

$\alpha$  particles are heavy and positively charged, being equivalent to the nuclei of helium atoms. They travel relatively slowly in air and although they cause a great deal of ionization along their paths, they have very little penetrating power, their range being just a few centimetres in air.  $\alpha$  particles cannot penetrate skin but may cause damage when emitted by radio-nuclides inserted into the body.  $\beta$  particles are negatively charged and have the same mass as an electron. In air the penetrating power of these particles is a few metres but they will be stopped by a thin sheet of aluminium.  $\beta$  particles resulting from radioactive decay are therefore not sufficiently penetrative for use in sterilization processes, but the production of accelerated electrons from man-made machines (cathode rays) results in particles of great energy with enhanced penetrating power.

## Electromagnetic radiation

$\gamma$  radiation results when the nucleus still has too much energy even after the emission of  $\alpha$  or  $\beta$  particles. This energy is dissipated in the form of very short wavelength radiation which, as it has no mass or charge, travels with the speed of light, penetrating even sheets of lead. Although travelling in a wave form,  $\gamma$  radiation behaves as if composed of discrete packets of energy called quanta (photons). A  $^{60}\text{Co}$  source emits  $\gamma$ -rays with photons of 1.17 and 1.33 MeV and the source has a half-life of 5.2 years. X-rays are generated when a heavy metal target is bombarded with fast electrons. They have similar properties to  $\gamma$ -rays despite originating from a shift in electron energy rather than from the nucleus.

### Units of radioactivity

The unit of activity is the becquerel (Bq), which is equal to one nuclear transformation per second. This replaces the term *curie* (Ci);  $3.7 \times 10^{10}$  becquerels = 1 curie. The unit of absorbed dose according to the SI system is the gray (Gy), which is equal to one joule per kilogram. However, the old term 'rad' is still used occasionally and is equivalent to 100 ergs per gram of irradiated material.

$$1 \text{ gray} = 100 \text{ rads}$$

The energy of radiation is measured in electron volts (eV) or millions of electron volts (MeV). An electron volt is the energy acquired by an electron falling through a potential difference of 1 volt.

## Effect of ionizing radiations on materials

Ionizing radiations are absorbed by materials in a variety of ways, depending upon the energy of the incident photons:

1. *Photoelectric effect*: low-energy radiation (<0.1 MeV) is absorbed by the atom of the material, resulting in the ejection or excitation of an electron.
2. *Compton effect*: incident photons of medium energy 'collide' with atoms and a portion of the energy is absorbed with the ejection of an electron. The remaining energy carries on impacting with further atoms and emitting further electrons until all the energy is scattered.
3. *Pair production*: radiations of very high energy are converted on impact into negatively charged electrons and positively charged particles called positrons. The positron has an extremely short life and quickly annihilates itself by colliding with an orbital electron.

The ionization caused by the primary radiation results in the formation of free radicals, excited atoms, etc., along a discrete track through the material. However, if secondary electrons contain sufficient energy they may cause excitation and ionization of adjacent atoms, thereby effectively widening the track. Accelerated electrons used in electron beam sterilizers are essentially equivalent to the secondary electrons arising from  $\gamma$  irradiation – they cause direct ionization of molecules within materials. Temperature rise during irradiation is very small and even high-energy radiation resulting in pair production is only accompanied by an increase of approximately 2 °C, but nevertheless, the chemical changes that occur in irradiated materials are very widespread. Of particular significance here are the deleterious changes that may occur in packaging materials at normal dosage levels. Such effects may include changes in tensile strength, colour, odour and gas formation of polymers. Materials most affected include acetal, FEP, PTFE and PVA. Total absorbed energy determines the extent of physical and chemical reactions that occur, and so damage is cumulative. For sterilization purposes, exposure times can be long but the process is predictable and delivers a reproducible level of lethality.

The lethal effect of irradiation on microorganisms can occur in two ways: