

Section Summary

32.1 Diagnostics and Medical Imaging

- Radiopharmaceuticals are compounds that are used for medical imaging and therapeutics.
- The process of attaching a radioactive substance is called tagging.
- Table 32.1 lists certain diagnostic uses of radiopharmaceuticals including the isotope and activity typically used in diagnostics.
- One common imaging device is the Anger camera, which consists of a lead collimator, radiation detectors, and an analysis computer.
- Tomography performed with γ -emitting radiopharmaceuticals is called SPECT and has the advantages of x-ray CT scans coupled with organ- and function-specific drugs.
- PET is a similar technique that uses β^+ emitters and detects the two annihilation γ rays, which aid to localize the source.

32.2 Biological Effects of Ionizing Radiation

- The biological effects of ionizing radiation are due to two effects it has on cells: interference with cell reproduction, and destruction of cell function.
- A radiation dose unit called the rad is defined in terms of the ionizing energy deposited per kilogram of tissue:
 - $1 \text{ rad} = 0.01 \text{ J/kg}$.
- The SI unit for radiation dose is the gray (Gy), which is defined to be $1 \text{ Gy} = 1 \text{ J/kg} = 100 \text{ rad}$.
- To account for the effect of the type of particle creating the ionization, we use the relative biological effectiveness (RBE) or quality factor (QF) given in Table 32.2 and define a unit called the roentgen equivalent man (rem) as
 - $\text{rem} = \text{rad} \times \text{RBE}$.
- Particles that have short ranges or create large ionization densities have RBEs greater than unity. The SI equivalent of the rem is the sievert (Sv), defined to be
 - $\text{Sv} = \text{Gy} \times \text{RBE}$ and $1 \text{ Sv} = 100 \text{ rem}$.
- Whole-body, single-exposure doses of 0.1 Sv or less are low doses while those of 0.1 to 1 Sv are moderate, and those over 1 Sv are high doses. Some immediate radiation effects are given in Table 32.4. Effects due to low doses are not observed, but their risk is assumed to be directly proportional to those of high doses, an assumption known as the linear hypothesis. Long-term effects are cancer deaths at the rate of $10/10^6 \text{ rem} \cdot \text{y}$ and genetic defects at roughly one-third this rate. Background radiation doses and sources are given in Table 32.5. World-wide average radiation exposure from natural sources, including radon, is about 3 mSv, or 300 mrem.

Radiation protection utilizes shielding, distance, and time to limit exposure.

32.3 Therapeutic Uses of Ionizing Radiation

- Radiotherapy is the use of ionizing radiation to treat ailments, now limited to cancer therapy.
- The sensitivity of cancer cells to radiation enhances the ratio of cancer cells killed to normal cells killed, which is called the therapeutic ratio.
- Doses for various organs are limited by the tolerance of normal tissue for radiation. Treatment is localized in one region of the body and spread out in time.

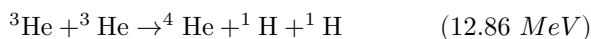
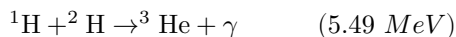
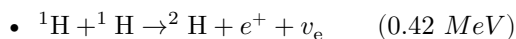
32.4 Food Irradiation

- Food irradiation is the treatment of food with ionizing radiation.
- Irradiating food can destroy insects and bacteria by creating free radicals and radiolytic products that can break apart cell membranes.
- Food irradiation has produced no observable negative short-term effects for humans, but its long-term effects are unknown.

32.5 Fusion

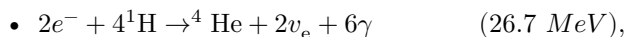
- Nuclear fusion is a reaction in which two nuclei are combined to form a larger nucleus. It releases energy when light nuclei are fused to form medium-mass nuclei.

- Fusion is the source of energy in stars, with the proton-proton cycle,



being the principal sequence of energy-producing reactions in our Sun.

- The overall effect of the proton-proton cycle is



where the 26.7 MeV includes the energy of the positrons emitted and annihilated.

- Attempts to utilize controlled fusion as an energy source on Earth are related to deuterium and tritium, and the reactions play important roles.
- Ignition is the condition under which controlled fusion is self-sustaining; it has not yet been achieved. Break-even, in which the fusion energy output is as great as the external energy input, has nearly been achieved.

- Magnetic confinement and inertial confinement are the two methods being developed for heating fuel to sufficiently high temperatures, at sufficient density, and for sufficiently long times to achieve ignition. The first method uses magnetic fields and the second method uses the momentum of impinging laser beams for confinement.

32.6 Fission

- Nuclear fission is a reaction in which a nucleus is split.
- Fission releases energy when heavy nuclei are split into medium-mass nuclei.
- Self-sustained fission is possible, because neutron-induced fission also produces neutrons that can induce other fissions, $n + {}^A_ZX \rightarrow \text{FF}_1 + \text{FF}_2 + xn$, where FF_1 and FF_2 are the two daughter nuclei, or fission fragments, and x is the number of neutrons produced.
- A minimum mass, called the critical mass, should be present to achieve criticality.
- More than a critical mass can produce supercriticality.
- The production of new or different isotopes (especially ${}^{239}\text{Pu}$) by nuclear transformation is called breeding, and reactors designed for this purpose are called breeder reactors.

32.7 Nuclear Weapons

- There are two types of nuclear weapons—fission bombs use fission alone, whereas thermonuclear bombs use fission to ignite fusion.
- Both types of weapons produce huge numbers of nuclear reactions in a very short time.
- Energy yields are measured in kilotons or megatons of equivalent conventional explosives and range from 0.1 kT to more than 20 MT.
- Nuclear bombs are characterized by far more thermal output and nuclear radiation output than conventional explosives.