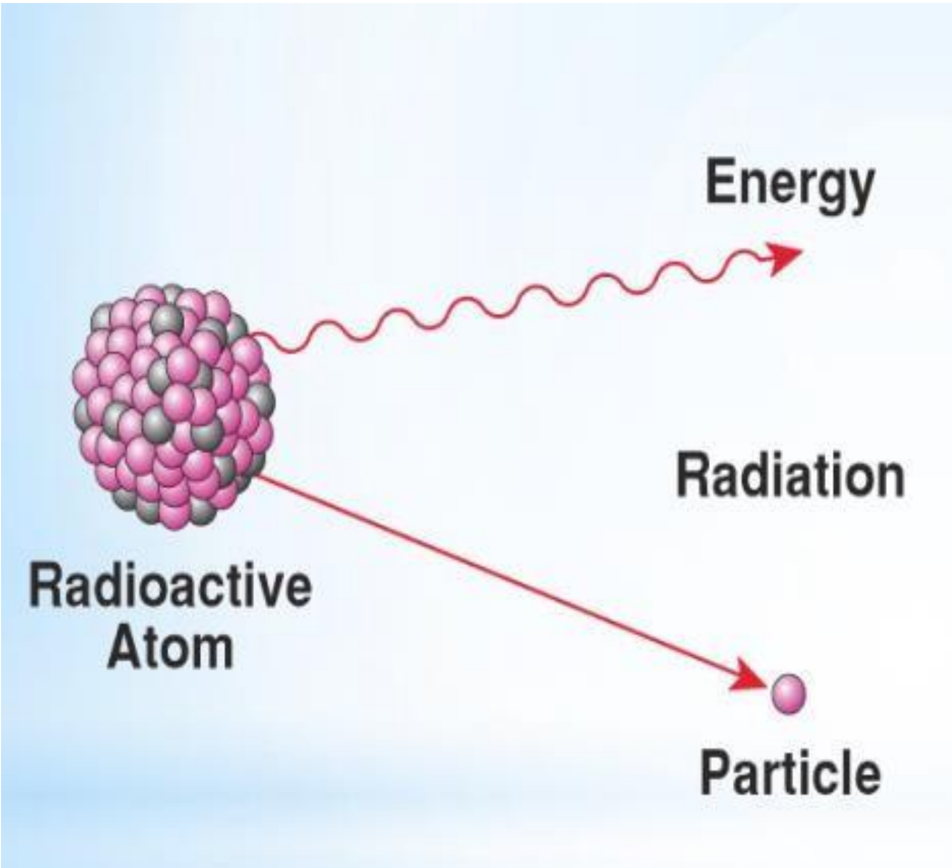
An α particle is a helium nucleus, thus it comprises two protons and two neutrons. After α emission, the charge is reduced by two units and the mass by four unit.

1.4 Half-Life

An important concept is the half-life or the time (T½) after which the activity has decayed to half its original valu



Radiation



Radiation is energy that moves from one place to another in a form that can be described as waves

1-5 Electromagnetic Spectrum

Is the movement of energy through space as a combination of electric and magnetic field. Electromagnetic (EM) radiation is classified by wavelength into radio, microwave, infrared, the visible region we perceive as light, ultraviolet, X-ray and gamma (γ) ray. The behavior of EM radiation depends on its wavelength. Higher frequencies have shorter wavelengths, and lower frequencies have longer wavelengths as shown in Figure Electromagnetic Spectrum. Radiation is emitted and absorbed in tiny "packets" called photons, the smallest unit of light. Photons are emitted when electrons in an atom jump from one orbit to another.

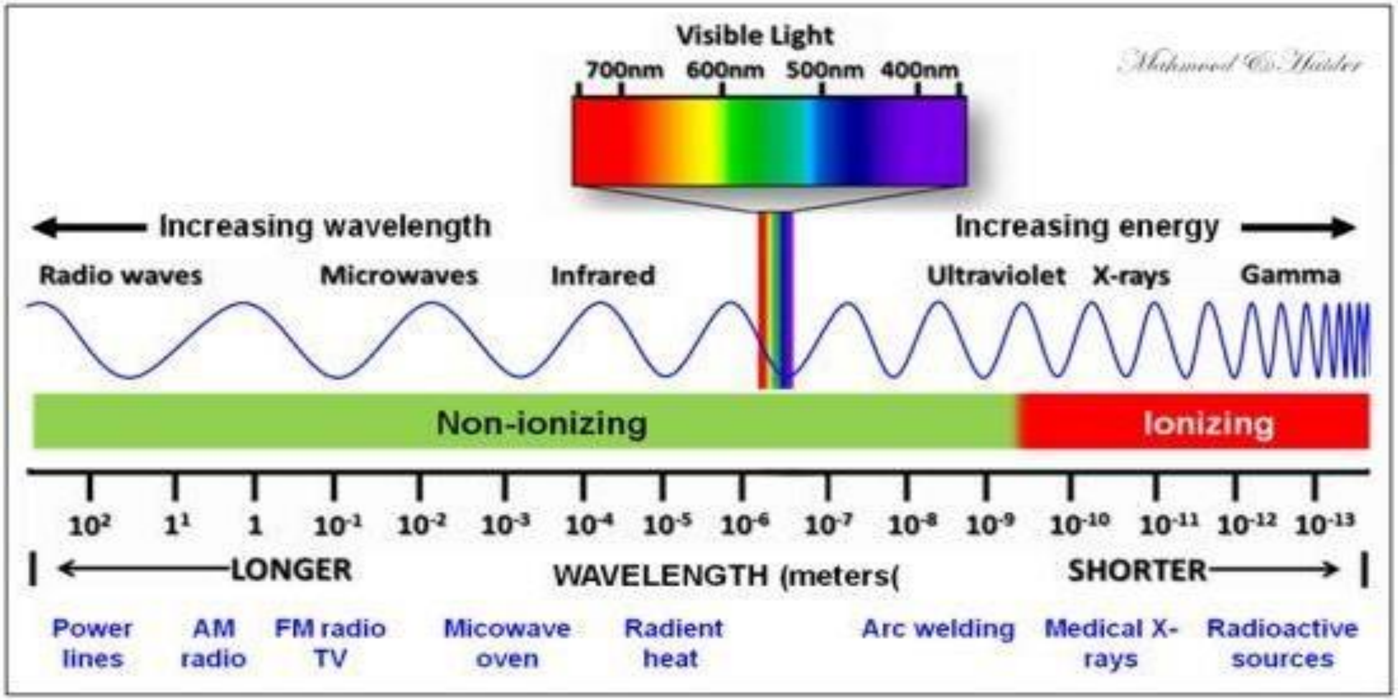
The speed for all electromagnetic waves is a constant, usually denoted by c, and in which case:

$c = \lambda\nu$ ………………………….(1.1)

for X rays, wavelength is usually expressed in nanometres (nm) (1 nm = 10^{-9} m) and frequency is expressed in hertz (hz) (1 hz = 1 cycle/s = $1s^{-1}$). When interactions with matter are considered, electromagnetic radiation is generally treated as series of individual particles, known as photons. the energy of each photon is given by:

$E = h\nu$ …………………………….(1.2)

where the constant h is known as Planck’s constant. in diagnostic radiology, the photon energy is usually expressed in units of keV, where 1 electronvolt (eV) is the energy received by an electron when it is accelerated across of a potential difference of 1 V.



Electromagnetic Spectrum

1-6 Particulate radiation

in diagnostic radiology, the only particulate radiation that needs to be considered is the electron. this has a rest mass of 9.109×10^{-31} kg and a rest energy of 511 keV.

1-7 Classification of Radiation:

Radiation is classified as ionizing or non-ionizing, depending on its ability

to ionize matter:

- non-ionizing radiation cannot ionize matter.
- ionizing radiation can ionize matter, either directly or indirectly:

1- Directly ionizing radiation: fast charged particles that deposit their energy in matter directly, through many small coulomb (electrostatic) interactions with orbital electrons along the particle track.

2- In directly ionizing radiation: X or gamma ray photons or neutrons that first transfer their energy to fast charged particles released in one or a few interactions in the matter through which they pass. the resulting fast charged particles then deposit their energy directly in the matter.

The minimum energy required to ionize an atom, i.e. to remove an electron, is known as the **ionization potential**. for elements, its magnitude ranges from a few electronvolts for alkali metals to 24.5 eV for helium. for water, it is 12.6 eV. electromagnetic radiation of frequency higher than the near-ultraviolet region of the electromagnetic spectrum is ionizing, whereas electromagnetic radiation with energy below the far-ultraviolet region (e.g. visible light, infrared and radiofrequency) is non-ionizing.

1-8 Diagnostic Radiology

Diagnostic and interventional radiology is a medical specialty that uses different types of readings in medical imaging to diagnose and treat diseases. There are many types of radiation used such as: regular rays (or X-rays), CT scans, ultrasound, magnetic resonance imaging, and medicine (the use of radioactive materials). These rays may be used in interventional medicine (inside the body) to diagnose or treat some diseases.

1-9 Diagnostic radiology uses

Diagnostic radiology has many uses, including:

- X-ray imaging of an injured body is used to determine whether there are scratches, fractures, or sprains in the bones as a result of the injury. Therefore, this type of imaging is very useful to doctors in determining the exact location of the injury and treating it.
- Ultrasound imaging also helps in knowing the growth of the fetus.
- CT scans are used to determine the incidence of cerebral hemorrhage or clots.

H.W

1. Isotopes are……

a. Nuclides that have the same number of neutrons but differentnumbers of protons

b. Nuclides that have the same number of protons but differentnumbers of neutrons

c. Nuclides that have the same number of electrons but different numbers of neutrons

d. number of protons

2. …….. are used to determine the incidence of cerebralhemorrhage or clots.

a. X. Ray b. Ultrasound imaging c. MRI d. CT scans

3. ………is a helium nucleus, thus it comprises two protons andtwo neutrons.

a. Beta particle b. Neutron particle c. Alpha particle d. None of them

4. in diagnostic radiology, the only particulate radiation that needs to be considered is the electron. this has a rest mass of ……………

a. 9.109 × 10–31 kg b. 511 kev c. 9.109 × 10–19 kg d. 1.7 × 10–27 kg


Thank you