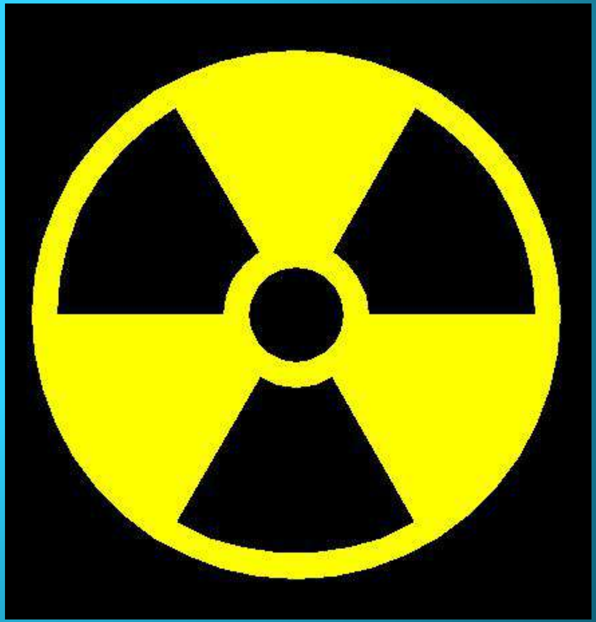
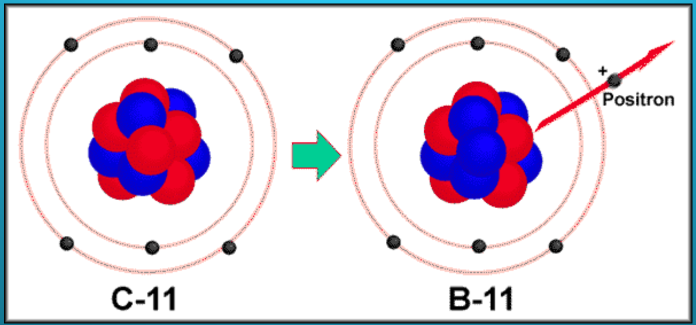
Chapter 10 – Nuclear Chemistry

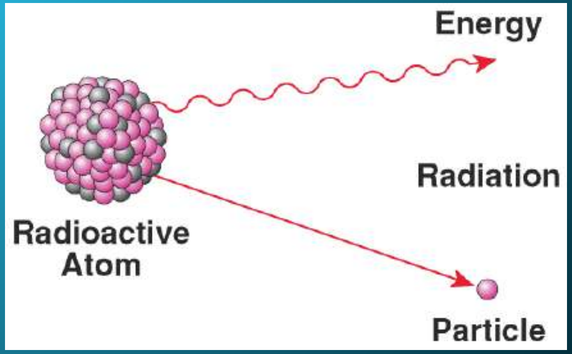


Jennie L. Borders

Section 10.1 - Radioactivity

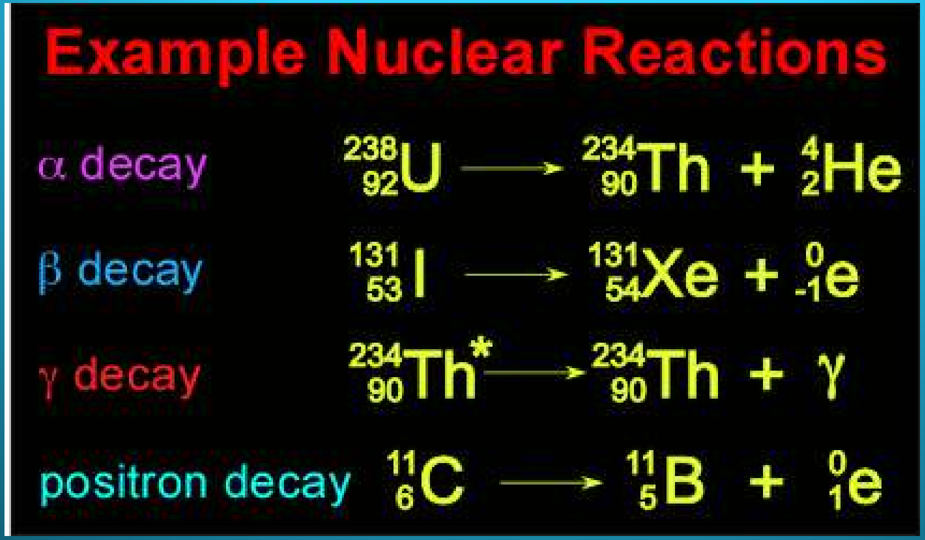
- Radioactivity is the process in which an unstable atomic nucleus emits charged particles and energy.
- Any atom containing an unstable nucleus is called a radioactive isotope, or radioisotope for short.
- During nuclear decay, atoms of one element can change into atoms of a different element all together.





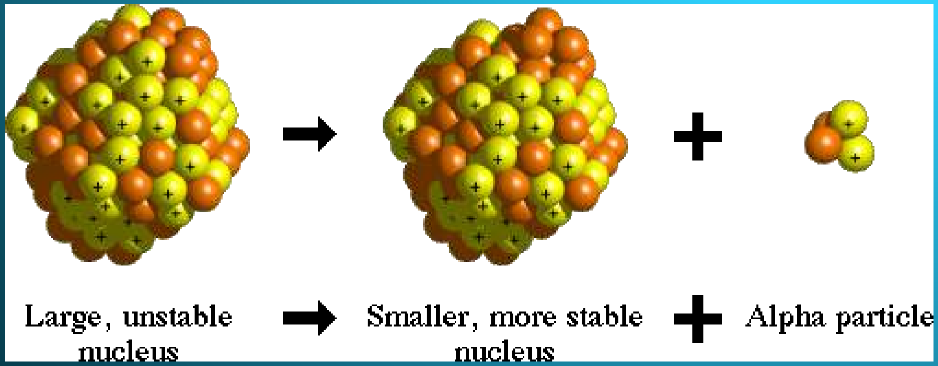
Types of Nuclear Radiation

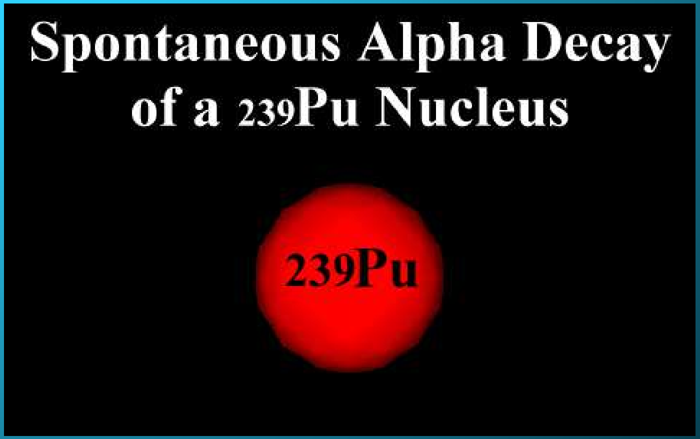
- <u>Nuclear radiation</u> is charged particles and <u>energy</u> that are emitted from the <u>nuclei</u> of radioisotopes.
- Common types of nuclear radiation include <u>alpha particles, beta particles, and gamma rays</u>.



Alpha Decay

- An alpha particle (α) is a positively charged particle made up of two protons and two neutrons – the same as a helium nucleus.
- It has a +2 charge and the common symbol for the alpha particle is $^{4}_{2}He$.
- Alpha particles are the least penetrating type of nuclear radiation.





Alpha Decay

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

- In the equation above, the mass number on the left (238) equals the sum of the mass numbers on the right (234 + 4).
- Also, the atomic number on the left (92) equals the sum of the atomic numbers on the right (90 + 2).

$$^{256}_{103}Lr \rightarrow {}^{252}_{101}Md + {}^{4}_{2}He$$

$$^{231}_{91}Pa \rightarrow {}^{227}_{89}Ac + {}^{4}_{2}He$$

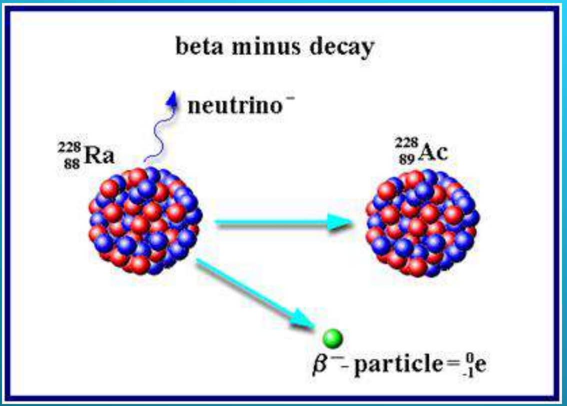
$$^{225}_{89}Ac \rightarrow {}^{221}_{87}Fr + {}^{4}_{2}He$$

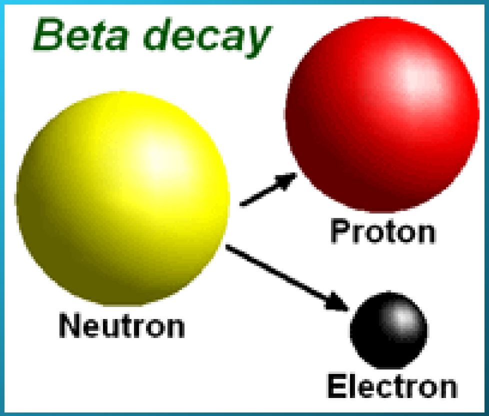
$$^{211}_{87}Fr \rightarrow {}^{4}_{2}He + {}^{207}_{85}At$$

$$^{185}_{79}Au \rightarrow {}^{4}_{2}He + {}^{181}_{77}Ir$$

Beta Decay

- A beta particle (β) is an electron emitted by an unstable nucleus.
- In nuclear reactions, a beta particle is written as ${}^{0}_{-1}e$ and it has a charge of -1.
- During a beta decay, a neutron decomposes into a proton and an electron. The proton stays trapped in the nucleus while the electron is released.





Beta Decay

$$^{234}_{90}Th \rightarrow ^{234}_{91}Pa + ^{0}_{-1}e$$

- Again the mass numbers and the atomic numbers are the same on both sides of the equation.
- Beta particles are more penetrating than alpha particles.

$$^{6}_{2}He \longrightarrow ^{6}_{3}Li + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$$

$$^{24}_{11}Na \longrightarrow ^{24}_{12}Mg + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$$

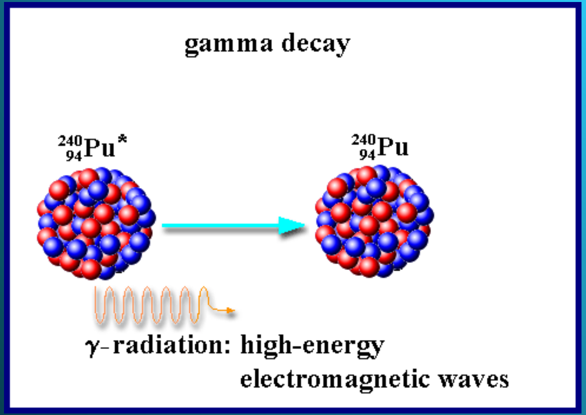
$$^{201}_{79}Au \longrightarrow ^{201}_{80}Hg + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$$

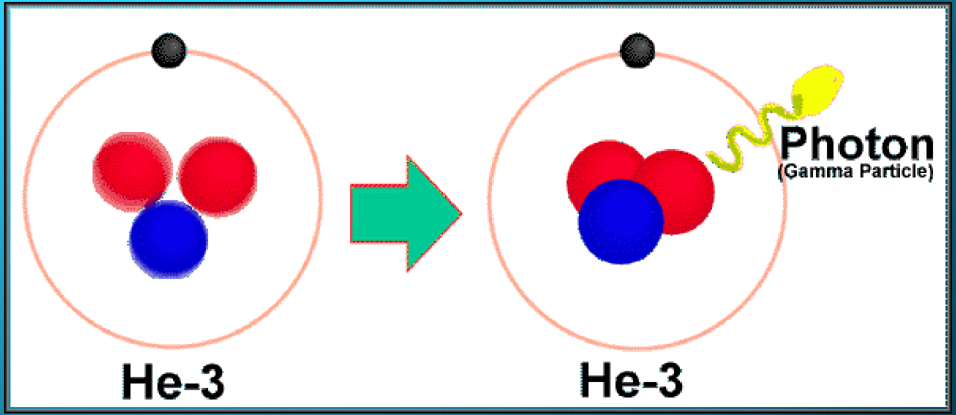
$$^{52}_{26}Fe \longrightarrow ^{52}_{27}Co + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$$

$$^{42}_{19}K \longrightarrow ^{42}_{20}Ca + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$$

Gamma Decay

- A gamma ray (γ) is a penetrating ray of energy emitted by an unstable nucleus.
- Gamma radiation has no mass and no charge.
- During gamma radiation, the atomic number and mass number of the atom remain the same, but the energy of the nucleus decreases. It often accompanies alpha or beta decay.

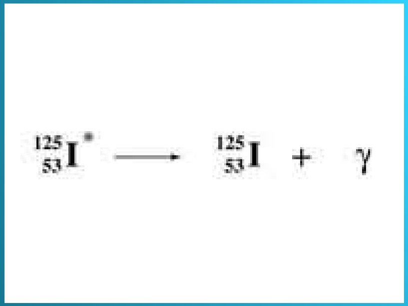




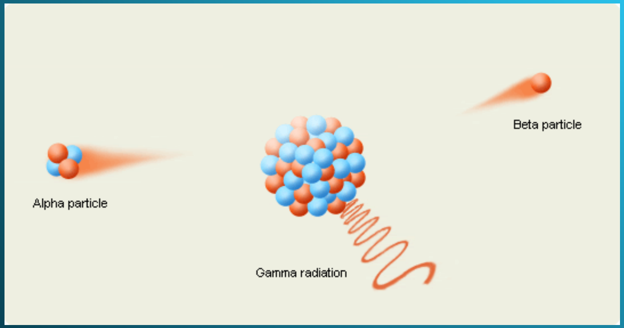
Gamma Decay

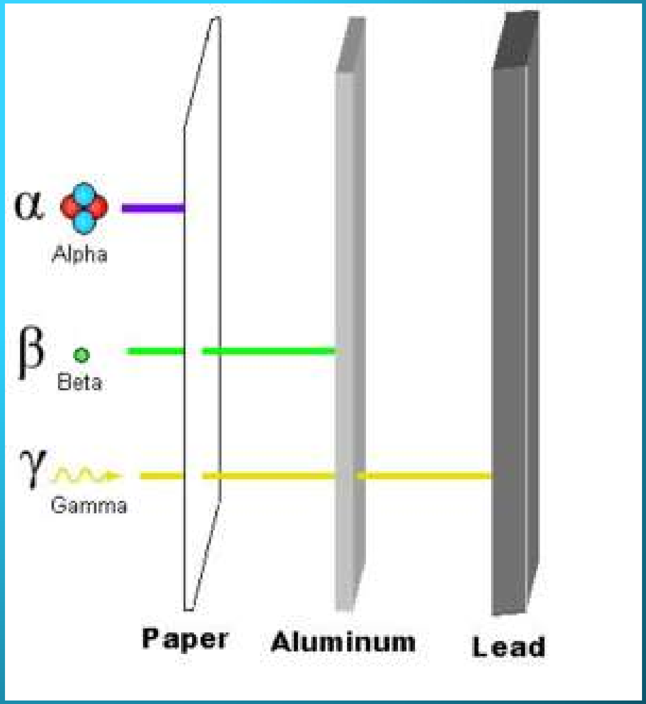
$^{234}_{90}Th \rightarrow \; ^{234}_{91}Pa + \; ^{0}_{-1}e + \gamma$

- <u>Gamma rays</u> are <u>more</u> penetrating than either <u>alpha or beta</u> particles.



$^{125}_{53}I^{*} \longrightarrow \; ^{125}_{53}I + \gamma$





Comparing Radiation

Radiation Type	Abbreviation	Symbol	Charge	Mass
alpha	α	${}^{4}_{2}He$	+2	4
beta	β	${}^{0}_{-1}e$	-1	0
gamma	γ	γ	0	0

Sample Problem

- Write a balanced nuclear equation for the alpha decay of polonium – 210.

$$^{210}_{84}Po \rightarrow {}^{4}_{2}He + {}^{206}_{82}Pb$$

Practice Problems

1. Write a balanced nuclear equation for the alpha decay of thorium – 232.

$$^{232}_{90}Th \rightarrow {}^{4}_{2}He + {}^{228}_{88}Ra$$

2. Write a balanced nuclear equation for the beta decay of carbon – 14.

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

Practice Problems

3. What type of decay is in the following reaction?

$^{241}_{95}Am \rightarrow ^{237}_{93}Np + ?$

$? = ^{4}_{2}He$ decay = alpha

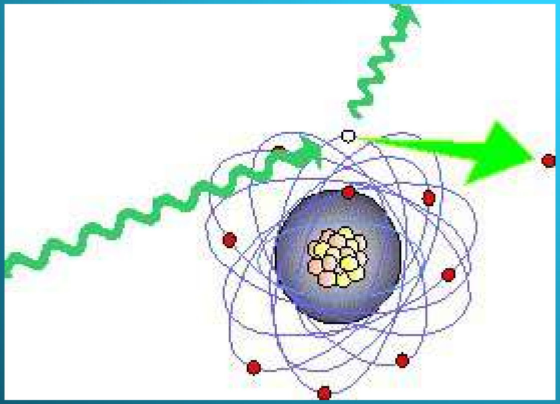
4. What type of decay is in the following reaction?

$^{90}_{38}Sr \rightarrow ^{90}_{39}Y + ?$

$? = ^{0}_{-1}e$ decay = beta

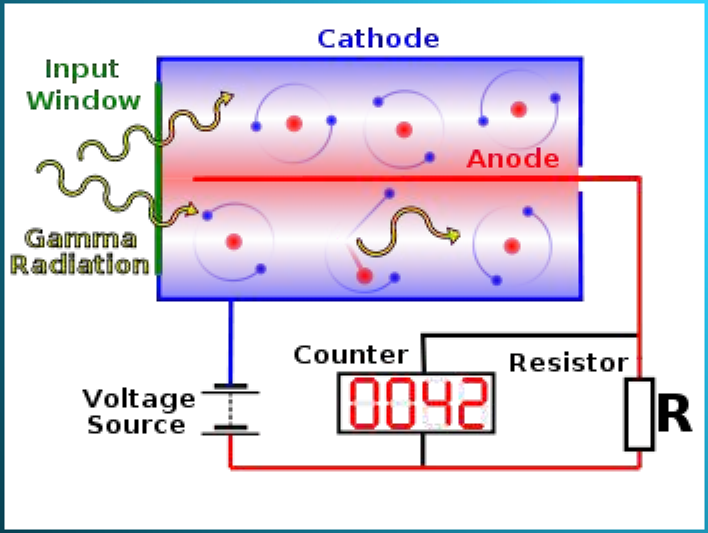
Effects of Nuclear Radiation

- Nuclear radiation that occurs naturally in the environment is called background radiation.
- When nuclear radiation exceeds background levels, it can damage the cells and tissues of your body.
- Nuclear radiation can ionize atoms.



Detecting Nuclear Radiation

- Devices that are used to detect nuclear radiation include Geiger counters and film badges.



Section 10.1 Assessment

1. How does an element change during nuclear decay?
2. What are three types of nuclear radiation?
3. How are atoms affected by nuclear radiation?
4. What devices can be used to detect nuclear radiation?
5. How do types of nuclear radiation differ in electric charge?
6. Describe the penetrating power of each common type of radiation.

Section 10.1 Assessment

7. What is background radiation?
8. What is the effect of beta decay on the composition of the nucleus?
9. Write the balanced nuclear equation for the alpha decay of radium – 226.

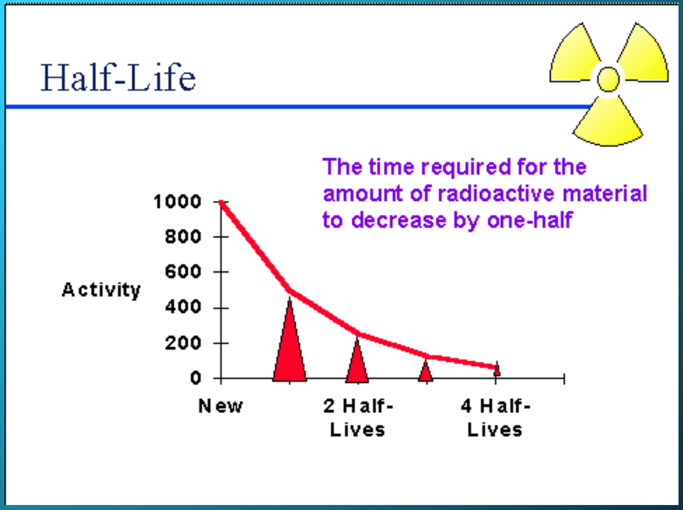
$$^{226}_{88}Ra \rightarrow {}^{4}_{2}He + {}^{222}_{86}Rn$$

10. Fill in the reactant for the following nuclear reaction. $? \rightarrow {}^{3}_{2}He + {}^{0}_{-1}e$

$$? = {}^{3}_{1}H$$

Section 10.2 – Rates of Nuclear Decay

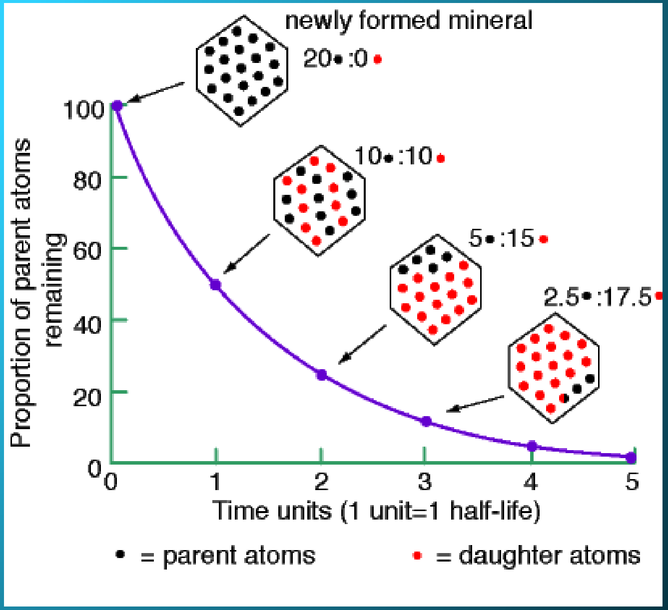
- Every radioisotope decays at a specific rate that can be expressed as a half-life.
- A half-life is the time required for one half of a sample of a radioisotope to decay.
- After one half-life, half of the atoms in a radioactive sample have decayed, while the other half remain unchanged.



Half-Life

- Unlike chemical reaction rates, which vary with the conditions of a reaction, nuclear decay rates are constant.
- To calculate the half-lives, you use the following formula.

$$\#\text{ of half lives} = \frac{\text{total time of decay}}{\text{half-life}}$$



Sample Problem

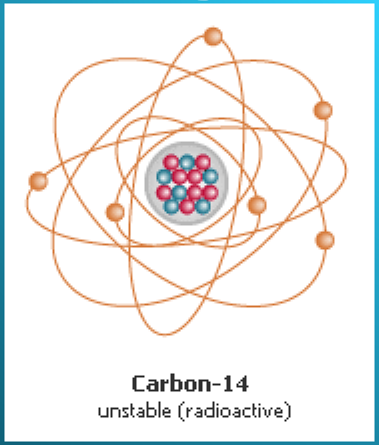
- Suppose you have a 1 gram sample of iridium – 182, which undergoes beta decay with a half-life of 15 minutes. After 45 minutes, how much iridium – 182 will remain in the sample?

$$\# \text{ of half- lives} = \frac{\text{Total time of decay}}{\text{half-life}} = \frac{45 \text{ min.}}{15 \text{ min.}} = 3$$

$$\frac{1g}{2} = \frac{0.5g}{2} = \frac{0.25g}{2} = 0.125g$$

Radioactive Dating

- In radiocarbon dating, the age of an object is determined by comparing the object's carbon-14 levels with carbon-14 levels in the atmosphere.
- Because atmospheric levels of carbon-14 can change over time, the calculated age of a fossil is not totally accurate.



Radiocarbon Dating

- To get a more accurate radiocarbon date, scientists compare the carbon-14 levels in a sample to carbon-14 levels in objects of known age.
- Objects older than 50,000 years contain too little carbon-14 to be measureable.

Section 10.2 Assessment

1. How are nuclear decay rates different from chemical reaction rates?
2. How can scientists determine the age of an object that contains carbon-14?
3. If a radioactive sample has decayed until only one eighth of the original sample remains unchanged, how many half-lives have elapsed?

$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$

3 half – lives have passed

Section 10.2 Assessment

4. Can radiocarbon dating be used to determine the age of dinosaur fossils?
5. A certain isotope of technicium has a half-life of six hours. If it is given to a patient as part of a medical procedure, what fraction of the radioisotope remains in the body after one day?

$\frac{24\text{ hr.}}{6\text{ hr.}} = 4$ half-lives

$$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{16}$$

Warm-Up Apr. 22

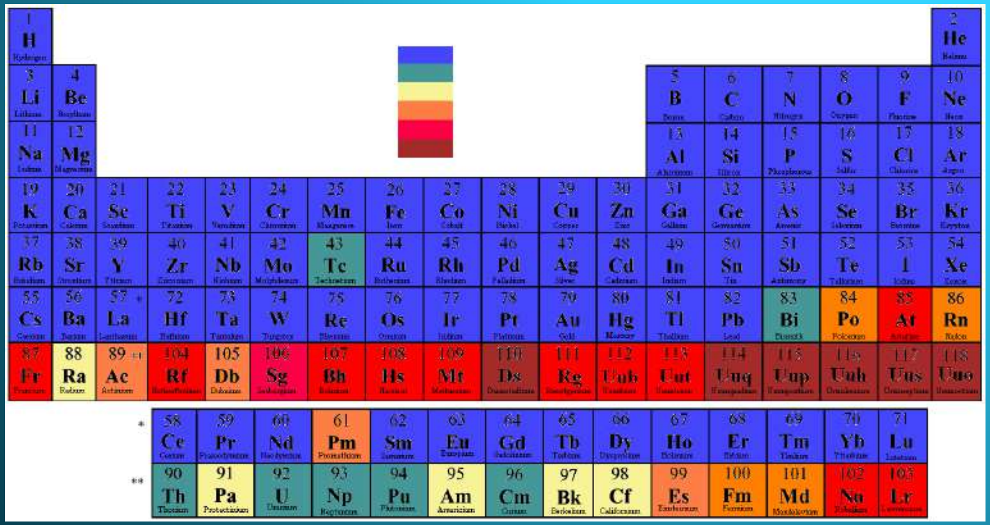
1. What is half-life?
2. What is the formula for calculating how many half-lives have passed?
3. If you start with 50g of a radioisotope that has a half-life of 2 hours, how much of the sample would be left after 4 hours?

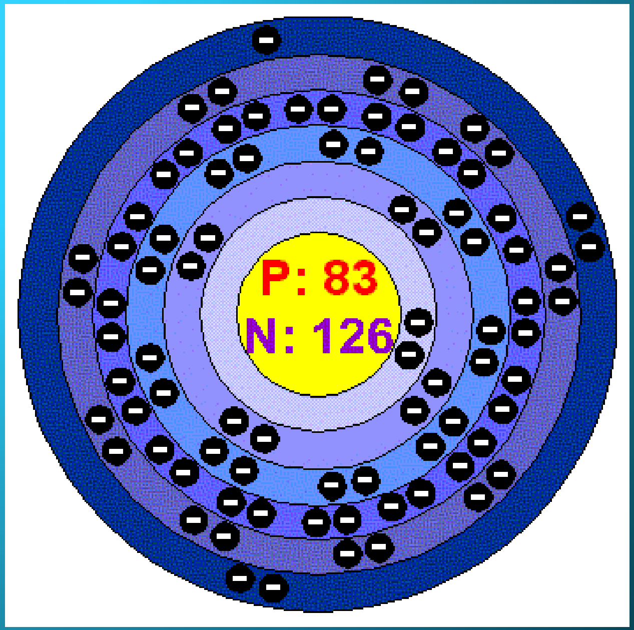
Section 10.4 – Fission and Fusion

- Nuclear energy is energy released by nuclear reactions.
- The strong nuclear force is the attractive force that binds protons and neutrons together in the nucleus.
- Over very short distances, the strong nuclear force is much greater than the electric forces among protons.

Unstable Nuclei

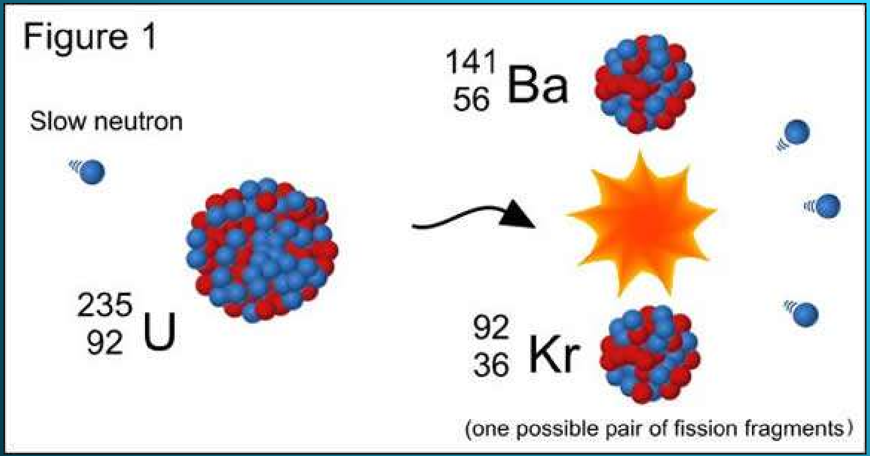
- The greater the number of protons in a nucleus, the greater the electric force that repels those protons.
- All nuclei with more than 83 protons are radioactive.





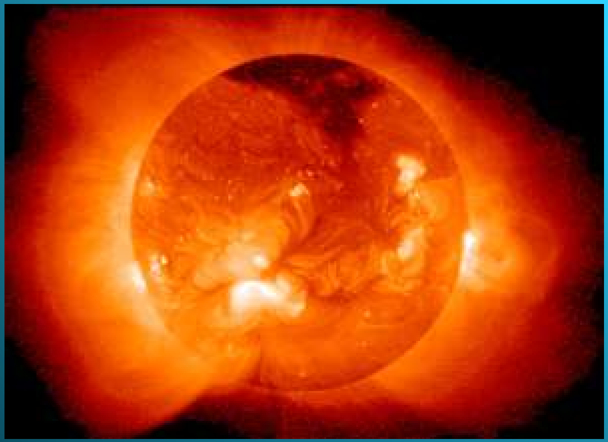
Fission

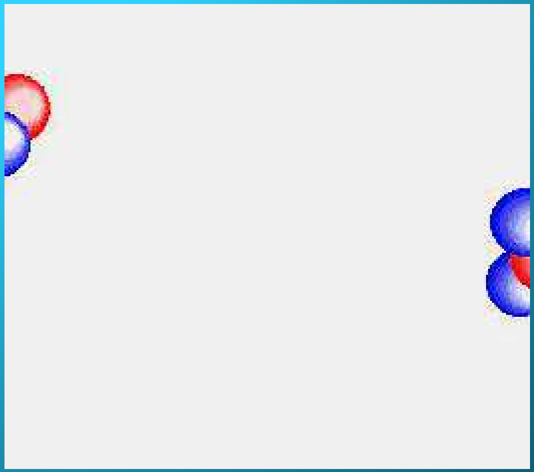
- Fission is the splitting of an atomic nucleus into two smaller parts.
- In nuclear fission, tremendous amounts of energy can be produced from very small amounts of mass.



Fusion

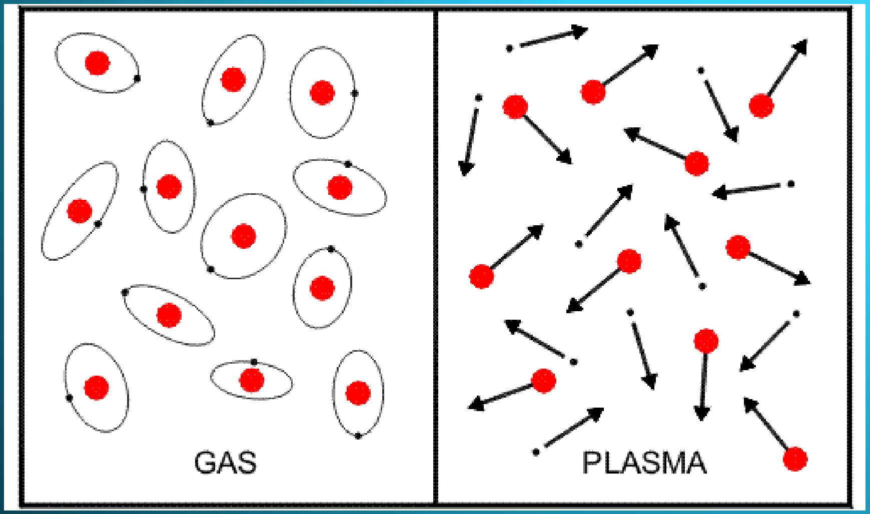
- Fusion is a process in which the nuclei of two atoms combine to form a larger nucleus.
- As in fission, during fusion a small fraction of the reactant mass is converted to energy.
- The sun and other stars are powered by the fusion of hydrogen into helium.

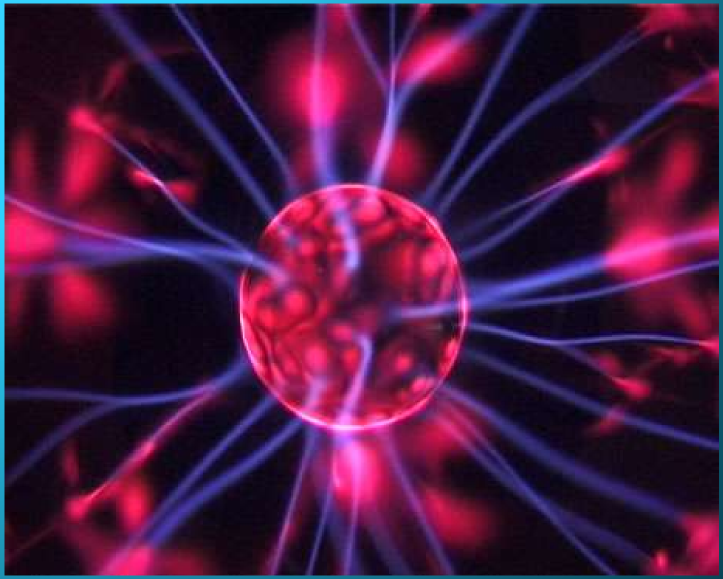




Plasma

- Fusion requires extremely high temperatures.
- Plasma is a state of matter in which atoms have been stripped of their electrons.





Section 10.4 Assessment

1. Under what conditions does the strong nuclear force overcome the repulsive effect of electric forces in the nucleus?
2. What property of fission makes it a useful reaction?
3. What particles are affected by strong nuclear forces?
4. How does the products of a fusion reaction differ from the products of a fission reaction?