Radioactivity

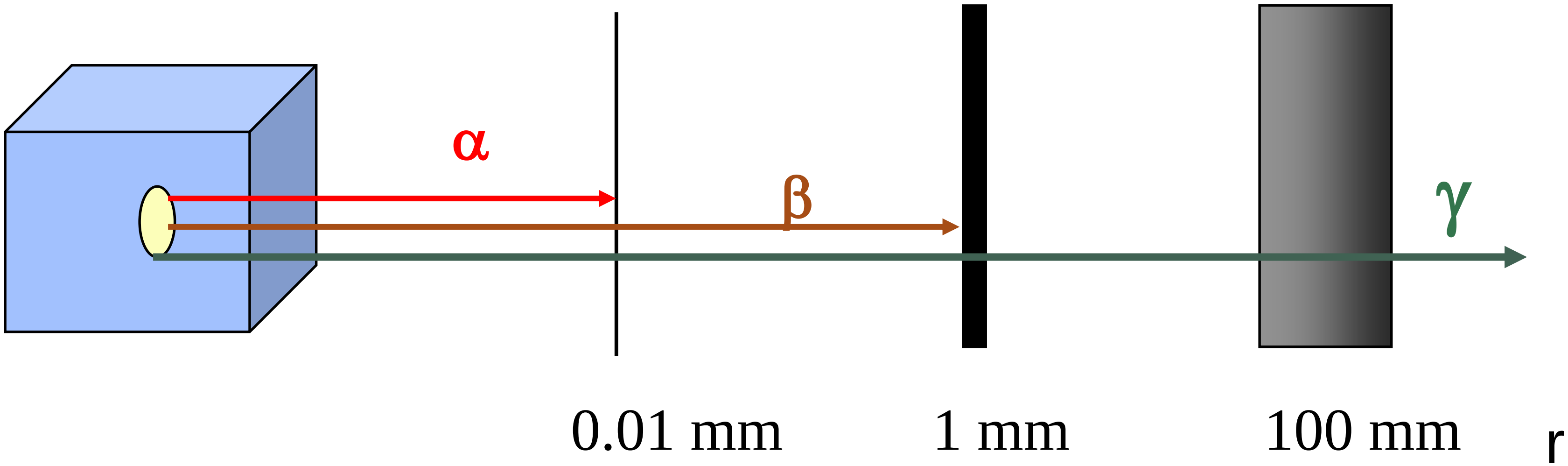
- **Radionuclides (**unstable nuclei) change or decay spontaneously, **emitting radiation**. They are said to be **radioactive**.
- Several ways for radionuclides decay into a different nuclide..

Most Common Kinds of Radiation Emitted by a Radionuclide

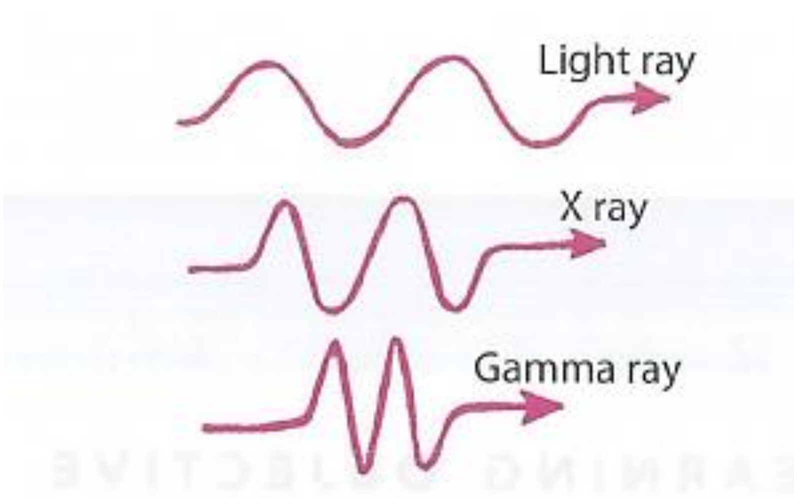
TABLE 21.1 Properties of Alpha, Beta, and Gamma Radiation

	Type of Radiation		
Property	α	β	γ
Charge	2+	1−	0
Mass	6.64×10^{-24} g	9.11×10^{-28} g	0
Relative penetrating power	1	100	10,000
Nature of radiation	${}^{4}_{2}$He nuclei	Electrons	High-energy photons

Penetrating Ability of Radioactive Rays



Pieces of Lead



Gamma ray is much higher in frequency and energy than UV-vis light and X-rays.

Radiation Dose

Two units are commonly used to measure exposure to radiation:

- **Gray (Gy)**, absorption of **1 J of energy per kg of tissue**
- **Rad** (***r***adiation ***a***bsorbed ***d***ose) = **0.01 Gy,** corresponds to the absorption of 0.01 J/kg of tissue

Not all forms of radiation harm tissue equally, the radiation dose is multiplied by **a factor that measures the relative damage caused by the radiation**, **Relative Biological Effectiveness (RBE).**

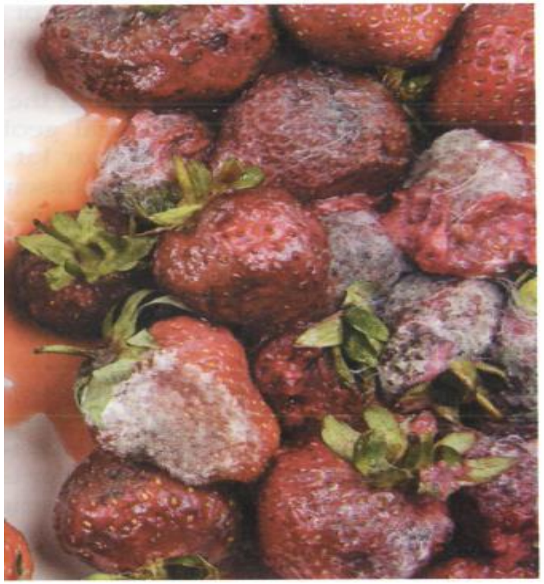
The RBE is approximately

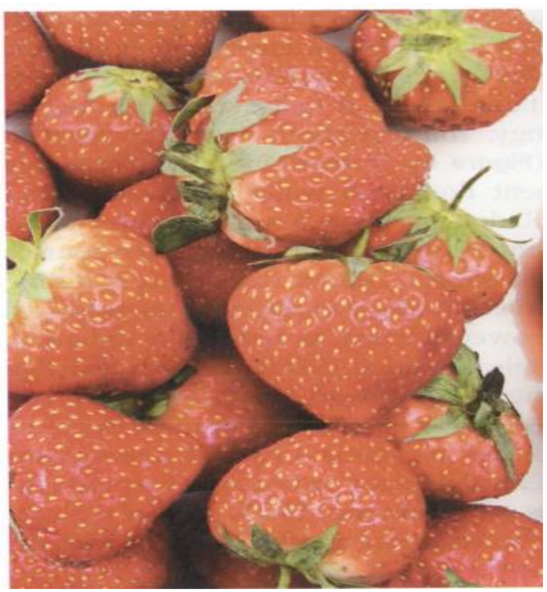
1 for γ and β radiation and **10 for α** radiation.

Food irradiation

1958 World first commercial food irradiation (spices) at Stuttgart, Germany

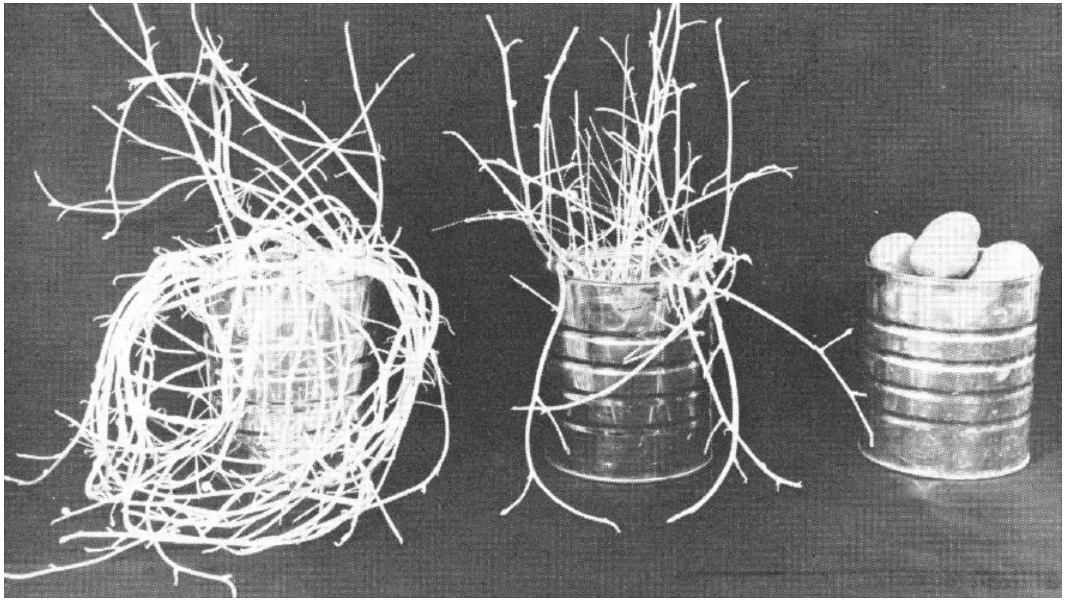
Most irradiated food is processed by gamma irradiation from radioisotope.





Gamma Radiation Effects on Fruits and Vegetables[1,2]

Several million dollars are lost in the United States each year as a result of post harvest diseases of crops. Claim costs to railroads alone in 1958 amounted to $11 million. This work demonstrates that it is possible to extend the shelf-life of fresh fruits and vegetables at room as well as at refrigeration temperatures by gamma radiation, by surface pasteurization, sprout inhibition, and also by retarding the ripening processes. The information presented should be useful to researchers, shippers, packers, and processors.



Effect of radiation dose on the sprout inhibition of potatoes stored for five months at 50 °F. Left to right--non-irradiated; 4.65 X 10^3 rads; and 9.30 X 10^3 rads.

Measuring Radioactivity: Units

- Activity is the rate at which a sample decays.
- The units used to measure activity are as follows:
  - Becquerel (Bq): one nucleus decays per second
  - Curie (Ci): 3.7×10^{10} nucleus decays per second which is the rate of decay of 1 g of radium

TABLE 21.8 Average Abundances and Activities of Natural Radionuclides†

	Potassium-40	Rubidium-87
Land elemental abundance (ppm)	28,000	112
Land activity (Bq/kg)	870	102
Ocean elemental concentration (mg/L)	339	0.12
Ocean activity (Bq/L)	12	0.11
Ocean sediments elemental abundance (ppm)	17,000	—
Ocean sediments activity (Bq/kg)	500	—
Human body activity (Bq)	4000	600

†Data from "Ionizing Radiation Exposure of the Population of the United States," Report 93, 1987, and on Radiation Protection.

‡Includes lead-210 and polonium-210, daughter nuclei of uranium-238.

The RBE is approximately

1 for γ and β radiation and **10 for α** radiation.

The effective dosage, **rem** (***r***oentgen ***e***quivalent for ***m***an)

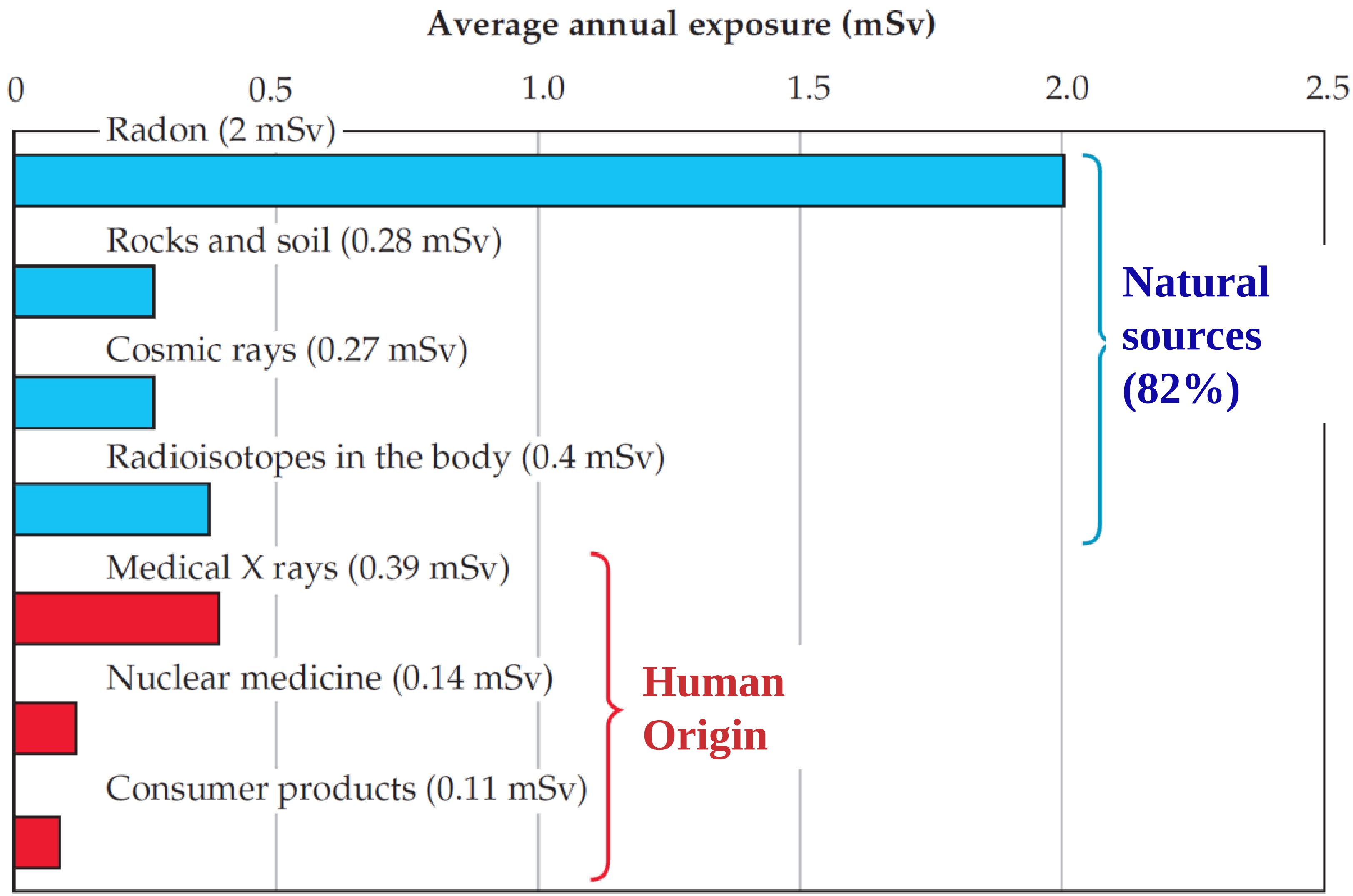
1 Sv = 100 rem (the SI unit for rem is ***Sv*** (*Sievert)*) .

The rem is the unit of radiation damage usually used in medicine:

Number of rem = (number of rad) (RBE)

Give it Some Thought? *(p. 974)*

If a 15-kg child is uniformly irradiated by 0.010-J alpha radiation, what is the absorbed dosage in rad and the effective dosage in rem



- **500** (600) **rem** is **fatal** to most humans. **(Accumulative, though)**
- **Average exposure per year is about 360 mrem**.

About 20 percent of our annual exposure to radiation comes from sources outside of nature, primarily medical procedures. Fallout from nuclear testing and the coal and nuclear power industries are also contributors. Interestingly, the coal industry outranks the nuclear power industry as a source of radiation. The global combustion of coal annually releases about 13,000 tons of radioactive thorium and uranium into the atmosphere (in addition to other environmentally damaging molecules, including greenhouse gases). Both of these elements are found naturally in coal deposits, so their release is a natural consequence of burning coal. Nuclear power plants also produce radioactive by-products. Worldwide, the nuclear power industries generate about 10,000 tons of radioactive waste each year. Most of this waste, however, is contained and not released into the environment.

When radiation encounters our intricately structured cells, it can create chaos. Cells are able to repair most kinds of damage caused by radiation if the damage is not too severe. A cell can survive an otherwise lethal dose of radiation if the dose is spread over a long period of time to allow intervals for healing. When radiation is sufficient to kill cells, the dead cells can be replaced by new ones. Sometimes a radiated cell will survive with damaged DNA. This can alter the genetic information contained in a cell, producing one or more *mutations*. Although the effects of most mutations are inconsequential in terms of a person's health, some mutations affect the functioning of cells. Genetic mutations are the cause of most cancers, for example. In addition, mutations that occur in an individual's reproductive cells can be passed to the individual's offspring. In this case, the mutation will be present in every cell in the offspring organism's body—and may well have an effect on the functioning of the organism.

Exposure to Radiation

- We are constantly exposed to radiation. What amount is safe?
- Setting standards for safety is difficult.
- Low-level, long-term exposure can cause health issues.
- Damage to the growth-regulation mechanism of cells results in cancer.

TABLE 21.9 Effects of Short-Term Exposures to Radiation

Dose (Sv)	Effect
0–0.25	No detectable clinical effects
0.25–0.50	Slight, temporary decrease in white blood cell counts
1–2	Nausea; marked decrease in white blood cell counts
5	Death of half the exposed population within 30 days

Damage to Cells

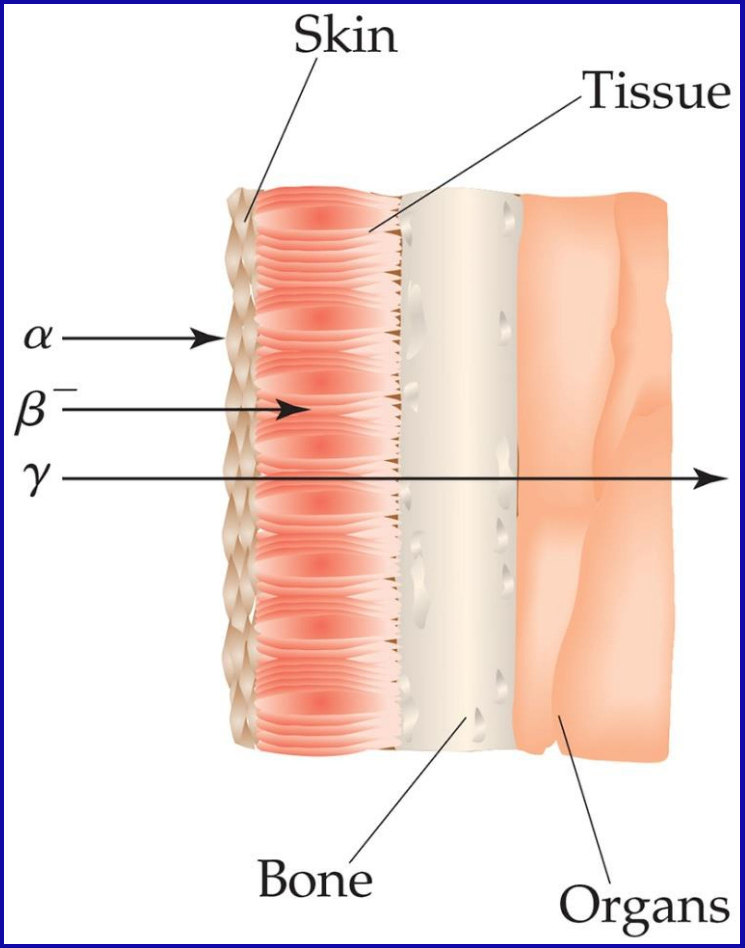


Figure 21.23 Relative penetrating abilities of alpha, beta, and gamma radiation.

- **The damage** to cells depends on the type of radioactivity, the **length of exposure**, and whether the source is inside or outside the body.
- **Outside the body**, gamma rays are most dangerous.
- **Inside the body**, alpha radiation can cause most harm.

The **tissues** damaged most by radiation are those that **reproduce rapidly**, such as bone marrow, blood-forming tissues, and lymph nodes

Table 21.6 Radiotracers

Nuclide	Half-Life	Area of the Body Studied
Iodine-131	8.04 days	Thyroid
Iron-59	44.5 days	Red blood cells
Phosphorus-32	14.3 days	Eyes, liver, tumors
Technetium-99[a]	6.0 hours	Heart, bones, liver, and lungs
Thallium-201	73 hours	Heart, arteries
Sodium-24	14.8 hours	Circulatory system

[a]The isotope of technetium is actually a special isotope of Tc-99 called Tc-99*m*, where the *m* indicates a so-called *metastable* isotope.

Table 21.10 Radiation Therapy

Isotope	Half-Life	Isotope	Half-Life
^{32}P	14.3 days	^{137}Cs	30 yr
^{60}Co	5.27 yr	^{192}Ir	74.2 days
^{90}Sr	28.8 yr	^{198}Au	2.7 days
^{125}I	60.25 days	^{222}Rn	3.82 days
^{131}I	8.04 days	^{226}Ra	1600 yr

Types of Radioactive Decay

- **Alpha decay**
- **Beta decay**
- **Positron emission**
- **Electron capture**
- **Gamma emission**

TABLE 21.2 Particles Found in Nuclear Reactions

Particle	Symbol
Neutron	${}^{1}_{0}n$ or n
Proton	${}^{1}_{1}H$ or p
Electron	${}^{0}_{-1}e$
Alpha particle	${}^{4}_{2}He$ or α
Beta particle	${}^{0}_{-1}e$ or β^{-}
Positron	${}^{0}_{+1}e$ or β^{+}

TABLE 21.3 Types of Radioactive Decay

	Type	Nuclear Equations	Change in Atomic Number	Change in Mass Number
α	Alpha emission	${}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$	−2	−4
β	Beta emission	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$	+1	Unchanged
	Positron emission	${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e$	−1	Unchanged
	Electron capture*	${}^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}^{A}_{Z-1}Y$	−1	Unchanged

*The electron captured comes from the electron cloud surrounding the nucleus.

In chemical equations, atoms and charges need to balance.

In nuclear equations, atomic number and mass number need to balance.

Each nuclide is identified by a symbol

${}^{A}_{Z}E$ for example: ${}^{238}_{92}U$

Mass number *A* = number of protons + neutrons

Isotopes are identified by their mass number (*A*).

Alpha Decay

α particle is essentially a helium nucleus ($^{4}_{2}He$ composed of two protons and two neutrons with a charge of plus two.

$$^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He$$

balancing the equation: atomic number: 92 = 90 + 2; mass number: 238 = 234 + 4

Alpha decay is essentially loss of two protons and two neutrons):

$$^{230}_{90}Th \longrightarrow ^{4}_{2}He + ^{226}_{88}Ra$$

Alpha-particle production is a very common mode of decay for heavy radioactive nuclide.

Polonium-210 is a powerful alpha emitter, write a nuclear equation for alpha decay of Po-210.

What is the fate of the alpha particle ($^{4}_{2}He^{2+}$) emitted?

FYI

Most **helium atoms produced** within the Earth find their way to the surface and then **upward to outer space**. Some helium, however, collects within natural gas deposits, which can contain as much as 7 percent helium. **Most helium used in the world is isolated from the natural gas** reserves of the Great Plains of the United States. Prior to World War II, the United States stopped supplying helium to the Germans, who then needed to use combustible hydrogen gas to fill their **large zeppelin airships**. One such airship, the *Hindenburg*, famously exploded in 1937.

Beta Decay

Beta decay or emission is the loss of a β-particle (a high-speed electron emitted by the nucleus):

$$ {}^{0}_{-1}\beta \quad \text{or} \quad {}^{0}_{-1}\text{e} $$

$$ {}^{131}_{53}\text{I} \rightarrow {}^{0}_{-1}\text{e} + {}^{131}_{54}\text{Xe} $$

the mass number of the decaying nucleus remains constant

The net effect is that one of the neutrons in nucleus is converted to a proton to reduce the neutron/proton ratio.

$$ {}^{1}_{0}\text{n} \longrightarrow {}^{1}_{1}\text{H} + {}^{0}_{-1}\text{e} \quad \text{or} \quad \text{n} \longrightarrow \text{p} + \beta^{-} $$

$$ \boxed{n \rightarrow p + e^{-}} $$

Iodine-131 has a **half-life** of **8.02 days**. How many beta particles are emitted in 1 *second* by a 1.00 mg sample of ^{131}I?

Half-life is the time required for half of a radionuclide sample to decay.

TABLE 21.5 The Half-Lives and Type of Decay for Several Radioisotopes

	Isotope	Half-Life (yr)	Type of Decay
Natural radioisotopes	$^{238}_{92}U$	4.5×10^9	Alpha
	$^{235}_{92}U$	7.0×10^8	Alpha
	$^{232}_{90}Th$	1.4×10^{10}	Alpha
	$^{40}_{19}K$	1.3×10^9	Beta
	$^{14}_{6}C$	5700	Beta
Synthetic radioisotopes	$^{239}_{94}Pu$	24,000	Alpha
	$^{137}_{55}Cs$	30.2	Beta
	$^{90}_{38}Sr$	28.8	Beta
	$^{131}_{53}I$	0.022	Beta

Positron Emission

Some nuclei decay by emitting a positron, a particle that has the same mass as, but an opposite charge to, that of an electron:

$$^{11}_{6}C \longrightarrow {}^{11}_{5}B + {}^{0}_{+1}e$$

Nuclear mass remains constant, decaying to low Z element

Positron emission has the effect of converting a proton to a neutron

$$^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{+1}e$$

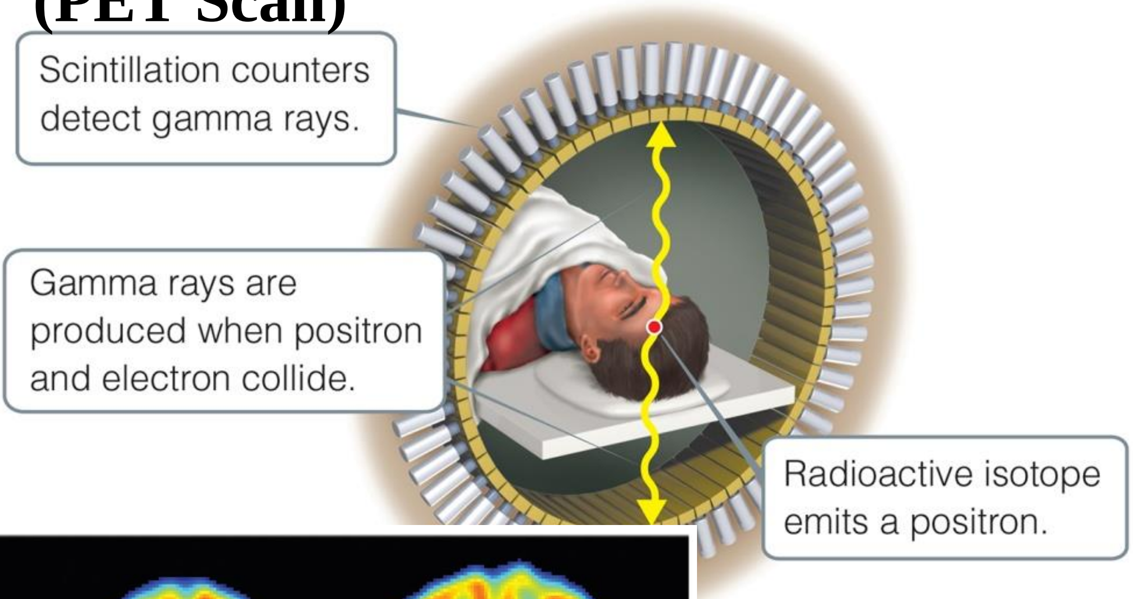
$$\boxed{p \rightarrow n + {}_{+1}e}$$

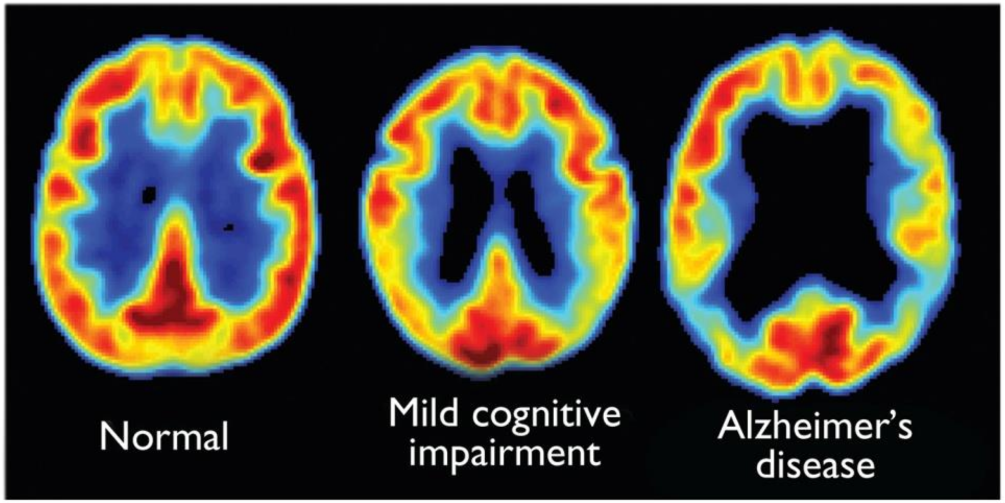
Fluorine-18 undergoes positron emission with a half-life of 110 minutes. It is used in PET (Positron Emission Tomography) as a tracer.

(a) Write the nuclear equation for the decay of ^{18}F.

(b) If a patient is given a 248 mg dose for a PET scan, how long will it take for the amount of fluorine-18 to drop to 31 mg?

Positron Emission Tomography (PET Scan)





▲ **Figure 21.11** Positron emission tomography (PET) scans showing glucose metabolism levels in the brain. Red and yellow colors show higher levels of glucose metabolism.

- **A radioactive isotope which is a positron emitter is injected into a patient.**
- **Labeled glucose is used to study the brain, as seen in the figure to the left.**