Physics 105

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Chapter -31-
(Nuclear Energy; Effects and Uses of Radiation)

❖ Section (31.4): **Passage of Radiation Through Matter; Biological Damage**

- Radiation: includes *alpha*, *beta*, and *gamma rays*; *X-rays*; along with protons, neutrons, pions, and other particles.
  - These are collectively referred to as ***ionizing radiation*** because they ionize the materials they pass through. Although **X-rays** are a form of radiation, they are not classified as nuclear radiation, as they do not originate from the nucleus.
  - Instead, X-rays are emitted during transitions of electrons between atomic energy levels.

- Both nuclear radiation and X-rays are classified as ***ionizing radiation*** because they ionize atoms by creating free electrons and positive ions as they travel through matter.
  - **Biological Damage:**
    - ✓ Radiation primarily **causes damage to biological cells through ionization**.
    - ✓ The free electrons and positive ions generated by radiation can disrupt normal cellular functions, such as important chemical reactions. Ionization, which knocks electrons off atoms and molecules, can break molecular bonds and alter molecular structures, leading to interference with the cell's regular activities. Radiation can also damage DNA, and each change to the DNA may affect a gene, altering the molecule it encodes.

❖ Section (31.5): **Measurement of Radiation - Dosimetry**

- Another important measurement is the ***absorbed dose***, which reflects the effect radiation has on the material that absorbs it. Dosimetry is used to quantify the amount or dose of radiation received.

$$\textbf{Dose} = \frac{energy}{mass}$$

- The definition of exposure is limited to specific radiation types, such as X-rays and gamma (γ) radiation, and applies to situations where energy is deposited in air. Exposure is measured in units of Roentgen (R), with 1 R equal to 0.878×10^{-2} joules of energy per kilogram of air.
- ***The Roentgen*** has largely been replaced by the rad, a unit of absorbed dose that applies to any type of radiation.
  - One rad is equivalent to 1.0×10^{-2} joules per kilogram (J/kg).
  - The SI unit for absorbed dose is the gray (Gy), where **1 Gy equals 1 J/kg**, which is also **equal to 100 rad**.

TABLE 31–1 Relative Biological Effectiveness (RBE)

Type	RBE
X- and γ rays	1
β (electrons)	1
Protons	2
Slow neutrons	5
Fast neutrons	≈10
α particles and heavy ions	≈20

- The effective dose is expressed as the product of the dose in rads and the relative biological effectiveness (RBE), measured in ***rems.***
  - This unit has been replaced by the SI unit for ***effective dose***, the Sievert (Sv), where **1 Sv equals 100 rem**.
  - The **formula** for effective dose is as follows:
    - Effective dose (in **rem**) = **dose (in rad) × RBE**
    - Effective dose (in **Sv**) = **dose (in Gy) × RBE, where 1 Sv = 100 rem**

- RBE, or relative biological effectiveness: is defined as the number of rads of X-rays or gamma radiation that cause the same biological damage as 1 rad of the radiation being measured and it has no units.

- Natural background radiation is approximately 0.3 rem per year. For radiation workers, the maximum allowable exposure is 5 rem in a single year, with an average of less than 2 rem per year over a 5-year period. A short-term exposure of 1000 rem is almost always fatal, while a short-term dose of 400 rem has a 50% fatality rate.

✓ ***Example:*** 350 rads of α-particle radiation is equivalent to how many rads of X-rays in terms of biological damage? (RBE for α-particle = 20 , RBE for X-rays = 1)

✓ ***Solution:***

Equivalent that's mean:

Effective dose for α-particle = Effective dose for X-rays

Dose * RBE = Dose * RBE

3500 = Dose * 1

Dose = 7000 rads

✓ ***Example:*** How much energy is deposited in the body of a 65-kg adult exposed to a 2.5-Gy dose?

✓ ***Solution:***

Dose = $\frac{energy}{mass}$

2.5 Gy = $\frac{energy}{65\ kg}$

Energy = 162.5 J (Gy .kg)

✓ ***Example:*** What whole-body dose is received by a 70-kg laboratory worker exposed to a 40-mCi $^{60}_{27}Co$ source, assuming the person's body has cross-sectional area 1.5 m^2 and is normally about 4.0 m from the source for 4.0 h per day? $^{60}_{27}Co$ emits ɤ rays of energy 1.33 MeV and 1.17 MeV in quick succession. Approximately 50% of the ɤ rays interact in the body and deposit all their energy. (The rest pass through.)

✓ ***Solution:***

The total ɤ ray energy per decay:

(1.33 + 1.17) MeV = 2.50MeV ,

So the total energy emitted by the source per second is:

(0.040Ci) ($3.7*10^{10}$ decays/Ci.s) (2.50MeV) = $3.70*10^9$MeV/s

The proportion of this energy intercepted by the body is its 1.5 m^2 area divided by the area of a sphere of radius 4.0 m

$$\frac{1.5m^2}{4\pi r^2} = \frac{1.5m^2}{4\pi(4m)^2} = 7.5 * 10^{-3}$$

So the rate energy is deposited in the body (remembering that only 50 % of the ɤ rays interact in the body) is:

E = (0.5) ($7.5*10^{-3}$)($3.7*10^9$MeV/s)($1.6*10^{-13}$J/MeV) = $2.2 *10^{-6}$ J/s

1Gy = 1J/kg so

Dose = $\frac{2.2*10^{-6}}{70} = 3.1 * 10^{-8} Gy/s$

In 4 h this amount to a dose of:

(4 h *3600 s/h) ($3.1*10^{-8}$ Gy/s) = $4.5*10^{-4}$ Gy

❖ Section (31.6): Radiation Therapy

- Radiation therapy: is ***a medical treatment*** that uses ionizing radiation to target and destroy cancer cells. It is one of the most common and effective treatments for cancer, often used alone or in combination with other treatments like surgery or chemotherapy.

❖ Section (31.8): Emission Tomography PET and SPECT

- Radioactive *tracers can be detected* using tomographic techniques that create a three-dimensional image through multiple scans.
  - ➢ This process is called single photon emission computed tomography (**SPECT**), or simply single photon emission tomography (**SPET**). Another important imaging method is positron emission tomography (**PET**).

❖ Section (31.9): Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging

- Nuclear magnetic resonance (NMR): is a ***phenomenon*** which soon after its discovery in 1946 became a powerful research tool in a variety of fields from physics to chemistry and biochemistry.
  - ➢ It is also an important medical imaging technique.

- Magnetic Resonance Imaging (MRI): is *a non-invasive* medical imaging technique used to produce detailed images of the internal structures of the body.
  - ➢ It operates by using strong magnetic fields, radio waves, and a computer to generate high-resolution, cross-sectional images of organs, tissues, and other internal body structures.

- **How it Works:**
  1. Magnetic Field: (NMR) relies on the fact that certain atomic nuclei, such as hydrogen (^1H), behave like tiny magnets due to their spin. When placed in a strong magnetic field, these nuclei align with or against the field.
  2. Radio Frequency (RF) Pulse: A radio frequency pulse is then applied, causing some of the nuclei to absorb energy and flip their orientation.
  3. Relaxation and Signal Detection: When the pulse is turned off, the nuclei relax back to their original state, releasing the absorbed energy.
     - ✓ This energy is detected as a signal, which can be analyzed to determine the molecular structure

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- It has many **Applications** like Medicine:
  - ➢ In medical imaging, a *version of* NMR called Magnetic Resonance Imaging (**MRI** is used to produce detailed images of organs and tissues in the body.)

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