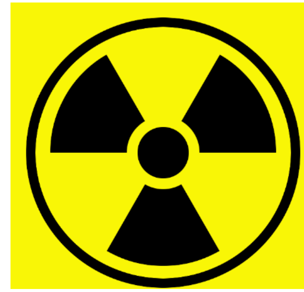
Bonus Unit: Radiation

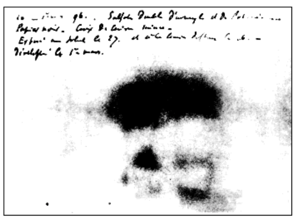
Lesson 1: Atomic Theory and Isotopes



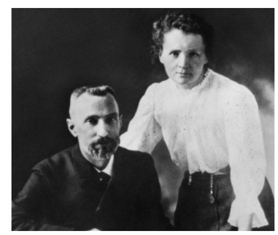
The discovery of Radiation

In 1895 German physicist Wilhelm Roentgen observed that certain materials emitted an unknown kind of energy when he bombarded them with electrons.

These mysterious rays darkened photographic plates just like visible light did



French physicist Henry Becquerel found that a rock containing uranium salts emitted these X-rays naturally (did not have to bombard them with electrons)



Chemists Marie and Pierre Curie were able to isolate the minerals emitting the X-rays and found it to be from the uranium atoms in the rock sample.

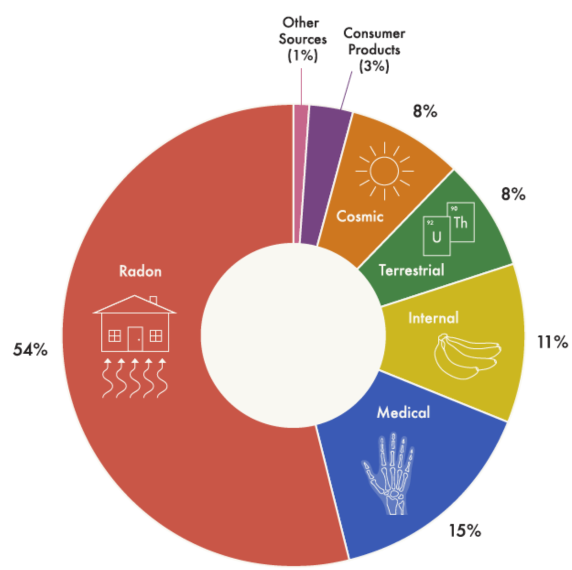
They called this process radioactivity

Radioactivity

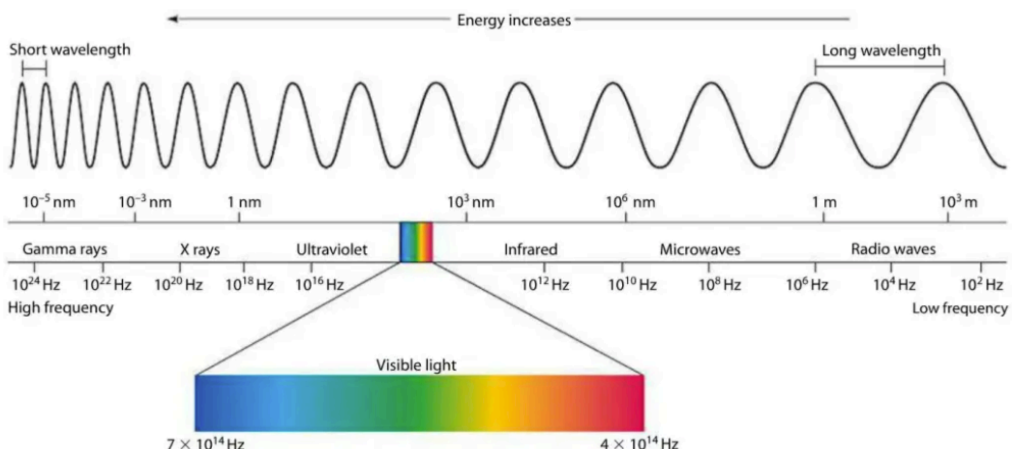
Radioactivity is the release of high-energy particles and rays of energy from a substance as a result of changes in the nuclei of atoms.

Radiation is the general term for these high-energy particles and rays of energy.

These processes occurs all around us and are known as Natural Background Radiation.

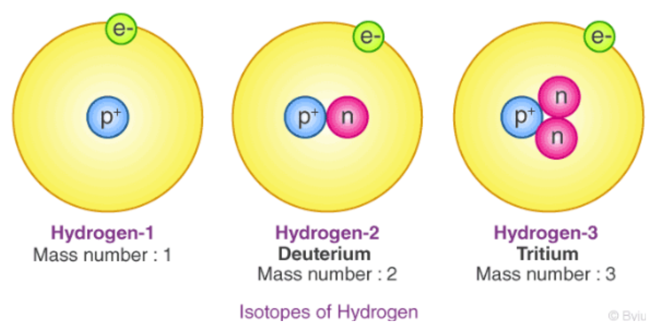


The electromagnetic spectrum covers all of the different types of energy rays.



Note that, regardless of the type of radiation (microwave, gamma rays, etc), the amount of energy contained in one wavelength is constant but because gamma rays hit an object more frequently, it imparts more energy to that object

Isotopes



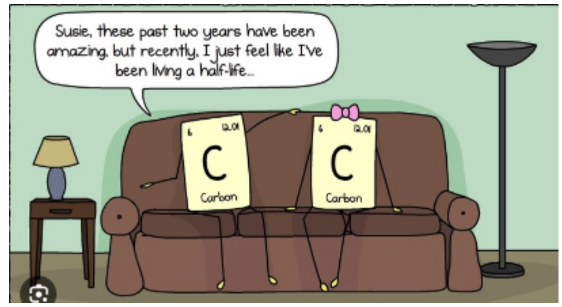
Recall from the periodic table that some elements have different atomic masses.

Where does the change in masses come from?

All of the mass in an atom is located in the nucleus. Atomic number has to stay the same or you change the element. The only thing that can change is the number of neutrons.

Isotopes are atoms of the same element with different atomic masses (different number of neutrons). This can make some nuclei unstable

Eg.1 Carbon occurs naturally in 3 forms:



$^{12}_{6}C$, $^{13}_{6}C$, $^{14}_{6}C$ ← called standard atomic notation or the nuclear symbol

Isotope	# Protons	# Electrons	# Neutrons
$^{12}_{6}C$	6	6	6
$^{13}_{6}C$	6	6	7
$^{14}_{6}C$	6	6	8

Carbon 12 ($^{12}_{6}C$) and Carbon 13 ($^{13}_{6}C$) are the stable isotopes

Carbon 14 ($^{14}_{6}C$) is the unstable form

Radiation is the result of unstable nuclei of some atoms giving off energy as they become a more stable nuclei.

Isotopes

1. What is an isotope?

____

2. Atomic number + number of neutrons = ______________

3. Number of protons + number of neutrons = ______________

4. Mass number – atomic number = ______________

Use the following standard atomic notation of an isotope to answer questions 5 to 7.

______________ → 13

______________ → 5

$^{13}_{5}B$

5. Label the mass number and the atomic number.

6. What is the name of this isotope? ______________

7. Determine the number of subatomic particles for this isotope:

(a) number of protons = ______________

(b) number of electrons = ______________

(c) number of neutrons = ______________

8. In each of the following cases, what element does the symbol X represent and how many neutrons are in the nucleus?

(a) ${}^{21}_{10}X$ Element = ____________

Number of neutrons = ________

(b) ${}^{32}_{16}X$ Element = ____________

Number of neutrons = ________

(c) ${}^{230}_{89}X$ Element = ____________

Number of neutrons = ________

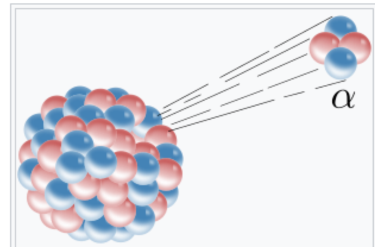
(d) ${}^{234}_{90}X$ Element = ____________

Number of neutrons = ________

9. Complete the following table. The first row has been completed to help guide you.

Isotope	Standard atomic notation	Atomic number	Mass number	Number of protons	Number of neutrons
carbon-14	${}^{14}_{6}C$	6	14	6	8
		27	52		
nickel-60					
			14	7	
thallium-201					
	${}^{226}_{88}Ra$				
				82	126

Lesson 2: Radioactive Decay



Radioactivity

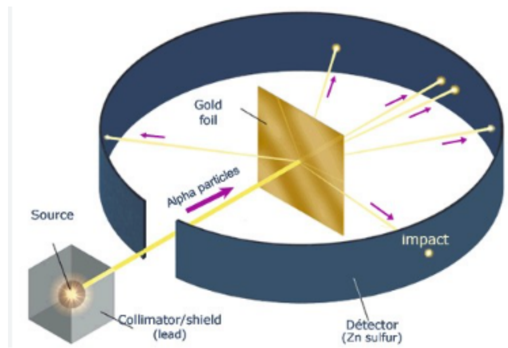
Radioactivity is the release of energy as a result of changes in the nuclei of an atom.

Scientists discovered that when radioactive energy was given off, the atoms of one type of element were changed into the atoms of another type of element.

Isotopes that are unstable become stable by losing energy by emitting radiation

- This process of giving off radiation is called radioactive decay
- When an the atom of an element decays, it usually turns into a different type of atom

Types of Radiation

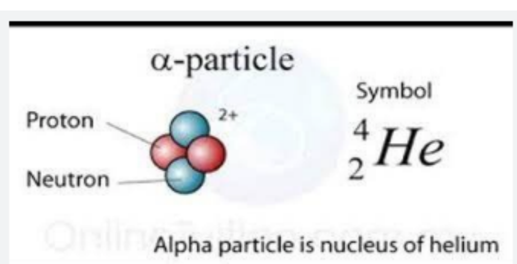


While working at McGill University in Montreal, Ernest Rutherford discovered that there are three common types of radiation:

1. Alpha Radiation

A stream of alpha particles is called alpha decay.
The Alpha particle is the same as the nucleus of a helium atom (${}^{4}_{2}\mathrm{He}$ or ${}^{4}_{2}\alpha$).

Because there is only 2 protons and 2 neutrons present, an alpha particle has a charge of +2.



Alpha particles are the largest and most massive type of radiation. They are relatively slow moving and they do not penetrate through other objects. Alpha particles can be stopped by a sheet of paper.

Since 2 protons are given off, a different type of atom is formed with an atomic number 2 less than the parent atom

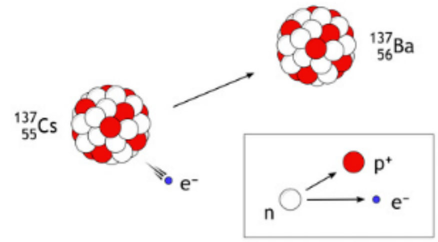
Example: ${}^{208}_{84}\mathrm{Po} \rightarrow {}^{204}_{82}\mathrm{Pb} + {}^{4}_{2}\alpha$

Daughter Isotope

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

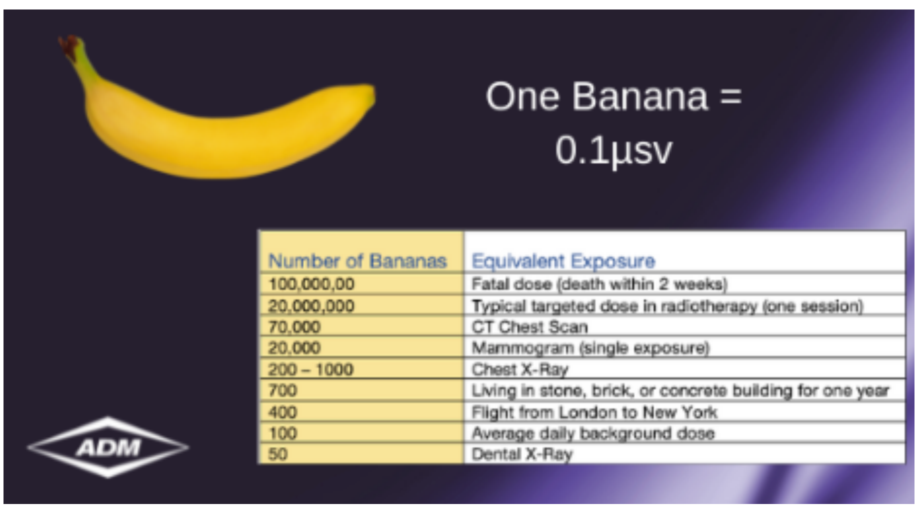
2. Beta Radiation

A beta particle is equal to a high energy electron which is called beta decay



- Written as $^{0}_{-1}e$ or $^{0}_{-1}\beta$
- Has a charge of -1
- Lightweight and fast moving
- Can penetrate more than an alpha particle
- Can be stopped by a sheet of aluminum foil

The electron comes from the breakdown of a neutron which forms an electron and a proton which increases the atomic number by 1

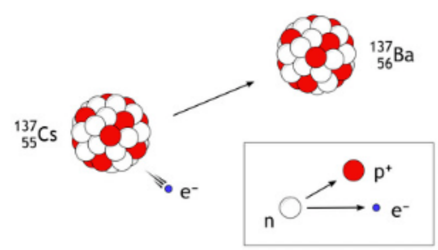


Number of Bananas	Equivalent Exposure
100,000,00	Fatal dose (death within 2 weeks)
20,000,000	Typical targeted dose in radiotherapy (one session)
70,000	CT Chest Scan
20,000	Mammogram (single exposure)
200 – 1000	Chest X-Ray
700	Living in stone, brick, or concrete building for one year
400	Flight from London to New York
100	Average daily background dose
50	Dental X-Ray

Example:

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

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



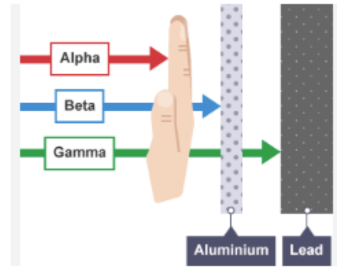
3. Gamma Radiation

Gamma radiation is a ray of high-energy, short wavelength energy. When an atom emits a gamma ray this is called gamma decay.

Results when the nucleus of an atom has too much energy

Gamma decay can be written as $^{0}_{0}\gamma$

Gamma rays have almost no mass and no charge and have the greatest penetrating power. Thick blocks of dense material (lead or concrete) are required to stop them.



Does not result in the formation of a new atom

Example: $^{60}_{28}\text{Ni}^* \rightarrow ^{60}_{28}\text{Ni} + ^{0}_{0}\gamma$ the * means extra energy

Gamma decay can happen when other types of radioactive decay produce a new atom with too much energy in the nucleus.

Example: $^{238}_{92}\text{U} \rightarrow ^{234}_{90}\text{Th}^* + ^{4}_{2}\alpha$

$$^{234}_{90}\text{Th}^* \rightarrow ^{234}_{90}\text{Th} + 2^{0}_{0}\gamma$$

Indicate whether the description is referring to an alpha particle, a beta particle, or a gamma ray. The description can refer to more than one of the forms of radiation.

(a) $^{0}_{0}\gamma$ ______________________

(b) $^{0}_{-1}\beta$ or $^{0}_{-1}e$ ______________________

(c) $^{4}_{2}\alpha$ o+++r $^{4}_{2}$He ______________________

(d) has a charge of 0 ______________________

(e) has a charge of 1- ______________________

(f) has a charge of 2+ ______________________

(g) is a helium nucleus ______________________

(h) is a high-speed electron ______________________

(i) is emitted from the nucleus ______________________

(j) is emitted only during beta decay ______________________

(k) is emitted only during alpha decay ______________________

(l) can be stopped by aluminum foil ______________________

(m) is emitted only during gamma decay ______________________

(n) is affected by electric and magnetic fields ______________________

(o) is not affected by electric and magnetic fields ______________________

(p) is a high energy wave with short wavelengths ______________________

(q) is the highest energy form of electromagnetic radiation ______________________

(r) has low penetrating power (can be stopped by a single piece of paper) ______________________

Identify each nuclear equation as alpha decay, beta decay, or gamma decay, and then complete the nuclear equation.

1. $^{32}_{15}P \dashrightarrow {}^{32}_{16}S$ + ________ ________________
2. $^{218}_{84}Po \dashrightarrow$ ________ + $^{4}_{2}He$ ________________
3. ________ $\dashrightarrow {}^{18}_{5}Ar$ + $^{0}_{-1}e$ ________________
4. $^{24}_{12}Mg^{*} \dashrightarrow$ ________ + $^{0}_{0}\gamma$ ________________
5. $^{234}_{91}Pa \dashrightarrow$ ________ + $^{4}_{2}\alpha$ ________________
6. $^{141}_{58}Ce \dashrightarrow$ ________ + $^{0}_{-1}e$ ________________
7. $^{216}_{84}Po \dashrightarrow$ ________ + $^{0}_{-1}\beta$ ________________
8. $^{20}_{9}F \dashrightarrow {}^{20}_{10}Ne$ + ________ ________________
9. $^{58}_{26}Fe^{*} \dashrightarrow {}^{58}_{26}Fe$ + ________ ________________
10. ________ $\dashrightarrow {}^{221}_{87}Fr$ + $^{4}_{2}\alpha$ ________________
11. $^{149}_{64}Gd^{*} \dashrightarrow$ ________ + $^{0}_{0}\gamma$ ________________
12. $^{226}_{86}Ra \dashrightarrow {}^{222}_{26}Rn$ + ________ ________________
13. ________ $\dashrightarrow {}^{212}_{82}Pb$ + $^{0}_{-1}\beta$ ________________
14. $^{214}_{83}Bi \dashrightarrow {}^{210}_{81}Tl$ + ________ ________________
15. ________ $\dashrightarrow {}^{254}_{98}Cf$ + $^{0}_{0}\gamma$ ________________

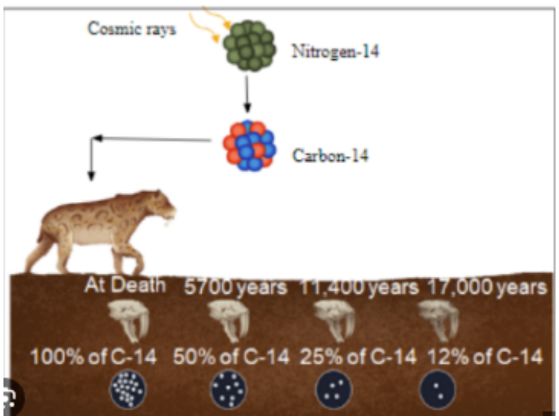
Lesson 3: Half Life Decay

Half Life

The amount of time required for half of the radioactive atoms in a sample to decay

Strontium-90 has a half-life of 29 years which means if 10 g of strontium-90 was started with, there would only be 5 g of strontium-90 after 29 years had passed

This is a useful tool because it can be used to date things



Carbon Dating

Uses Carbon-14 to date the remains of organic materials.

Carbon-14 has a half-life of 5730 years

All organic materials contain the same percentage of carbon-14 (1 in a trillion carbon) atoms. As carbon atoms decay in a living organism, they are constantly replaced so the total number of carbon-14 atoms is almost constant.

When an organism dies, it no longer takes in carbon-14 atoms so the total number starts to decrease.

By measuring the amount of carbon-14 left in a sample, the length of time it has been dead can be determined.

Only useful for samples up to 50 000 years old. After this, there is not enough carbon-14 left to measure

Radioactive Dating

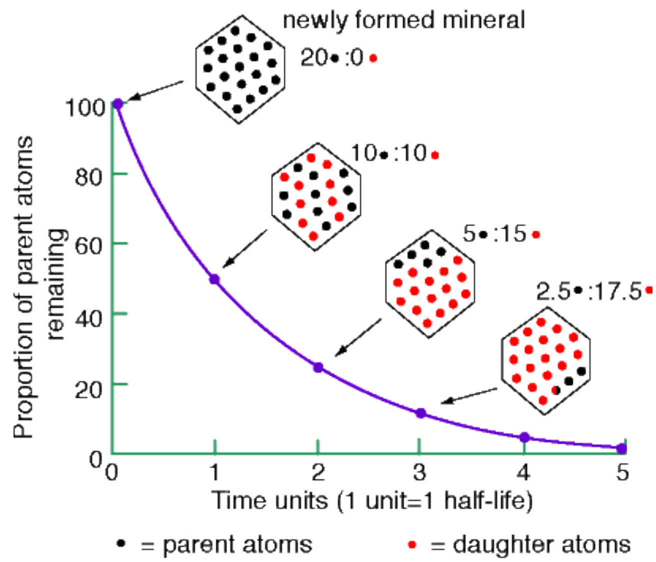
Other elements with different half-lives can be used to age older samples

Radioactive Element	Half-Life
Radon-222	3.8 days
Potassium-40	1.3 billion years
Uranium-238	4.5 billion years
Rubidium-87	49 billion years

Decay Curve

A decay curve is a graph that shows the quantity of a radioactive isotope left after a given period of time.

The shape of a decay curve for different radioactive isotopes does not change, only the time frame changes.



Half-Life Calculations

Eg. 1. Iodine-131 has a half-life of 8 days. If you started with 50 grams of iodine-131, how much would be left after:

a) 8 days?

$8 \div 8 = 1$ → 1 half-life has passed

b) 32 days?

$32 \div 8 = 4$ → 4 half-lives

50g ÷ 2 ÷ 2÷ 2 ÷ 2 = 3.125g

1. Use the decay curve to answer the questions.

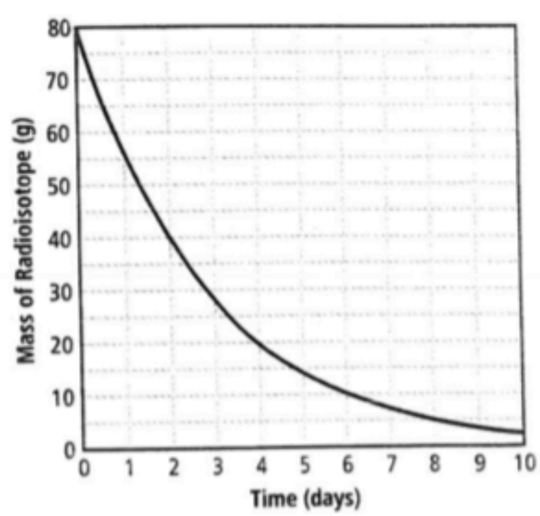
(a) What is the half-life of the isotope? ____________

(b) How much of the parent isotope remains after 4 days? ____________

(c) How much of the daughter isotope is present after 6 days? ____________

(d) What fraction of the parent isotope remains after 8 days? ____________

(e) How long does it take for the parent isotope to decay to 5 g? ____________



2. Use the decay curve to answer the questions.

(a) What is the common isotope pair for this decay curve? ____________________

(b) What is the half-life of the parent isotope?

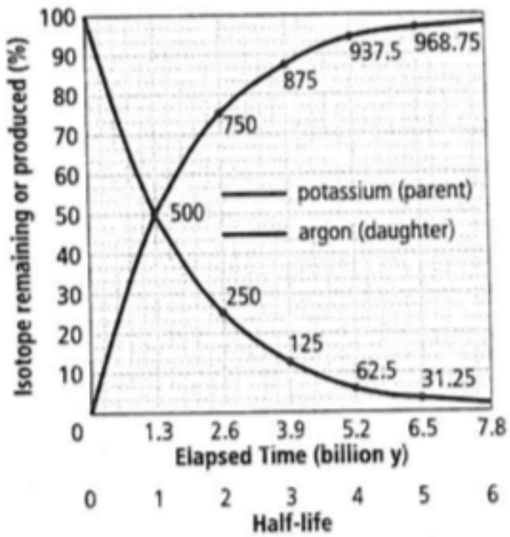
____

(c) What does the intersection of the two lines represent? ____________________

(d) What fraction of the daughter isotope is present after 5.2 billion years have passed?

____

(e) What is the ratio of parent isotope to daughter isotope after 2.6 billion years have passed? ____________________



Calculating half-life

1. A radioactive isotope has a half-life of 10 minutes.

(a) What fraction of the parent isotope will be left after 30 minutes?

____

(b) What percent of the parent isotope will be left after 40 minutes?

____

(c) What fraction of the daughter isotope will be present after 20 minutes?

____

(d) What percent of the daughter isotope will be present after 50 minutes?

____

2. A 36 g sample of a radioactive isotope decayed to 4.5 g in 36 minutes. How much of the original parent isotope would remain after the first 12 minutes?

____

3. The half-life of a particular radioactive isotope is 8 hours. What percent of the parent isotope would remain after 1 day? ____________________

4. A radioactive isotope sample has a half-life of 4 days. If 6 g of the sample remains unchanged after 12 days, what was the initial mass of the sample?

____

5. Suppose the ratio of a radioactive parent isotope to a stable daughter isotope within a rock sample is 1:3. The half-life of the parent isotope is 710 million years. How old is the rock sample? ______________

6. A rock sample was dated using potassium-40. Measurement indicates that 1/8 of the original parent isotope is left in the rock sample. How old is the rock sample?

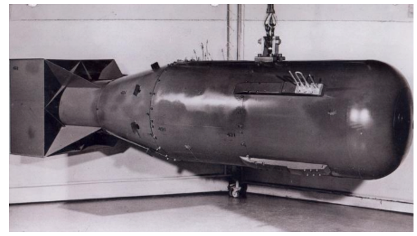
____

7. When a sample of lava solidified, it contained 28 g of uranium-238. If that lava sample was later found to contain only 7 g of U-238, how many years had passed since the lava solidified? ______________

8. After 25 years, the number of radioactive cobalt atoms in a sample is reduced to $\frac{1}{32}$ of the original count. What is the half-life of this isotope? ______________

9. The half-life of Sr-90 is 28 years. If an 80 g sample of Sr-90 is currently in a sample of soil, how much Sr-90 will be present in the soil 84 years later? ______________

Lesson 4: Nuclear Reactions



Nuclear Fission

Nuclear reaction in which the nucleus of a massive atom is split into two smaller nuclei, subatomic particles and energy

This results in the production of a large amount of energy

Example: fission of 1 g of uranium-235 = energy from burning 2 tonnes of coal

Or, explosion is 1 million times greater than TNT by mass.

Advantage

Allows the use of a small amount of nuclear material to produce large amounts of electricity

Disadvantage

Results in the production of radioactive waste material with a long half-life

Waste materials must be stored

Life span of nuclear reactors is approximately 40 years

Fission reactions can be induced (caused to occur) by bombarding certain atoms with neutrons

Nuclear Fission of Uranium

$$\underbrace{{}^{1}_{0}n + {}^{235}_{92}\mathrm{U}}_{\text{Uranium atom combined with a neutron}} \rightarrow \underbrace{{}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 3\ {}^{1}_{0}n + \text{energy}}_{\text{Two new elements formed plus 3 neutrons and energy}}$$

Rules:

The sum of the atomic mass on each side must equal

The sum of the charges must equal (count atomic numbers)

This is the reaction used in the Canadian-built CANDU (Canadian Deuterium Uranium) reactors

Chain Reactions

The above reaction was started by a neutron hitting a stable atom of uranium to create an unstable uranium nucleus.

Note that on the products side are three new neutrons. These neutrons are free to collide with three other uranium atoms to create three new fission reactions each of which will result in 3 more neutrons and so it continues.

Chain Reaction is a self-driving reaction

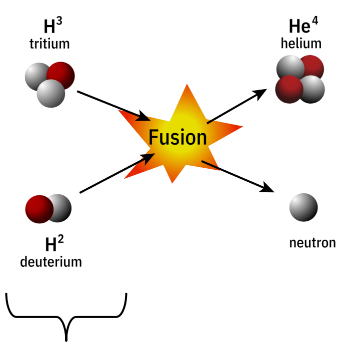
This reaction is slowed down using a cooling system

If the reaction gets out of control, it results in a nuclear reactor meltdown.

The reaction produces so much energy that it literally destroys the power plant and releases all of the radioactive waste material into the environment.

Nuclear Fusion

Nuclear fusion is the process of combining two nuclei into one more massive nucleus. This is the process that drives solar reactions in our Sun



Hydrogen-2 and Hydrogen-3 isotopes

Advantages of Fusion vs. Fission

Produces approximately 4.5 times the amount of energy per equivalent mass of starting material.

Product is helium, a non-hazardous material

Disadvantages

Need extreme temperatures and pressures (10 million Kelvin in sun = 100 million Kelvin on Earth due to less pressure)

Have no way to contain the energy and heat from a nuclear fusion reaction

Only way to start a fusion reaction at present is with a fission reaction (ex: Hydrogen bomb

On March 1, 1954, a deliverable hydrogen bomb using solid lithium deuteride was tested by the United States on Bikini Atoll in the Marshall Islands. By missing an important fusion reaction, the scientists had grossly underestimated the size of the explosion.
The predicted yield was 5 megatons, but, in fact, "BRAVO" yielded 14.8 megatons, making it the largest U.S. nuclear test ever exploded.

The blast gouged a crater more than ½ mile wide and several hundred feet deep and ejected several million tons of radioactive debris into the air. Within seconds the fireball was nearly 3 miles in diameter.