Name: ______________________ Date: ______________

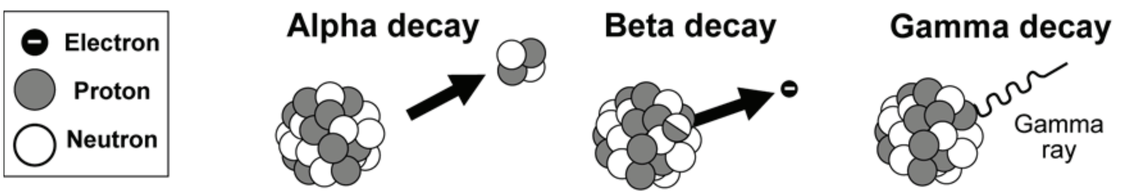
11.3

Radioactivity

READ

There are three main types of radiation that involve the decay of the nucleus of an atom:

- **alpha radiation** (α): release of a helium-4 nucleus (two protons and two neutrons). We can represent helium-4 using isotope notation: ${}^{4}_{2}He$. The top number, 4, represents the mass number, and the bottom number represents the atomic number for helium, 2.
- **beta radiation** (β): release of an electron.
- **gamma radiation** (γ): release of an electromagnetic wave.



Protons	Decrease by 2	Increase by 1	Unchanged
Neutrons	Decrease by 2	Decrease by 1	Unchanged

Half-life

The time it takes for half of the atoms in a sample to decay is called the half-life. Four kilograms of a certain substance undergo radioactive decay. Let's calculate the amount of substance left over after 1, 2, and 3 half-lives.

- After one half-life, the substance will be reduced by half, to 2 kilograms.
- After two half-lives, the substance will be reduced by another half, to 1 kilogram.
- After three half-lives, the substance will be reduced by another half, to 0.5 kilogram.

So, if we start with a sample of mass *m* that decays, after a few half-lives, the mass of the sample will be:

Number of half-lives	Mass left	
1	$\frac{1}{2^1}m =$	$\frac{1}{2}m$
2	$\frac{1}{2^2}m =$	$\frac{1}{4}m$
3	$\frac{1}{2^3}m =$	$\frac{1}{8}m$
4	$\frac{1}{2^4}m =$	$\frac{1}{16}m$

PRACTICE 11.3

PRACTICE

1. The decay series for uranium-238 and plutonium-240 are listed below. Above each arrow, write “a” for alpha decay or “b” for beta decay to indicate which type of decay took place at each step.

a. $^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} \rightarrow {}^{234}_{92}\text{U} \rightarrow {}^{230}_{90}\text{Th} \rightarrow$

$^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} \rightarrow {}^{214}_{82}\text{Pb} \rightarrow {}^{214}_{83}\text{Bi} \rightarrow$

$^{214}_{84}\text{Po} \rightarrow {}^{210}_{82}\text{Pb} \rightarrow {}^{210}_{83}\text{Bi} \rightarrow {}^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb}$

b. $^{240}_{94}\text{Pu} \rightarrow {}^{240}_{95}\text{Am} \rightarrow {}^{236}_{93}\text{Np} \rightarrow {}^{232}_{91}\text{Pa} \rightarrow {}^{232}_{92}\text{U} \rightarrow$

$^{228}_{90}\text{Bi} \rightarrow {}^{224}_{88}\text{Ra} \rightarrow {}^{224}_{89}\text{Ac} \rightarrow {}^{220}_{87}\text{Fr} \rightarrow {}^{216}_{85}\text{At} \rightarrow$

$^{212}_{83}\text{Bi} \rightarrow {}^{212}_{84}\text{Po} \rightarrow {}^{208}_{82}\text{Pb} \rightarrow {}^{208}_{83}\text{Bi}$

2. Fluorine-18 ($^{18}_{9}\text{F}$) has a half-life of 110 seconds. This material is used extensively in medicine. The hospital laboratory starts the day at 9 a.m. with 10 grams of $^{18}_{9}\text{F}$.
   a. How many half-lives for fluorine-18 occur in 11 minutes (660 seconds)?
   b. How much of the 10-gram sample of fluorine-18 would be left after 11 minutes?

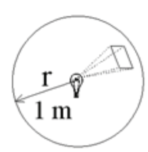
3. The isotope $^{14}_{6}\text{C}$ has a half-life of 5,730 years. What is the fraction of $^{14}_{6}\text{C}$ in a sample with mass, *m*, after 28,650 years?

4. What is the half-life of this radioactive isotope that decreases to one-fourth its original amount in 18 months?

5. This diagram illustrates a formula that is used to calculate the intensity of radiation from a radioactive source. Radiation “radiates” from a source into a spherical area. Therefore, you can calculate intensity using the area of a sphere ($4\pi r^2$). Use the formula and the diagram to help you answer the questions below.

Intensity

Intensity (W/m²) $I = \dfrac{P}{A}$ Power (W) / Area (m²)



Area, $A = 4\pi r^2 = 12.6 \text{ m}^2$

Intensity, $I = \dfrac{100 \text{ W}}{12.6 \text{ m}^2} = 7.96 \text{ W/m}^2$

   a. A radiation source with a power of 1,000 watts is located at a point in space. What is the intensity of radiation at a distance of 10 meters from the source?
   b. The fusion reaction $^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + n + \text{energy}$ releases 2.8×10^{-12} joules of energy. How many such reactions must occur every second in order to light a 100-watt light bulb? Note that one watt equals one joule per second.

Name: ______________________ Date: ______________

PRACTICE 12.1

Einstein's Formula

READ

Everything in the universe can be categorized as either matter or energy. Einstein worked to establish a relationship between the amount of matter (mass) making up an object and the amount of energy it contains. He derived the famous equation $E = mc^2$ to relate energy and mass.

EINSTEIN'S FORMULA

Energy (joules) → $E = mc^2$

Mass (kg)

Speed of light (3×10^8 m/sec)

Einstein's formula does not mean you can take an object such as a rock and easily convert its mass into energy. Einstein thought of mass as the measure of the energy contained in an object. Getting the energy from an object's mass is another matter.

Processes during which we can observe mass becoming energy include radioactive decay and nuclear reactions. Radioactive decay occurs when the nuclei of atoms in a radioactive substance release energy in the form of radiation. The mass of the substance gradually decreases. Nuclear reactions involve the splitting of nuclei (fission) or the combining of nuclei (fusion). Mass is converted into energy during these reactions.

PRACTICE

1. How much energy is contained in matter with a mass of 1 gram (0.001 kilogram)?
2. How much energy is contained in the mass of a 60-kilogram person?
3. Radioactive carbon-14 decays into nitrogen-14. A piece of carbon-14 that originally had a mass of 1 kilogram is later found to have a mass of 0.9999 kilogram. How much energy was released?
4. Nuclear fusion creates energy in the sun. During this process, hydrogen atoms combine to create helium. The mass of the helium created is less than the mass of the hydrogen from which it was made. The lost mass is converted to radiant energy.
    a. The sun loses 4.3×10^9 kilogram of mass every second. How much energy is released in one second?
    b. What is the power of the sun in watts?
    c. How much mass does the sun lose each year?
    d. How much energy is released in one year?
    e. Because Earth is so far from the sun, we receive only one-half of one billionth of the sun's energy. How much energy do we get from the sun in one year?
5. The annual energy consumption for the world totals approximately 4×10^{20} joules.
    a. How much mass would have to be converted to energy on the sun to provide this much energy?
    b. Based on your answers to question 4, do we get enough energy from the sun to be able to meet our energy needs?