20.2 Radioactivity

SECTION OUTCOMES

- Describe the products of radioactive decay and the characteristics of alpha, beta, and gamma radiation.
- Analyze data on radioactive decay to predict half-life.

KEY TERMS

- radioactive material
- alpha particle
- beta particle
- gamma ray
- radioactive isotope (radioisotope)
- parent nucleus
- daughter nucleus
- transmutation
- ionizing radiation
- neutrino
- antineutrino
- positron
- half-life

J.J. Thomson and others observed the effects of cathode ray tubes. Their observations stimulated many other scientists to perform related studies in which a material was bombarded with "rays" of various types. When Wilhelm Conrad Röntgen (1845–1923) was using a cathode ray tube, he was surprised to see a fluorescent screen glowing on the far side of the room. Because he did not know the nature of these rays, he called them "X rays." French physicist Henri Becquerel (1852–1908) became curious about the emission of these X rays and wondered if luminescent materials, when exposed to light, might also emit X rays.

At first, Becquerel's experiment seemed to confirm his hypothesis. He wrapped photographic film to shield it from natural light and placed it under phosphorescent uranium salts. When he exposed the phosphorescent salts to sunlight, silhouettes of the crystals appeared when he developed the film. The salts appeared to absorb sunlight and reemit the energy as X rays. The X rays then passed through the film's wrapping. However, during a cloudy period, Becquerel stored the uranium salts and wrapped film in a drawer. When he later developed the film, he discovered that it had been exposed while in the drawer. This is the first recorded observation of the effects of radioactivity.

Radioactive Isotopes

Physicists discovered, studied, and used **radioactive materials** (materials that emit high-energy particles and rays) long before they learned the reason for these emissions. As you know, Rutherford discovered **alpha particles** and used them in many of his famous experiments. He examined the nature of alpha (α) particles by passing some through an evacuated glass tube and then performing a spectral analysis of the tube's contents. The trapped alpha particles displayed the characteristic spectrum of helium; alpha particles are simply helium nuclei.

Rutherford also discovered **beta particles**, and other scientists studied their charge-to-mass ratio and showed that beta (β) particles were identical to electrons. French physicist Paul Villard discovered that, in addition to beta particles, radium emitted another form of very penetrating radiation, which was given the name "gamma (γ) rays." **Gamma rays** are a very high-frequency electromagnetic wave. Figure 20.5 on the following page shows the separation of these radioactive emissions as they pass between oppositely charged plates.

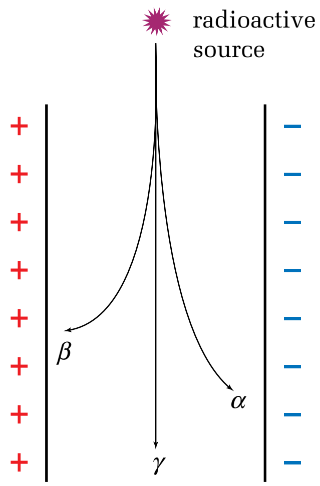


Figure 20.5 Positive alpha particles are attracted to the negative plate, while negatively charged beta particles are attracted to the positive plate. Gamma rays are not attracted to either plate, indicating that they do not carry a charge.

In section 20.1, you learned about the nuclei of atoms and about many of the characteristics that made them stable. Did you wonder what would happen to a nucleus if it was not stable? The answer is that it would disintegrate by emitting some form of radiation and transform into a more stable nucleus. Unstable nuclei are called **radioactive isotopes** (or "radioisotopes"). When a nucleus disintegrates or decays, the process obeys several conservation laws — conservation of mass-energy, conservation of momentum, conservation of nucleon number, and conservation of charge. The following subsections summarize the important characteristics of alpha, beta, and gamma radiation.

PHYSICS FILE

Pierre and Marie Curie once gave Henri Becquerel a sample of radium that they had prepared. When Becquerel carried the sample in his vest pocket, it burned his skin slightly. This observation triggered interest among physicians and eventually led to the use of radioactivity for medical purposes. Becquerel shared the 1903 Nobel Prize in Physics with the Curies.

Alpha Decay

When a radioactive isotope emits an alpha particle, it loses two protons and two neutrons. As a result, the atomic number (Z) decreases by two and the atomic mass number (A) decreases by four. Physicists describe this form of decay as shown below, where P represents the original nucleus or **parent nucleus** and D represents the resulting nucleus or **daughter nucleus**.

$$^{A}_{Z}\text{P} \rightarrow {}^{4}_{2}\text{He} + {}^{A-4}_{Z-2}\text{D}$$

Only very large nuclei emit alpha particles. One such reaction would be the alpha emission from radium-223 ($^{223}_{88}\text{Ra}$). To determine the identity of the daughter nucleus, write as much as you know about the reaction.

$$^{223}_{88}\text{Ra} \rightarrow {}^{4}_{2}\text{He} + {}^{219}_{86}?$$

Then look up the identity of an element with an atomic number of 86, and you will find that it is radon. The final equation becomes

$$^{223}_{88}\text{Ra} \rightarrow {}^{4}_{2}\text{He} + {}^{219}_{86}\text{Rn}$$

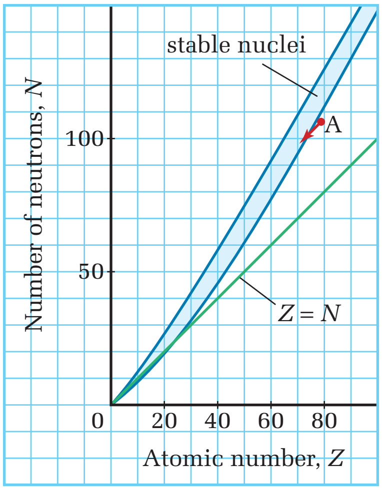


Figure 20.6 The emission of an alpha particle is represented here as a diagonal arrow going down and to the left. This process brings the tip of the arrow to a nucleus that has two fewer neutrons and two fewer protons than the nucleus at the tail of the arrow. (Note: The arrow is drawn larger than scale for visibility.)

During this reaction, one element is converted into a different element. Such a change is called **transmutation**. Why would such a transmutation result in a more stable nucleus? You can find the answer by studying the simplified representation of stable nuclei in Figure 20.6. The point labelled "A" represents a nuclide that lies outside of the range of stability. The arrow shows the location of the daughter nucleus when the unstable parent loses two neutrons and two protons. As you can see, the daughter nucleus lies within the range of stability. In addition, the helium nucleus — alpha particle — is one of the most stable nuclei of all. Since you now have two nuclei that are more stable than the parent nucleus, the total binding energy increased. The mass defect becomes kinetic energy of the alpha particle and daughter nucleus. Typical alpha particle energies are between 4 MeV and 10 MeV.

Conceptual Problem

- Write the nuclear reaction for the alpha decay of the following nuclei.

(a) ${}^{222}_{86}\text{Rn}$

(b) ${}^{210}_{84}\text{Po}$

(c) ${}^{214}_{83}\text{Bi}$

(d) ${}^{230}_{90}\text{Th}$

Alpha particles do not penetrate materials very well. A thick sheet of paper or about 5 cm of air can stop an alpha particle. In stopping, the alpha particle severely affects the atoms and molecules that are in its way. With the alpha particle's positive charge, relatively large mass, and very high speed (possibly close to 2×10^7 m/s), it gives some of the electrons in the atoms enough energy to break free, leaving a charged ion behind. For this reason, alpha particles are classified as **ionizing radiation**. These ions can disrupt biological molecules. Because of its low penetrating ability, alpha radiation is not usually harmful, unless the radioactive material is inhaled or ingested.

Beta Decay

When a radioactive isotope emits a beta particle, it appears to lose an electron from within the nucleus. However, electrons as such do not exist in the nucleus — a transformation of a nucleon had to take place to create the electron. In fact, in the process, a neutron becomes a proton, so the total nucleon number (A) remains the same, but the atomic number (Z) increases by one. You can write the general reaction for beta decay as follows, where ${}^{0}_{-1}\text{e}$ represents the beta particle, which is a high-energy electron. The superscript zero does not mean zero mass, because an electron has mass. The zero means that there are no nucleons.

$${}^{A}_{Z}\text{P} \rightarrow {}^{0}_{-1}\text{e} + {}^{A}_{Z+1}\text{D}$$

Many common elements such as carbon have isotopes that are beta emitters.

$$^{14}_{6}\text{C} \rightarrow {}^{0}_{-1}\text{e} + {}^{14}_{7}?$$

When you look up the identity of the element with an atomic number of 7, you will find that it is nitrogen. The equation is:

$$^{14}_{6}\text{C} \rightarrow {}^{0}_{-1}\text{e} + {}^{14}_{7}\text{N}$$

When physicists were doing some of the original research on beta decay, they made some very puzzling observations. Linear momentum of the beta particle and daughter nucleus was not conserved. As well, the physicists determined the spin of each particle and observed that angular momentum was not conserved. To add to the puzzle, they calculated the mass defect and discovered that mass-energy was not conserved.

Some physicists were ready to accept that these subatomic particles did not follow the conservation laws. However, Wolfgang Pauli (1900–1958) proposed an explanation for these apparent violations of the fundamental laws of physics. He proposed the existence of an as yet unknown, undiscovered particle that would account for all of the missing momentum and energy. It was more than 25 years before this elusive particle, the **neutrino** (ν_e), was discovered.

In reality, the particle that is emitted with a beta particle is an **antineutrino**, a form of antimatter. The antineutrino has a very small or zero rest mass and so can travel at or near the speed of light. It accounts for all of the "missing pieces" of beta decay. The correct equation for beta decay should be written as follows. The bar above the symbol ν_e for the neutrino indicates that it is an antiparticle.

$$^{A}_{Z}\text{P} \rightarrow {}^{0}_{-1}\text{e} + {}_{Z+1}^{A}\text{D} + \overline{\nu_e}$$

Physicists soon discovered a different form of beta decay — the emission of a "positive electron" that is, in fact, an antielectron. It has properties identical to those of electrons, except that it has a positive charge. The more common name for the antielectron is **positron**. Since the parent nucleus loses a positive charge but does not lose any nucleons, the value of A does not change, but Z decreases by one. A proton in the parent nucleus is transformed into a neutron. As you might suspect, the emission of a neutrino accompanies the positron. The reaction for positive electron or positron emission is written as follows.

$$^{A}_{Z}\text{P} \rightarrow {}^{0}_{+1}\text{e} + {}_{Z-1}^{A}\text{D} + \nu_e$$

You can understand why beta emission produces a more stable nucleus by examining Figure 20.7. The emission of an electron changes a neutron to a proton; in the chart, this is represented by an arrow going diagonally down to the right. Emission of a positron changes a proton into a neutron and the arrow in the chart goes diagonally upward and to the left.

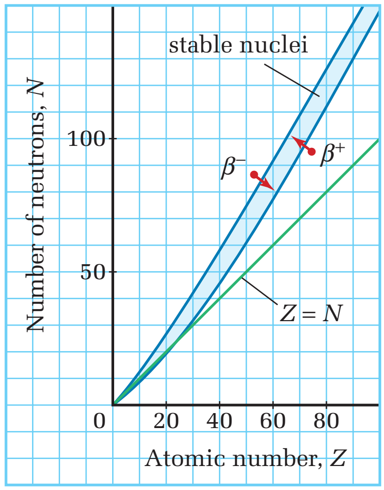
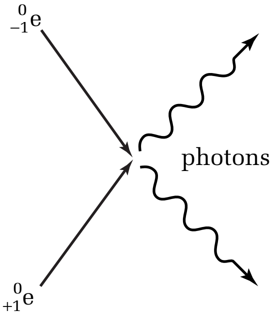


Figure 20.7 If a nucleus lies above the range of stability, it can transform into a more stable nucleus by beta emission. If it lies below the range of stability, it can transform into a more stable ion by emitting a positron. (Note: Arrows are not drawn to scale.)

PHYSICS FILE

The positron is the antimatter particle for the electron. When they meet, they annihilate each other and release their mass-energy as 2 photons.

$$^{0}_{1}e + ^{0}_{-1}e \rightarrow 2\gamma$$



The collision of a particle with its own antimatter particle results in the annihilation of the particles and the creation of two gamma ray photons.

Beta particles penetrate matter to a far greater extent than do alpha particles, mainly due to their much smaller mass, size, and charge. They can penetrate about 0.1 mm of lead or about 10 m of air. Although they can penetrate better than alpha particles, they are only about 5% to 10% as biologically destructive. Like alpha particles, they do their damage by ionizing atoms and molecules, and so are classified as ionizing radiation.

Conceptual Problems

- Free neutrons $\left(^{1}_{0}n\right)$ decay by beta minus emission. Write the equation.
- Free protons $\left(^{1}_{1}p\right)$ can decay by beta plus emission. Write the equation.
- Tritium, the isotope of hydrogen that consists of a proton and two neutrons, decays by beta minus emission. Write the equation.
- Carbon-10 decays by positron emission. Write the equation.
- Calcium-39 $\left(^{39}_{20}Ca\right)$ decays into potassium-39 $\left(^{39}_{19}K\right)$. Write the equation and identify the emitted particle.
- Plutonium-240 $\left(^{240}_{94}Pu\right)$ decays into uranium-236 $\left(^{236}_{92}U\right)$. Write the equation and identify the emitted particle.
- Lead-109 $\left(^{109}_{46}Pb\right)$ decays into silver-109 $\left(^{109}_{47}Ag\right)$. Write the equation and identify the emitted particle.
- Write the equation for the alpha decay of fermium-252 $\left(^{252}_{100}Fm\right)$.
- Write the equation for the beta positive decay of vanadium-48 $\left(^{48}_{23}V\right)$.
- Write the equation for the beta negative decay of gold-198 $\left(^{198}_{79}Au\right)$.

Gamma Decay

When a nucleus decays by alpha or beta emission, the daughter nucleus is often left in an excited state. The nucleus then emits a gamma ray to drop down to its ground state. This process can be compared to an electron in an atom that is in a high-energy level. When it drops to its ground state, it emits a photon. However, a gamma ray photon has much more energy than a photon emitted by an atom. The decay process can be expressed as follows, where the star indicates that the nucleus is in an excited state.

$$^{A}_{Z}P^{*} \rightarrow ^{A}_{Z}P + ^{0}_{0}\gamma$$

The following is an example of gamma decay:

$$^{192}_{77}Ir^{*} \rightarrow ^{192}_{77}Ir + ^{0}_{0}\gamma$$

Gamma radiation is the most penetrating of all. It can pass through about 10 cm of lead or about 2 km of air. The penetrating ability of gamma radiation is due to two factors. First, it carries no electric charge and therefore does not tend to disrupt electrons as it passes by. Second, its photon energy is far beyond any electron energy level in the atoms. Consequently, it cannot be absorbed through electron jumps between energy levels.

However, when gamma radiation is absorbed, it frees an electron from an atom, leaving behind a positive ion and producing an electron with the same range of kinetic energy as a beta particle — often called "secondary electron emission." For this reason, gamma radiation is found to be very biologically damaging. As in the case of alpha and beta radiation, gamma radiation is classified as ionizing radiation.

Decay Series

When a large nucleus decays by the emission of an alpha or beta particle, the daughter nucleus is more stable than the parent; however, the daughter nucleus might still be unstable. As a result, a nucleus can tumble through numerous transmutations before it reaches stability. Figure 20.8 shows one such decay sequence for uranium-238. Notice that the end product is lead-82, then go back to Figure 20.4 on page 902. You will find lead at the peak of the curve of binding energy per nucleon. Lead is one of the most stable nuclei of all the elements.

Notice that during the progress of the transmutations the following occurs.

- An alpha decay decreases the atomic number by 2 and decreases the atomic mass number by 4.
- A beta negative decay increases the atomic number by 1, while leaving the atomic mass number unchanged.

Knowledge of decay sequences such as the one in Figure 20.8 gives scientists information about the history of materials that contain lead. For example, if a rock contains traces of lead-82, that isotope of lead probably came from the decay of uranium-238 that was trapped in crystals as molten rock solidified in the past. A geologist can determine the original amount of uranium-238 in the rock and compare it to the amount of uranium-238 that remains. Knowing the disintegration rate of the isotopes in the series, a geologist can determine the age of the rock. This method was used to determine that the Canadian Shield contains some of the most ancient rock in the world, aged close to 4 billion years.

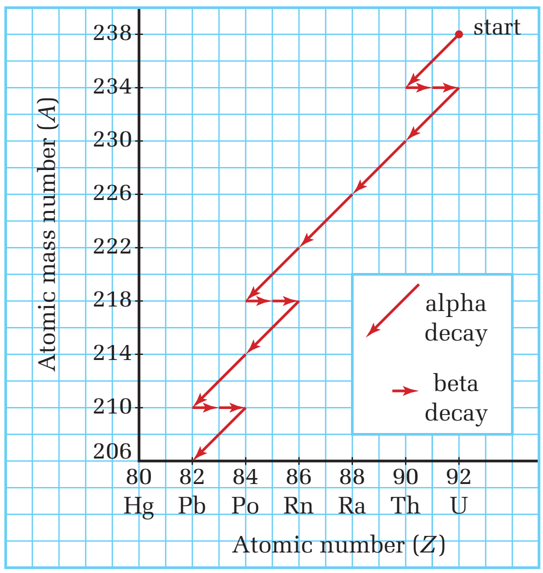


Figure 20.8 This series represents only one of several possible pathways of decay for uranium-238.

Rate of Radioactive Decay

You cannot predict exactly when a specific nucleus will disintegrate. You can only state the probability that it will disintegrate within a given time interval. Using probabilities might seem to be very imprecise, but if you have an exceedingly large number of atoms of the same isotope, you can state very precisely when half of them will have disintegrated. Physicists use the term **half-life**, symbolized by $T_{\frac{1}{2}}$, to describe the decay rate of radioactive isotopes. One half-life is the time during which the nucleus has a 50% probability of decaying. The half-life is also the time interval over which half of the nuclei in a large sample will disintegrate.

Imagine that you had a sample of polonium-218 $\left({}^{218}_{84}\text{Po}\right)$. It decays by alpha emission with a half-life of 3.0 min. If you started with 160.0 μg of the pure substance, it would decay as shown in Table 20.3.

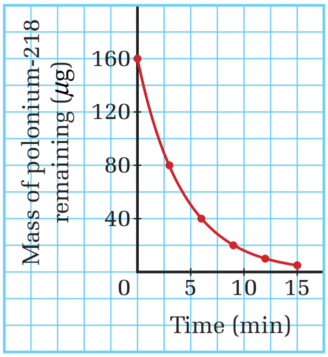


Figure 20.9 A graph of the decay of polonium and all other radioactive isotopes is an exponential curve.

Table 20.3 Decay of Polonium-218

Time (min)	Mass of Po-218 remaining (μg)
0	160.0
3.0	80.0
6.0	40.0
9.0	20.0
12.0	10.0
15.0	5.0

From Figure 20.9 we can estimate the following.

- After 7.0 min, there should be about 32 μg of polonium-218 remaining.
- It would take about 13 min to reduce the mass of polonium-218 to 8.0 μg.

You can obtain more accurate values by using a mathematical equation that relates the mass of the isotope and time interval. You can derive such an equation as follows.

- Let N represent the quantity of the original sample remaining after any given time interval.
- Let N_o represent the original quantity in the sample; must be given in the same units as N.
- Let Δt represent the time interval, and $T_{\frac{1}{2}}$ represent the half-life.
- After 1 half-life, $N = \frac{1}{2}N_o$.
- After 2 half-lives, $N = \frac{1}{2}\left(\frac{1}{2}N_o\right) = \left(\frac{1}{2}\right)^2 N_o$.

ELECTRONIC LEARNING PARTNER

To enhance your understanding of radioactive decay and half-life, go to your Electronic Learning Partner.

- After 3 half-lives, $N = \frac{1}{2}\left(\frac{1}{2}\right)^2 N_0 = \left(\frac{1}{2}\right)^3 N_0$.
- After 4 half-lives, $N = \frac{1}{2}\left(\frac{1}{2}\right)^3 N_0 = \left(\frac{1}{2}\right)^4 N_0$.
- You can now see a pattern emerging and can state the general expression in which "n" is the number of half-lives. $N = \left(\frac{1}{2}\right)^n N_0$
- However, the number, n, of half-lives is equal to the time interval divided by the time for 1 half-life. $n = \frac{\Delta t}{T_{\frac{1}{2}}}$
- Substituting the value for n, you obtain the final equation. $N = \left(\frac{1}{2}\right)^{\frac{\Delta t}{T_{\frac{1}{2}}}} N_0$

The quantity of sample, N, can be expressed as the number of nuclei, the number of moles of the isotope, the mass in grams, the decay rate, or any measurement that describes a quantity of a sample. The unit for decay rate in disintegrations per second is called the becquerel (Bq) in honour of Henri Becquerel.

RADIOACTIVE DECAY

The quantity of a sample remaining is one half to the exponent time interval divided by the half-life, all times the quantity of the original sample.

$$N = N_0\left(\frac{1}{2}\right)^{\frac{\Delta t}{T_{\frac{1}{2}}}}$$

Quantity	Symbol	SI unit
quantity of sample remaining	N	kilograms, moles, or Bq (might also be in number of atoms)
quantity in original sample	N_0	kilograms, moles, or Bq (might also be in number of atoms)
elapsed time	Δt	s (often reported in min, days, years, etc.)
half life	$T_{\frac{1}{2}}$	s (often reported in min, days, years, etc.)

Unit Analysis

kilograms = kilograms   kg = kg

Note: The elapsed time and the half-life must be given in the same units so that they will cancel, making the exponent of one half a pure number. Also, the quantity of the sample remaining and in the original sample at time zero must be given in the same units.

MODEL PROBLEM

Decay of Polonium-218

You have a 160.0 μg sample of polonium-218 that has a half-life of 3.0 min.

(a) How much will remain after 7.0 min?

(b) How long will it take to decrease the mass of the polonium-218 to 8.0 micrograms?

Frame the Problem

- The *half-life* of a radioactive isotope determines the *amount* of a sample at any given *time*.

Identify the Goal

Quantity of polonium-218, N_1, remaining after 7.0 min

Length of time, Δt_2, required for the mass of the sample to decrease to 8.0 μg

PROBLEM TIPS

The data for amounts of a sample, time intervals, and half-lives in decay rate problems can be given in a variety of units. Always be sure that, in your calculations, the amounts of a sample, N and N_o, are in the same units and that the time interval and the half-life are in the same units.

Variables and Constants

Known	Unknown
$N_0 = 160.0\ \mu g$	N_1 (at 7.0 min)
$T_{\frac{1}{2}} = 3.0$ min	Δt_2 (at 8.0 μg)
$\Delta t_1 = 7.0$ min	
$N_2 = 8.0\ \mu g$	

Strategy / Calculations

Write the decay relationship

$$N = N_o\left(\frac{1}{2}\right)^{\frac{\Delta t_1}{T_{\frac{1}{2}}}}$$

Substitute and solve.

$$N_1 = 160.0\ \mu g\left(\frac{1}{2}\right)^{\frac{7.0\ \cancel{min}}{3.0\ \cancel{min}}}$$

$$N_1 = 160.0\ \mu g(0.198\ 425)$$

$$N_1 = 31.748\ \mu g$$

$$N_1 \cong 32\ \mu g$$

(a) The mass remaining after 7.0 min will be 32 μg.

Write the decay equation.

$$N_2 = N_o\left(\frac{1}{2}\right)^{\frac{\Delta t_2}{T_{\frac{1}{2}}}}$$

Rearrange the equation to solve for the ratio N to N_o.

$$\frac{N_2}{N_o} = \left(\frac{1}{2}\right)^{\frac{\Delta t_2}{T_{\frac{1}{2}}}}$$

Substitute numerical values.

$$\left(\frac{1}{2}\right)^{\frac{\Delta t_2}{3.0\ min}} = \frac{8.0\ \cancel{\mu g}}{160.0\ \cancel{\mu g}}$$

Solve by taking logarithms on both sides.

$$\log\left(\frac{1}{2}\right)^{\frac{\Delta t_2}{3.0\ \text{min}}} = \log\frac{8.0}{160.0}$$

$$\frac{\Delta t_2}{3.0\ \text{min}}\log\left(\frac{1}{2}\right) = \log 0.050$$

$$\Delta t_2 = (3.0\ \text{min})\frac{\log 0.050}{\log\left(\frac{1}{2}\right)}$$

$$\Delta t_2 = (3.0\ \text{min})\left(\frac{-1.301\ 003}{-0.301\ 03}\right)$$

$$\Delta t_2 = 12.965\ 78\ \text{min}$$

$$\Delta t_2 \cong 13\ \text{min}$$

(b) The time interval after which only 8.0 μg of polonium-218 will remain is 13 min.

Validate

These answers are the same as the answers estimated from the graph in Figure 20.9.

PRACTICE PROBLEMS

4. When a sample of lava solidified, it contained 27.4 mg of uranium-238, which has a half-life of 4.5×10^9 a (annum or year). If that lava sample was later found to contain only 18.3 mg of U-238, how many years had passed since the lava solidified?

5. Carbon-14 has a half-life of 5730 a. Every gram of living plant or animal tissue absorbs enough radioactive C-14 to provide an activity of 0.23 Bq. Once the plant or animal dies, no more C-14 is taken in. If ashes from a fire (equivalent to 1 g of tissue) have an activity of 0.15 Bq, how old are they? Assume that all of the radiation comes from the remaining C-14.

6. Radioactive iodine-128, with a half-life of 24.99 min, is sometimes used to treat thyroid problems. If 40.0 mg of I-128 is injected into a patient, how much will remain after 12.0 h?

Nuclear Reactions

When you were solving the problems above, you encountered radioactive isotopes that have half-lives of 3.0 min and 25 min. Did you wonder how any such isotopes could exist and why they had not decayed entirely? Most of the radioactive isotopes that are used in medicine and research are produced artificially. One of the first observations of artificial production of a radioisotope was accomplished by bombarding aluminum-27 with alpha particles as follows.

$${}^{4}_{2}\text{He} + {}^{27}_{13}\text{Al} \rightarrow {}^{31}_{15}\text{P}^{*} \rightarrow {}^{30}_{15}\text{P} + {}^{1}_{0}\text{n}$$

The star on the phosphorus-31 indicates that it is very unstable and decays into phosphorus-30 and a neutron. Phosphorus-30 is a radioisotope that emits a positron. Today, many artificial isotopes are produced by bombarding stable isotopes with neutrons in nuclear reactors. For example, stable sodium-23 can absorb a neutron and become radioactive sodium-24. Cobalt-59 can absorb a neutron and become cobalt-60. In Chapter 21, you will learn about nuclear reactors and why they are a source of neutrons.

Applications of Radioactive Isotopes

Exposure to radiation can cause cancer, but it also can destroy cancerous tumours. How can radiation do both?

As you have learned, alpha, beta, and gamma radiation ionize atoms and molecules in their paths. In living cells, the resulting ions cause chemical reactions that can damage critical biological molecules. If that damage occurs in a few very precise regions of the genetic material, the result can be a mutation that destroys the cell's ability to control growth and cell division. Then, the cell divides over and over, out of control, and becomes a cancerous tumour.

On the other hand, if the amount of radiation is much higher, the damage to the molecules that maintain the cell functions will be too great, and the cell will die. If a few healthy cells die, they can usually be replaced, so little or no harm is caused to the individual. If cancerous cells die, the tumour could be destroyed and the person would be free of the cancer.

Great care must be taken when treating tumours with radiation, since healthy cells in the area are exposed to radiation and might themselves become cancerous. If the amount of irradiation is excessive (in a nuclear accident, for example) and the entire body is exposed, too many cells could die at the same time, seriously affecting the ability of the organs to function. Death would result.

Irradiating tumours with gamma radiation is sometimes the only feasible way to treat a tumour, however, and it can be very successful. Figure 20.10 shows one method of treating a tumour with radiation from the radioisotope cobalt-60. A thin beam of gamma rays is aimed at the tumour and then the unit rotates so that the beam is constantly aimed at the tumour. In this way the tumour is highly irradiated, while the surrounding tissue receives much less radiation.

COURSE CHALLENGE: SCANNING TECHNOLOGIES

"Seeing" with Radioisotopes

Techniques exist by which radioisotopes, injected into living bodies, will accumulate in infected areas or other diseased tissues. Observing the location of the radioisotopes provides critical information. You might want to include these scanning techniques in your *Course Challenge*.

MISCONCEPTION

Radiation Does Not Make Something Radioactive!

Many people believe that exposure to radiation makes objects radioactive. This is false. Only bombardment by neutrons can make something radioactive.

Figure 20.10 Gamma radiation from cobalt-60 is used to destroy tumours.

Radioactive Tracers

Because traces of radioactivity can be detected and identified, scientists can use very small quantities of radioactive substances to follow the chemical or physical activity of specific compounds. For example, iodine-131 is useful for investigating the heart and the thyroid gland. Phosphorus-32 accumulates in cancerous tumours, identifying their location. Technetium-99 portrays the structure of organs. Other applications include the following.

- Adding slight amounts of a radioisotope to a fluid passing through an underground pipe allows technicians to locate leaks.
- Gamma radiation is used to sterilize food so that it will stay fresh longer.
- Exposing plants to radioactive carbon dioxide allows researchers to determine the long series of chemical reactions that convert carbon dioxide and water into glucose.
- Radioisotopes are a common tool in biochemistry research.

Smoke Detectors

Examine Figure 20.11. Many smoke detectors contain a small amount of a radioisotope that emits alpha radiation. Because the gas in the detector is ionized, a current can pass through and be measured. When soot and ash particles in smoke enter the detector, they tend to collect these ions and neutralize them. The resulting drop in current triggers the smoke detector alarm.

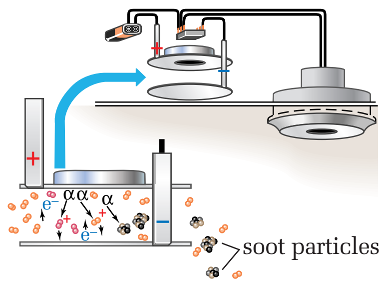


Figure 20.11 Some smoke detectors use alpha emitters, as shown here. When alpha particles ionize molecules in the air, the positive ions are attracted to the negative electrode and the electrons are attracted to the positive electrode and a current passes through the circuit. Soot particles absorb and neutralize some of the ions and the current decreases.

20.2 Section Review

1. K/U Explain why beta negative radiation tends to do less biological damage than an equal amount of alpha radiation, when inhaled or ingested.
2. K/U Why is gamma radiation much more penetrating than beta radiation?
3. K/U State the conservation laws used in writing nuclear reactions.
4. C Prepare a table for alpha radiation, beta radiation, and gamma radiation, comparing them with respect to mass, charge, relative penetrating ability, and relative biological damage.
5. C Draw a graph to illustrate the decay of carbon-14 in a wooden relic. Assume that the initial mass of the isotope in the wood was 240 mg.
6. C Draw a decay sequence similar to the one shown in Figure 20.8 on page 911. Begin with $\left({}^{255}_{101}Md\right)$. It emits four alpha particles in succession, then a beta negative particle, followed by two alpha particles and then a beta negative particle. Another alpha emission is followed by another beta emission. (There are more, but this is enough for this question.)
7. MC Give a possible reason why a smoke detector uses an alpha source rather than a beta or gamma emitter.
8. MC Suggest an equation to represent the transformation of nitrogen-14 into carbon-14.
9. I Research the use of radioisotopes for medical or non-medical purposes and prepare a poster to illustrate your findings.