Chapter 31
Ionizing Radiation

Ionizing radiation consists of products of nuclei decay and includes alpha, beta, and gamma rays; X rays; and protons, neutrons, pions, and other particles.

All these forms of radiation are called ionizing radiation, because they ionize material that they go through.

This ionization can cause damage to materials, including biological tissue.

Energy Loss Rate

The energy ΔK lost per unit distance by an ion with mass *m*, charge *q* and kinetic energy *K* is given by

$$\Delta K \propto \frac{-mq^2}{2K}$$

(provided that the speed of the ion is far smaller than the speed of light)

Positive Ions

❖Alpha particles

They can travel about 4 cm in air, but cannot penetrate a sheet of paper or a layer of skin.

They ionize the matter and get two electrons so they become neutral helium atoms.

They are heavy so they are not deflected in collisions and their path is a straight line

Since they have large mass lose energy rapidly and come to rest in short distance.

❖Protons

Example 31.1

Compare the rates of energy loss in a given material for protons and alpha particles having the same initial kinetic energies (assume $v \ll c$)

Electrons and positrons

Electrons and positrons are products of beta decay and have far larger ranges than alpha particles because of their far smaller mass.

Because of their small mass the get large deflection in each collision and they do not travel in a straight line.

Positrons when they slow down close to an electron they annihilate, producing gamma rays.

Photons

Gamma rays and X-rays are both electromagnetic photons or quanta.

Gamma rays are produced in nuclei while X-rays are produced in atoms. This is why gamma range typically have more energy.

Photons do not ionize directly. They interact with electrons and the electrons cause ionization. Consequently they have a long range in matter. For example, a 1-MeV photon in water has a mean range of roughly 10 cm.

Photons transfer energy to electrons by three processes:

- At energies below 0.1 MeV by the ***photoelectric effect***.
- At energies about 1 MeV by the ***Compton's scattering***.
- At higher energies by the transformation of a photon into an electron-positron pair.

Neutrons

Neutrons do not have charge and produce ionization only indirectly.

They interact primarily with the nucleus and not with the electrons, thus they have a very long range in matter. For example, neutrons with energies of a few million eV may travel a metre or so in water or in animal tissues.

When neutrons are slowed down (by elastic scattering from nuclei or by nuclear reactions) they have a high probability of being captured by the nucleus which is often followed by gamma-ray emission.

Summary

Radiation produced by radioactive nuclei ionize the matter

Ionizing radiation may consist of charged particles or photons

The energy lost with distance by the ionizing radiation is proportional to the mass of its particles for a given kinetic energy.

Massive particles lose energy rapidly so they have short range in matter.

Quizz- Radiation Shielding

Which type of radiation goes farther in matter before losing all of its energy ?

1) alpha radiation
2) beta radiation
3) gamma radiation
4) all about the same distance

Quizz- Radiation Damage

Radiation can damage matter such as metals or biological tissue by:

1) heating up the material
2) causing cancer in the metal
3) producing fission reactions in the material
4) removing electrons from the atoms
5) producing fusion reactions in the material

31.2 Measurement of Radiation – Dosimetry

Four types of radiation measurements are used in various applications:

- Source activity
- Exposure
- Absorbed dose
- Biologically equivalent dose

The source activity

The source activity *A* is defined as the rate of decrease in the number of radioactive nuclei present.

The activity is related to the half-life of a sample:

$$A = \lambda N = \frac{0.693}{T} N$$

❖The SI source activity unit is the *becquerel* (Bq), which is 1 disintegration per second.

$$1 \text{ Bq} = 1 \text{ disintegration/s}$$

❖Another unit is the *curie* (Ci), which is defined as:

$$1 \text{ Ci} = 3.70 \times 10^{10} \text{ disintegrations per second}$$

Example 31.2

Cobalt decays into Ni with a half-life of 5.27 years. What is the mass of a cobalt source of activity equal to 1000 Ci?

Exposure

Exposure is defined as the amount of ionization produced in a unit mass of dry air at standard temperature and pressure (STP), 1 atmosphere and 0 Celsius. The unit of exposure is the *roentgen* (R):

$$1 \text{ R} = 2.58 \times 10^{-4} \text{ coulomb per kilogram}$$

Exposure is defined only for X rays and gamma rays with energies up to 3 MeV and not for other types of radiation. Thus 1 R of X rays will produce 2.58×10^{-4}

of positive ions in a kilogram of air at STP, and an equal amount of negative ions.

Absorbed Dose

The absorbed dose is the energy imparted by ionizing radiation to a unit mass of absorbing tissue.

The SI unit for adsorbed dose is the one *gray* (Gy), which is defined as 1 joule per kilogram.

Another unit is the one *rad,* which is defined as 0.01 joule per kilogram. Thus 1 Gy = 100 rad.

Absorbed dose is used with all kinds of ionizing radiation.

Example 31.3

Living tissues exposed to 10,000 rads are completely destroyed. By how much will this absorbed dose raise the temperature of the tissues if none of the heat is lost? (Assume that the specific heat of the tissue is the same as that of the water, $c = 4180$ J/(kg*K)).

Biological Quantities I

The effects of radiation on biological systems depends on the type of radiation and its energy.

Each radiation has a quality factor (QF) associated with it. This factor is defined by comparing its effect to those of a standard kind of radiation, which is usually taken to be 200-keV X rays.

For example, fast neutrons have a quality fator equal to 10 for causing cataracts. This means that the dose of 200-keV X rays needed to produce cataracts is 10 times the dose required for neutrons.

The QF varies with animal species and the biological effect under consideration.

Biological Quantities II

The units used in discussion of biological effects are: In SI system the *sievert* (Sv) and the *rem* and the millirem (0.001 rem).

The *biologically equivalent dose* in SI units (sieverts) is given by the product of the physical absorbed dose in grays times the QF.

The *biologically equivalent dose* in rems is given by the product of the physical absorbed dose in rads times the QF.

Example 31.4

A cancer is irradiated with 100 rads of Co gamma rays, which have QF of 0.7. Find the exposure in roentgens and the biologically equivalent dose in rems.

Example 31.5

A laboratory experiment in a physics class uses a 10 microcurie Cs source. Each decay emits a 0.66 MeV gamma ray. (a) How many decays occur per hour? (b) A 60 kg student standing nearby absorbs 10% of the gamma rays. What is her absorbed dose in rads in 1 hour? (c) the QF is 0.8. Find her biologically equivalent dose in rems.

Summary

Radiation damage is measured using dosimetry

Effect of absorbed dose depends on type of radiation

Homework

31.14, 31.16, 31.17, 31.23, 31.29, 31.47