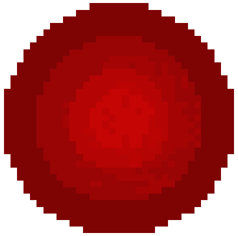
Physics 2204

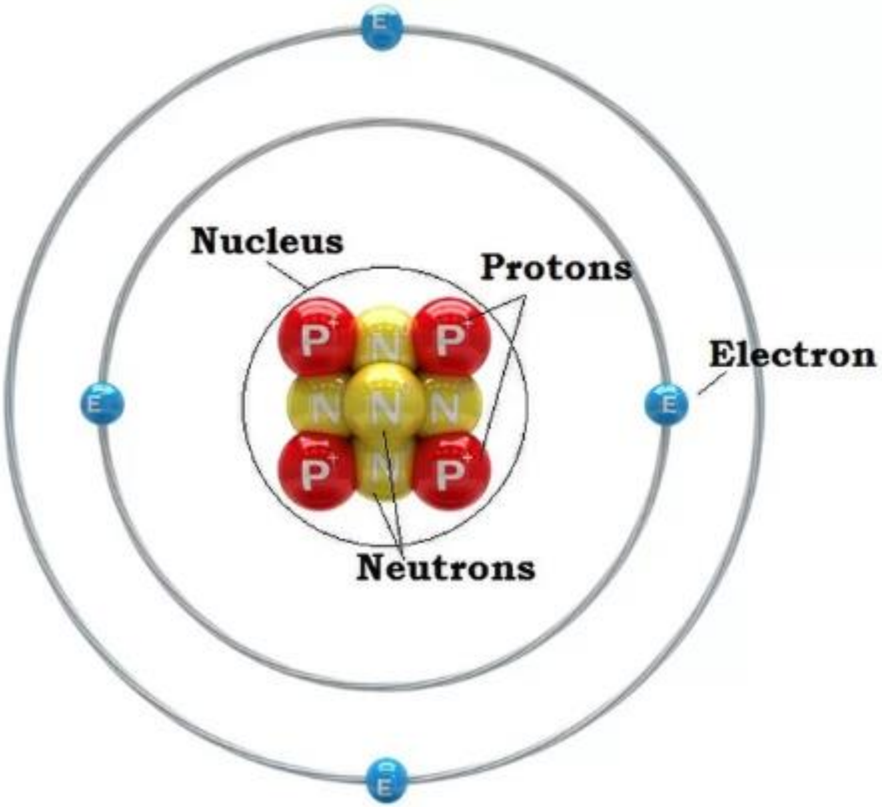
UNIT 3 Topic 11



- Nuclear Structure and Properties

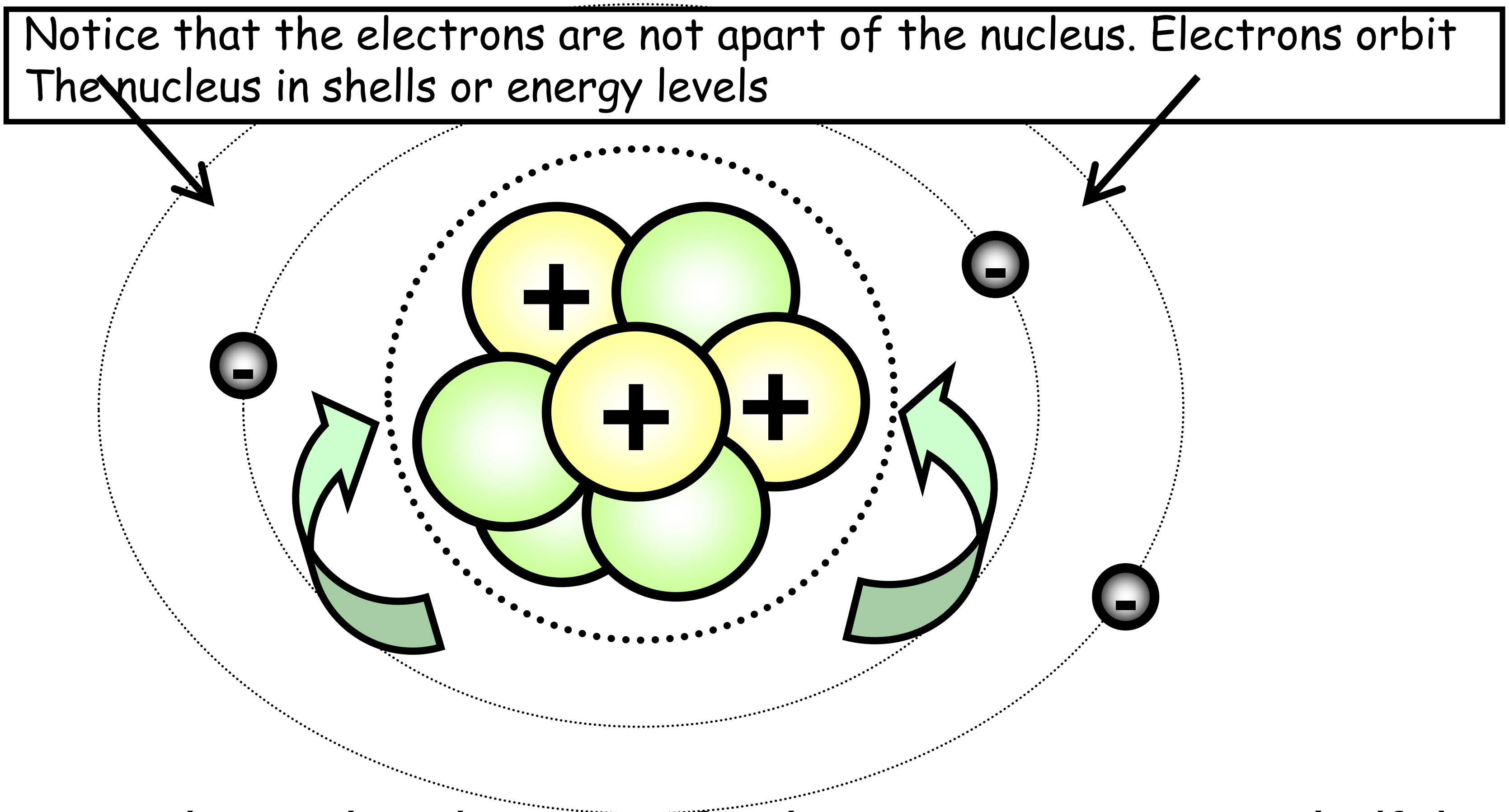
The Atom

Atom refers to the smallest unit of any chemical element. It is the building block of matter.



Model of the atom

- Protons and neutrons are grouped together to form the “center” or <u>**nucleus**</u> of an atom.

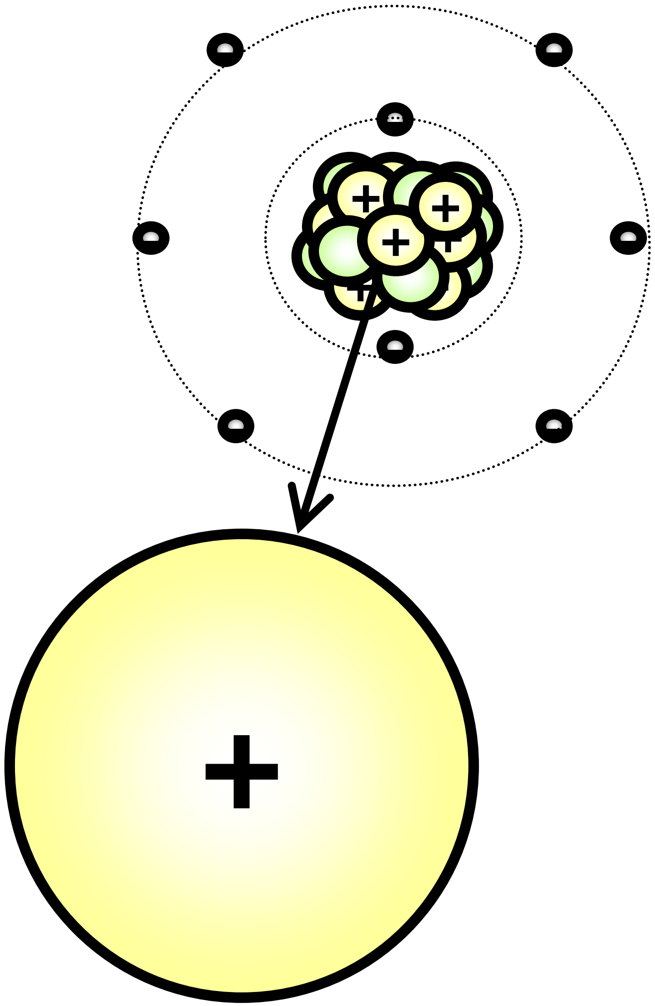


Notice that the electrons are not apart of the nucleus. Electrons orbit
The nucleus in shells or energy levels

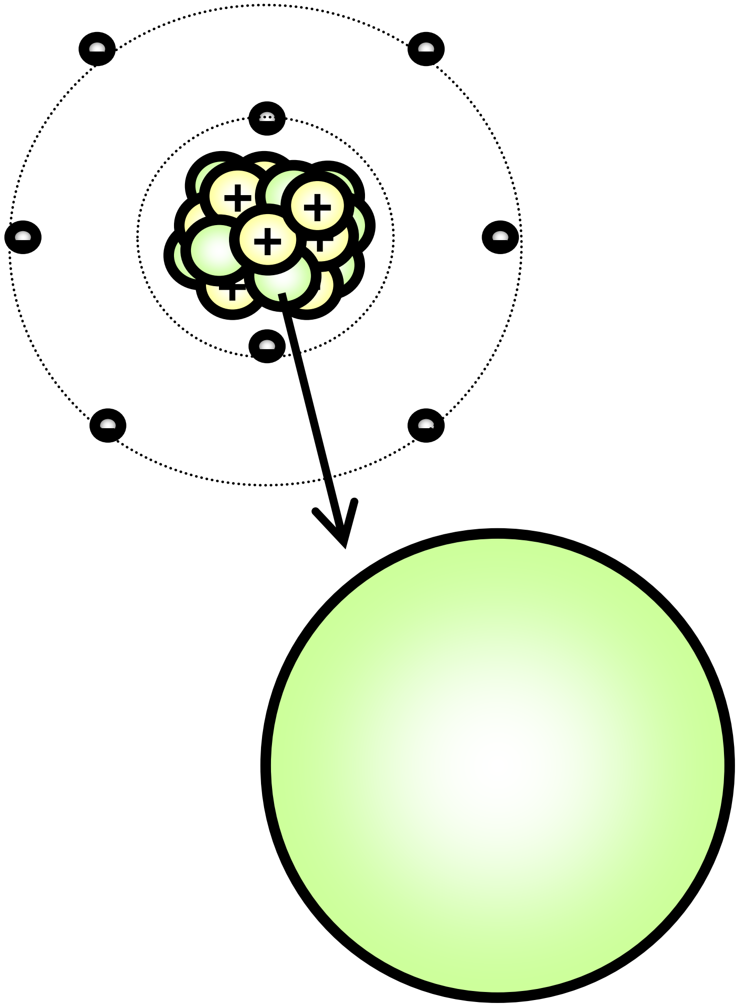
Only **protons** determine the type of substance. For example if the atoms each contain 79 protons (and 79 electrons), then you have gold.

Protons (+)

- Positively charged particles
- Help make up the nucleus of the atom
- Help identify the atom (could be considered an atom's DNA)
- Equal to the atomic number of the atom
- Contribute to the atomic mass
- Equal to the number of electrons



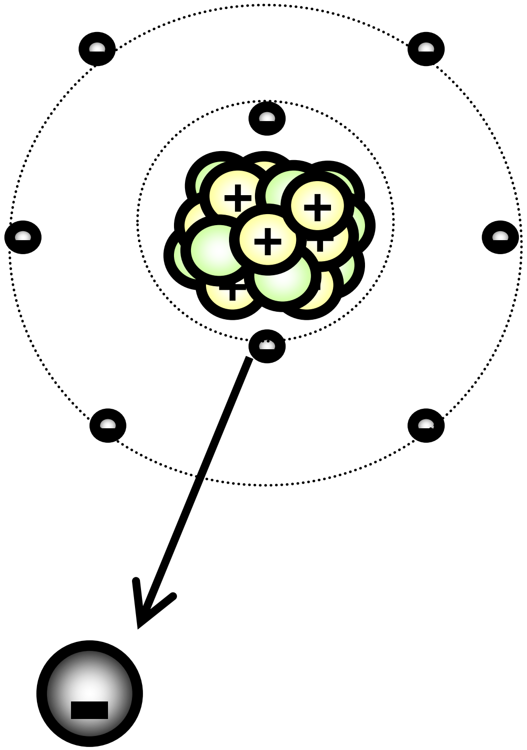
Neutrons



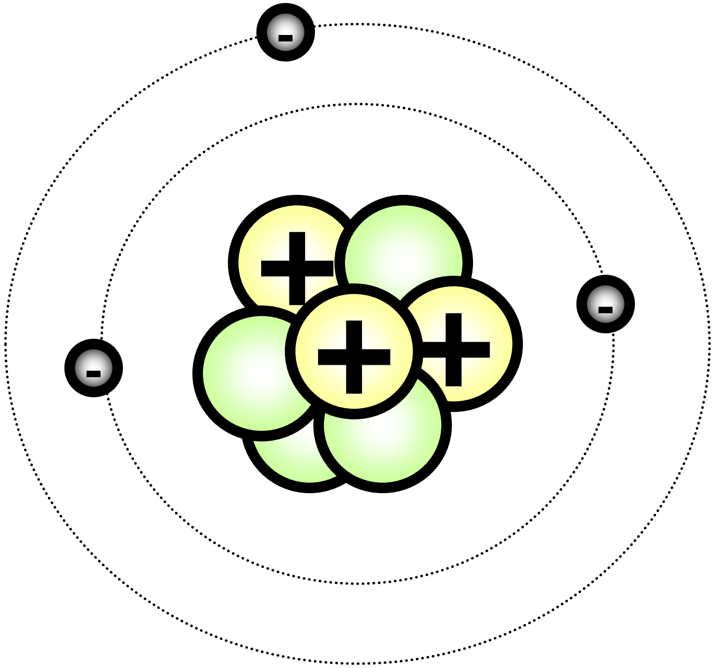
- Neutral particles; have no electric charge
- Help make up the nucleus of the atom
- Contribute to the atomic mass

Electrons (-)

- Negatively charged particles
- Found outside the nucleus of the atom, in the electron
- Move so rapidly around the nucleus that they create an electron cloud
- Mass is insignificant when compared to protons and neutrons
- Equal to the number of protons
- Involved in the formation of chemical bonds



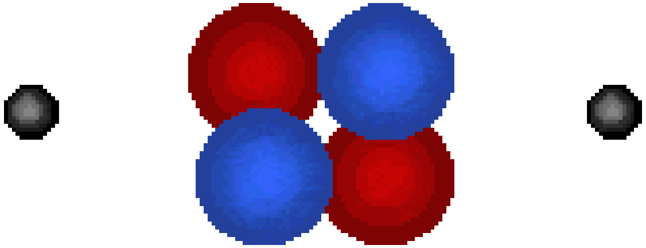
Atomic Number



- This refers to how many protons an atom of that element has.
- No two elements, have the same number of protons.

Atomic Mass Number

- Atomic Mass refers to the “weight” of the atom.
- It is derived at by adding the number of protons with the number of neutrons.



This is a helium atom. Its atomic
Hmass is 4 (protons plus neutrons).

What is its atomic number?

How do I find the number of protons, electrons, and neutrons in an element using the periodic table?

of PROTONS = ATOMIC NUMBER

# of ELECTRONS = ATOMIC NUMBER

# of NEUTRONS = ATOMIC WEIGHT _ ATOMIC NUMBER

ATOMIC FORMULA

4 **Atomic mass** the number of protons and neutrons in an atom

He

2 **Atomic number** the number of protons in an atom

number of electrons = number of protons

Isotopes

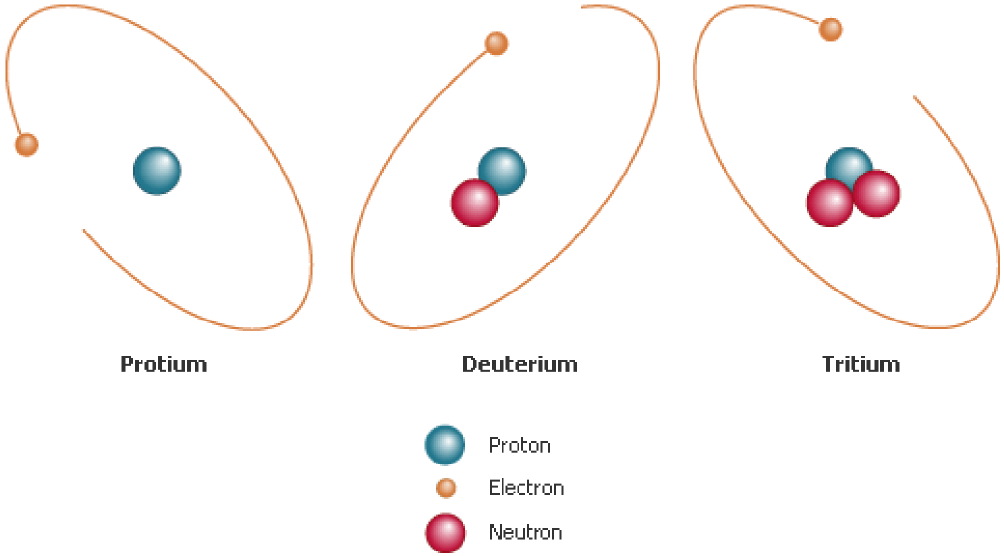
- **Isotopes** are atoms of the same elements that contain different numbers of neutrons. Neutrons carry no charge, they do not affect the chemical properties of the substance except to add weight.

Isotopes of chlorine

$^{35}_{17}\text{Cl}$ $^{37}_{17}\text{Cl}$

chlorine - 35 **chlorine - 37**

Three Isotopes of Hydrogen



Hydrogen isotopes:	normal hydrogen -	${}^{1}_{1}H$	mass = 1.67353×10^{-27} kg
	deuterium -	${}^{2}_{1}H$	mass = 3.34449×10^{-27} kg
	tritium -	${}^{3}_{1}H$	mass = 5.00827×10^{-27} kg

Isotopes - atoms of the same element (same Z) but having differing numbers of neutrons and thus differing atomic mass (differing A).

Example 1

What is the atomic notation for the isotope of element X that has 30 electrons and 36 neutrons.

Example 2:

An atom has a mass number of 222 and an atomic number of 86. Find the name of the element, its symbol, the number of protons (or electrons), and the number of neutrons using a periodic table.

Example 3:

How many protons, neutrons, and nucleons are in the nucleus of:

$${}^{45}_{20}Ca$$

Units For Mass of an atom

Three ways to write the mass of an atomic particle

1. Kilogram

proton: 1.67262×10^{-27} kg
neutron: 1.67493×10^{-27} kg
electron: 9.1164×10^{-31} kg

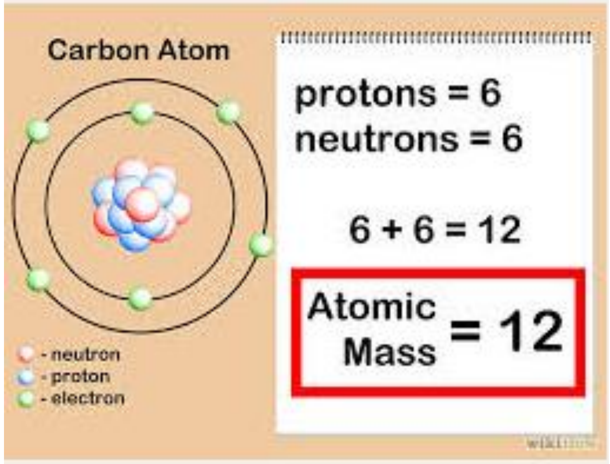
2. Unified atomic mass unit (amu), represented by the letter u.

As a result of the masses of atoms and subatomic particles being so small it was convenient to use atomic mass unit:

One atomic mass unit (1u) is equal to one twelfth of the mass of the most abundant form of the carbon atom—Carbon 12

$$1\ \text{u} = 1.6605 \times 10^{-27}\ \text{kg.}$$

An atom that is twice as massive as carbon-12 will have a mass of 24 u. Of course when considering isotopes the periodic table gives the mass of carbon as 12.011 u.



3. The electron-volt energy unit (energy equivalence unit)

We can use $E = mc^2$ to determine the energy equivalent (in electron-volts) of a particle with mass 1u.

$c = 2.9979 \times 10^{8}$ m/s
$1 \text{ u} = 1.6605 \times 10^{-27}$ kg.

$E = mc^2 = 1.6605 \times 10^{-27} \text{ kg} \times (2.9979 \times 10^{8} \text{ m/s})^2$
$= 1.4924 \times 10^{-10}$ J.

Recall that $1 \text{ eV} = 1.6022 \times 10^{-19}$ J.

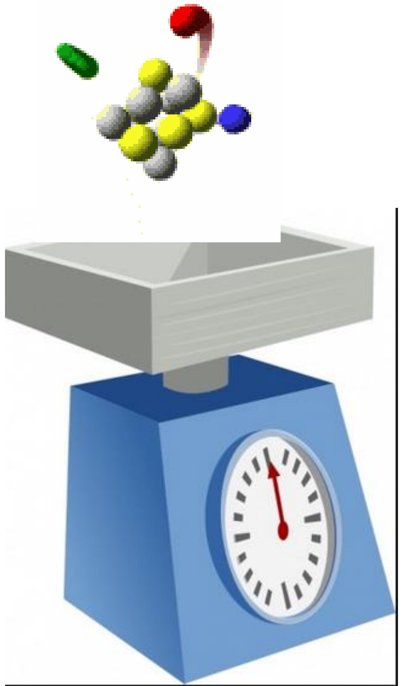
$E = 1.4924 \times 10^{-10} \text{ J} \div 1.6022 \times 10^{-19} \text{ J/eV}$
$E = 931{,}500{,}000 \text{ eV} = 931.5 \times 10^{6} \text{ eV}$
$E = 931.5 \text{ MeV}$ (where M stands for 10^6 or mega)

Summary

To convert between the units :

1 u = 1.6605×10^{-27} kg = 931.5 MeV/c^2.

This conversions factor is found on your formula sheet



Example 4:

If an element has atomic mass of 18.9984 u, what is its mass in kg.

Example 5:

An element has a mass of 6.647×10^{-27} kg. What is its mass in unified atomic mass units (u) ?

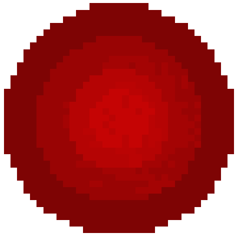
Example 6:

A particle has a mass of 106 MeV/c^2.

What is this mass in atomic mass units (u) and in kg?

Physics 2204

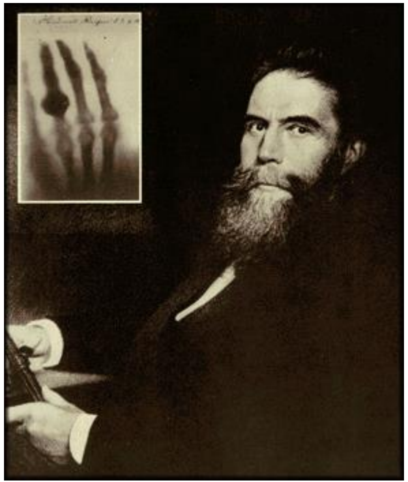
UNIT 3   Topic 12



- **Nuclear Stability**

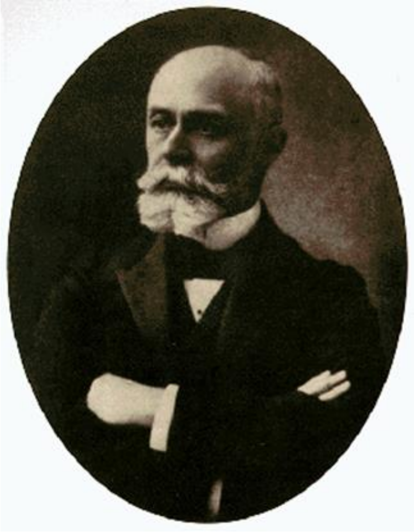
The Discovery of Radioactivity

- **Wilhelm Roentgen** (1845–1923)
  - 1895-invisible rays were emitted when electrons bombarded the surface of certain materials.
    - caused photographic plates to darken.
    - named the invisible high-energy emissions **X rays.**

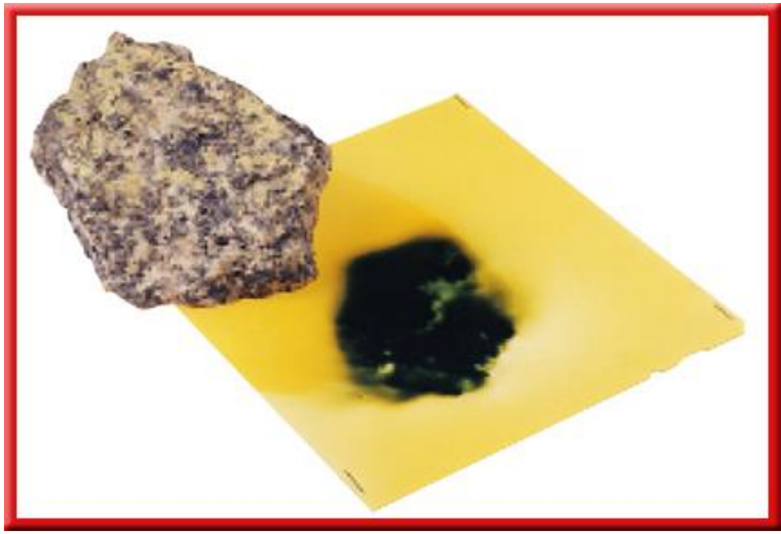


Henri Becquerel (1852–1908) was studying **phosphorescence**

- minerals that emit light after being exposed to sunlight



•Phosphorescent uranium salts produced spontaneous emissions that darkened photographic plates.



- **Marie Curie** (1867–1934) and her husband Pierre (1859–1906) took Becquerel's mineral sample (called pitchblende) and isolated the components emitting the rays.

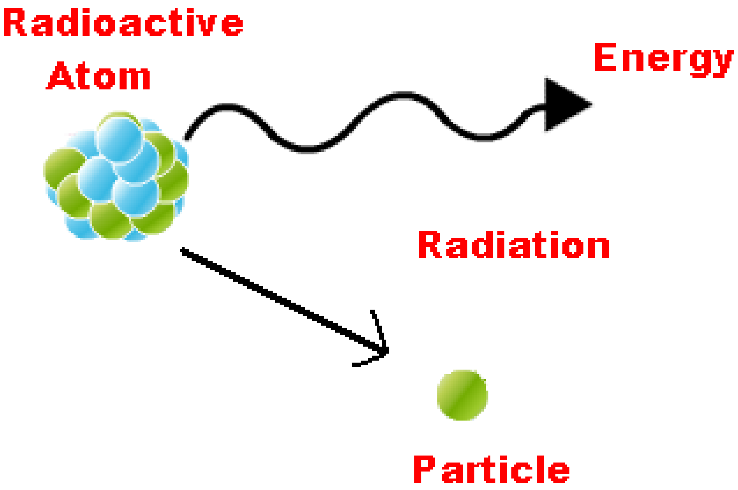
- Darkening of the photographic plates was due to rays emitted specifically from the uranium atoms present in the mineral sample.

Marie Curie named the process by which materials give off such **rays radioactivity**

the rays and particles emitted by a radioactive source are called **radiation.**

What is Radioactivity

- **Radioactivity (Radioactive decay)** is the process by which an unstable nucleus emits one or more particles or energy in the form of electromagnetic radiation. (it just wants to become stable)



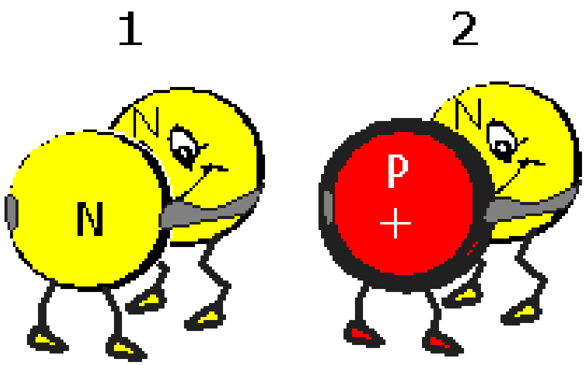
- In some instances, a new element is formed and in other cases, a new form of the original element, called an isotope, appears.

- the nucleus decays into a different atom.

Why Does Radioactivity Occur?

- The 4-part picture below may help you understand the roles of these two forces.

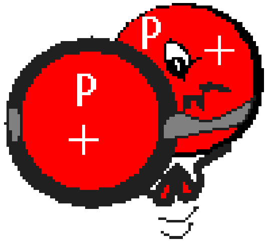
- The yellow particles are neutrons and the red particles are protons.



1 - Here you see **two neutrons attracted to each** other. Their arms represent the **strong nuclear force**. Obviously, the strong nuclear force is not caused by charge because neutrons have no charge.

2 - The **same strong nuclear force exists between protons and neutrons**.

3



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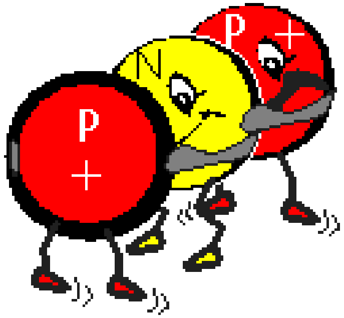


3 - Here there is a conflict:

- The **protons are bound together by the strong nuclear force**.

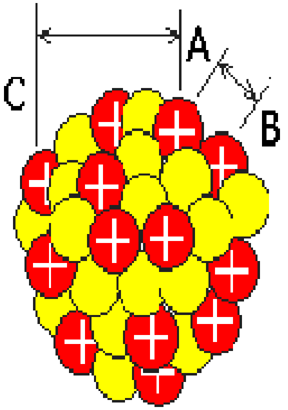
- However, all protons have the same positive charge, and you know from earlier lessons that "like charges repel". **These two protons are being repelled by the electric force.**

- If a nucleus were made up entirely of protons, it would be in great danger of disintegrating because the repelling electric force would overcome the strong nuclear force.

4 - The Neutron has placed himself between the two protons. All three particles are bound together by "the glue" of the **strong nuclear force**, and the protons are separated a little bit so the repelling electric force has a smaller effect.

- However, **as *Z* or atomic number increases**, the electric repelling force among the many protons would cause the nucleus to disintegrate to some degree if it were not for many more neutrons than protons

Proton C is so far from A that only the repelling electric force is in play.

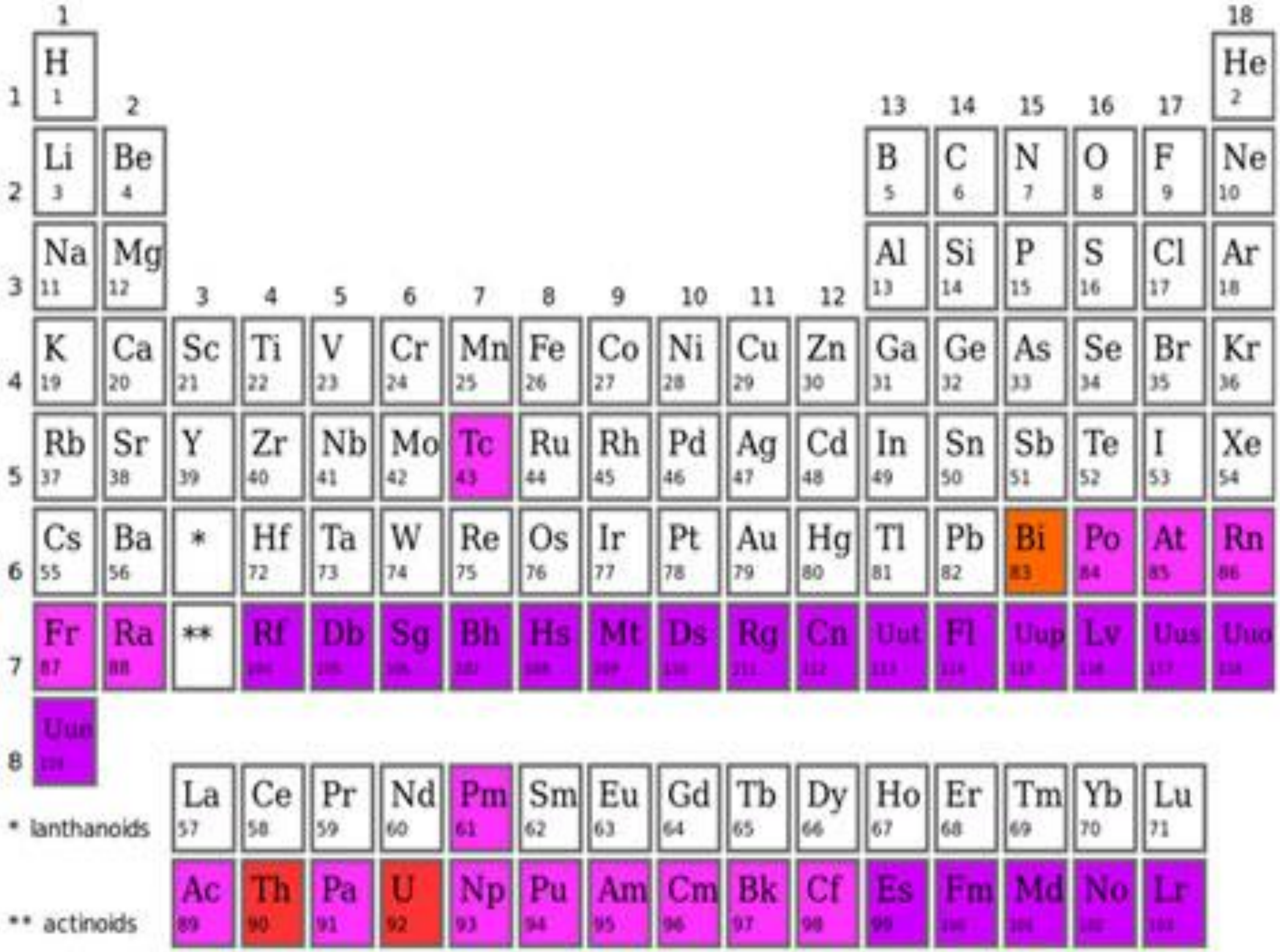


Proton A attracts proton B via the strong nuclear force, and also repels B via the electric force.

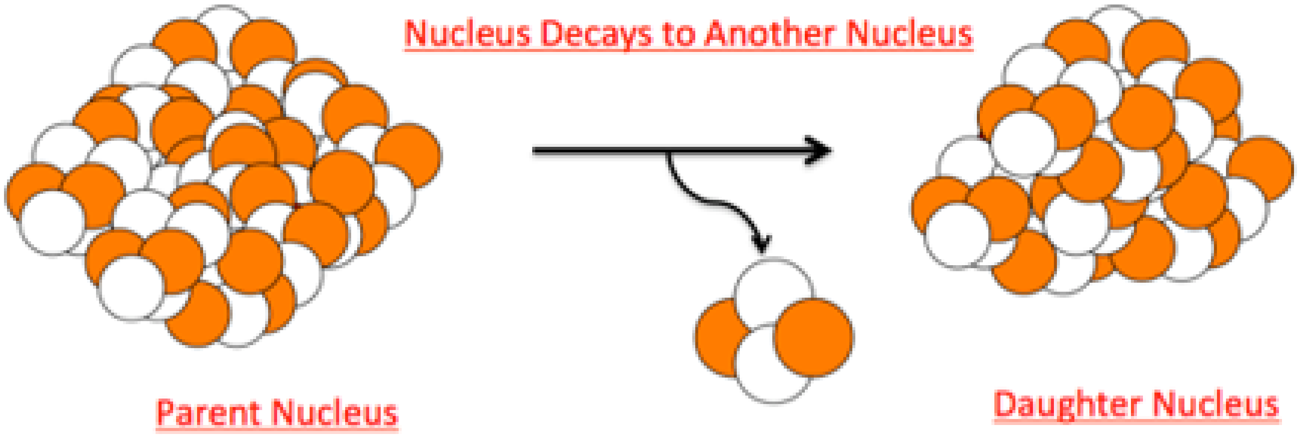
As a nucleus becomes larger, a proton only repels its distant neighbours. The distant protons are too far away to experience the strong nuclear force.

- However, when a nucleus becomes large (Z > 82), **the short-range strong nuclear force that acts only between neighboring particles cannot counterbalance the repelling electric force that each proton exerts on all other protons.**

All the elements heavier than Bismuth (At # 83)



Transmutation refers to the changing of one element into another by the process of radioactivity

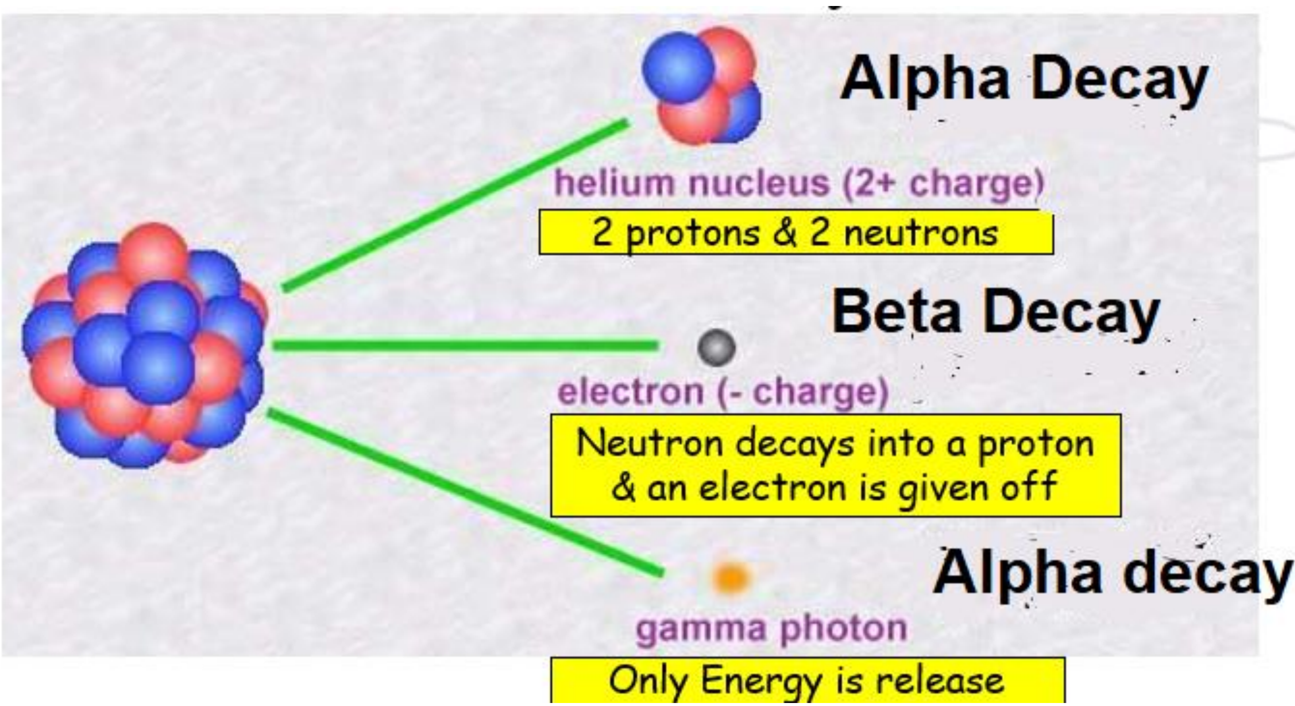


Particles or energy might be **emitted from a <u>parent nucleus</u>** resulting in a **new element called a <u>daughter nucleus</u>** which itself might be unstable and subsequently emit more particles or energy.

Three Types of Natural Transmutation

There are three types of natural Transmutations:

1) Alpha Decay
2) Beta Decay
3) Gamma Decay

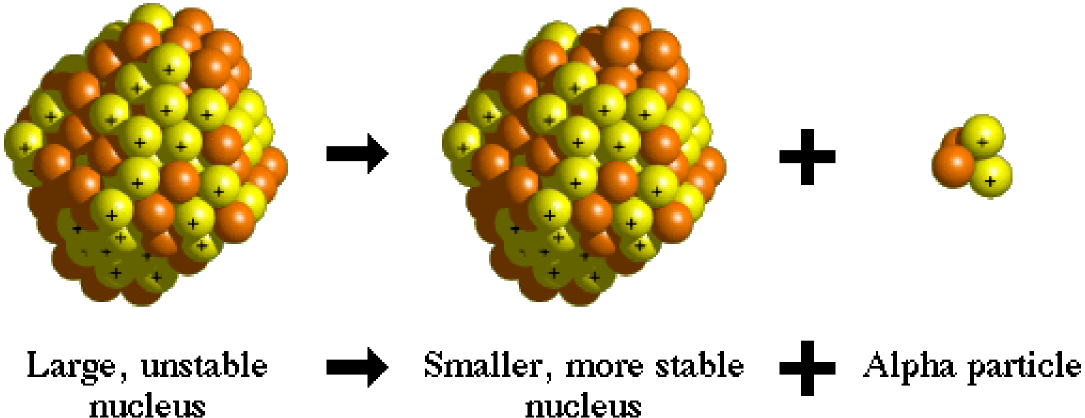


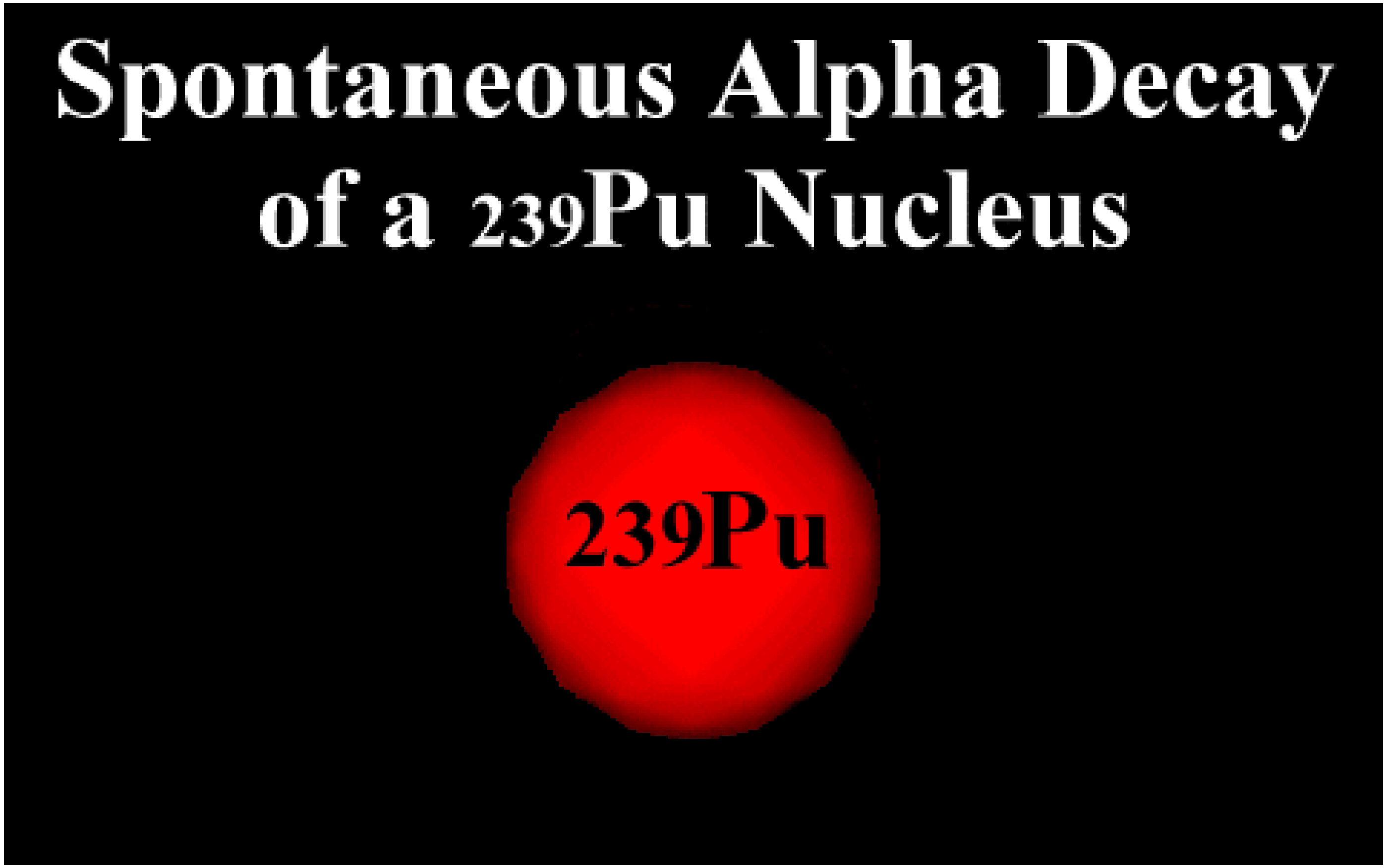
1) Alpha Decay

- Occurs when the nucleus is too large.
- An alpha particle is emitted, reducing the size of the nucleus.

Alpha particles consist of **2 protons and 2 neutrons**. This accounts for its mass and its charge. The atomic notation for an alpha particle is:

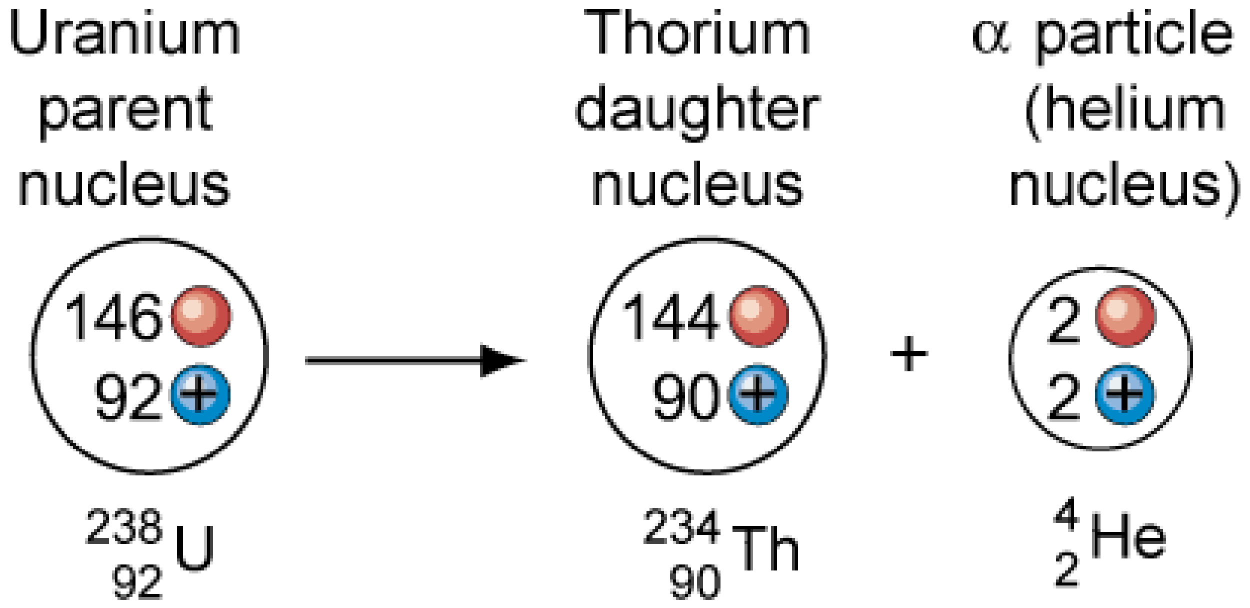
${}^{4}_{2}\alpha$ has the same form as ${}^{4}_{2}He$. You must remember, however, that the alpha particle has no electrons. Consequently, alpha particles must be **helium nuclei**





There is a difference in mass between the original nucleus and the sum of the mass of the alpha particle and resulting nucleus. This lost mass is converted into energy using the formula $E = mc^2$; the energy would equal the kinetic energy of the particle and the recoil energy of the resulting nucleus.

Uranium experiences Alpha Decay into Thorium



The general notation for alpha decay is therefore:

Parent Element

Daughter Element

α Particle

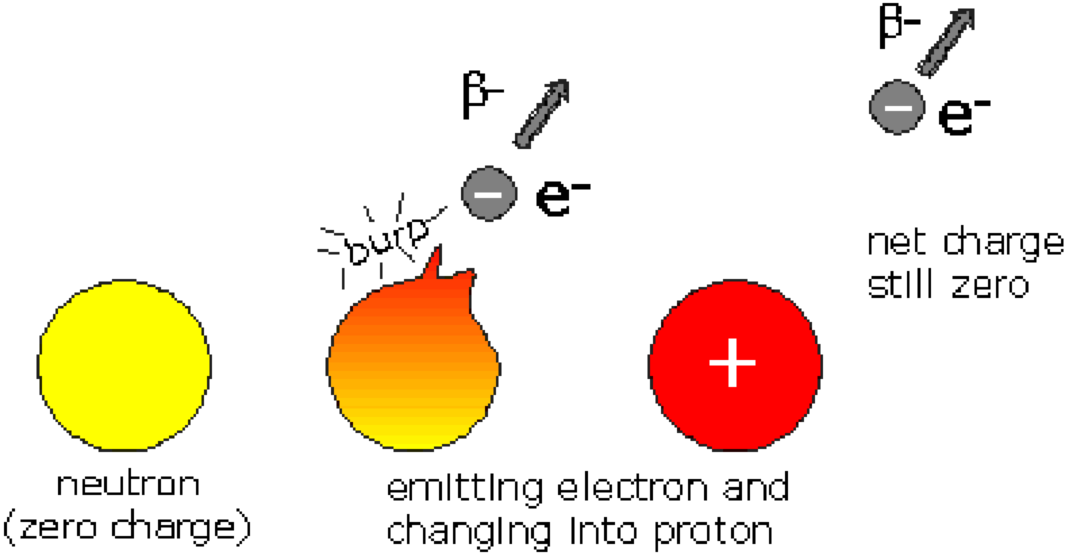
$${}^{A}_{Z}\mathrm{X} \rightarrow {}^{A-4}_{Z-2}\mathrm{Y} + {}^{4}_{2}\mathrm{He}$$

2) Natural Transmutations: Beta Decay

Occurs because the nucleus has too many neutrons relative to protons

The parent nucleus emits an electron (e-) as a neutron decays to a proton

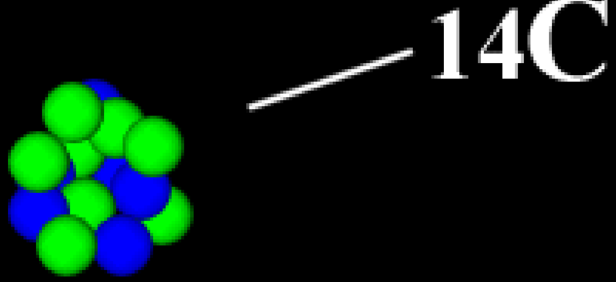
- The picture shows a neutron changing into a proton, emitting an electron as it does so. Note that the amount of charge is conserved. It was zero before the decay, and adds up to zero after the decay



ß- Decay

🟢 - Neutron

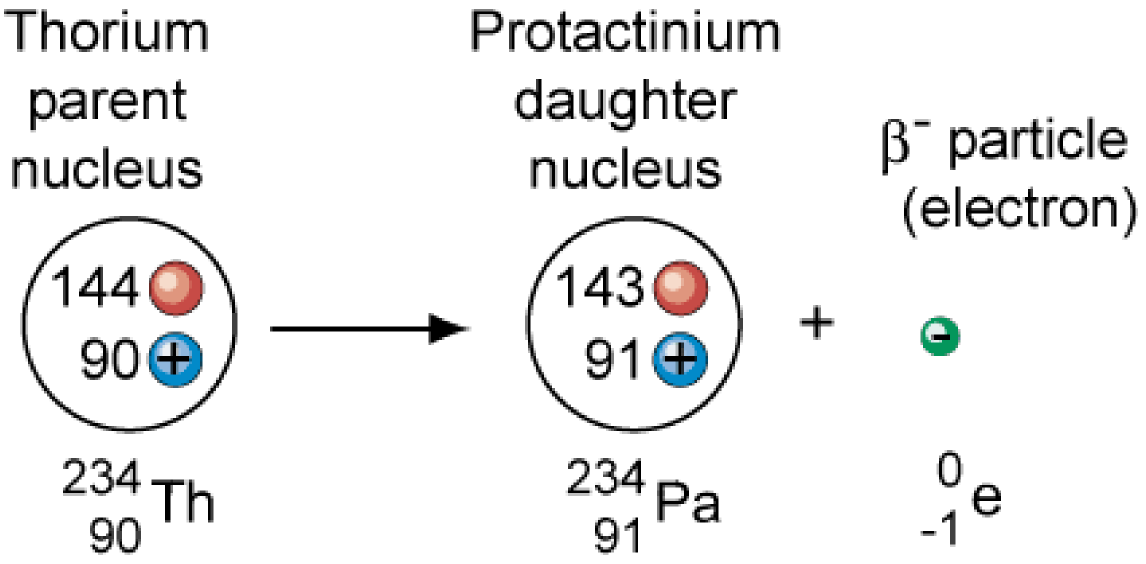
🔵 - Proton



Thorium experiences decay into protactinium

- One neutron converts to a proton and a β particle (electron) is released.

-

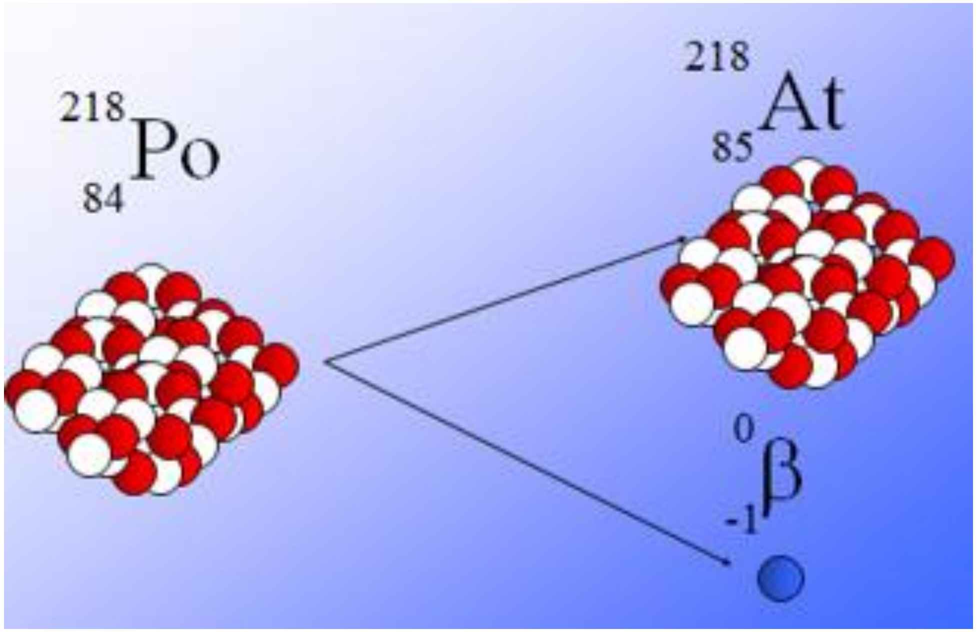


-The general notation for B-Decay is therefore:

Parent Element **Daughter Element** **β Particle**

$$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}e$$

-

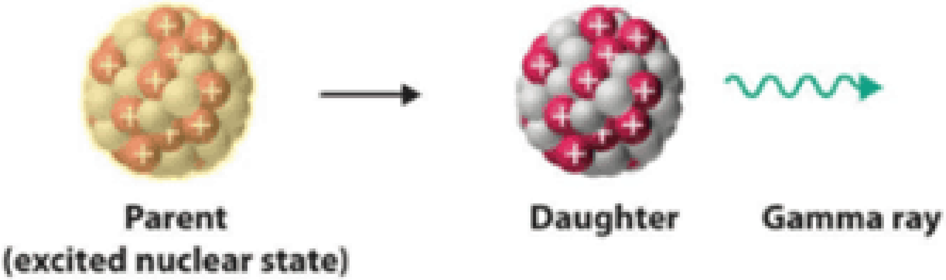


3)Natural Transmutations: Gamma Decay

- A nucleus which is in an excited state emits one or more packets of electromagnetic radiation of discrete energies. It does release charged particles like alpha and Beta
- The emission of gamma rays does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from a higher to a lower energy state (unstable to stable).

Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes.

$$^{234m}_{91}Pa \qquad ^{234}_{91}Pa + {}^{0}_{0}\gamma$$

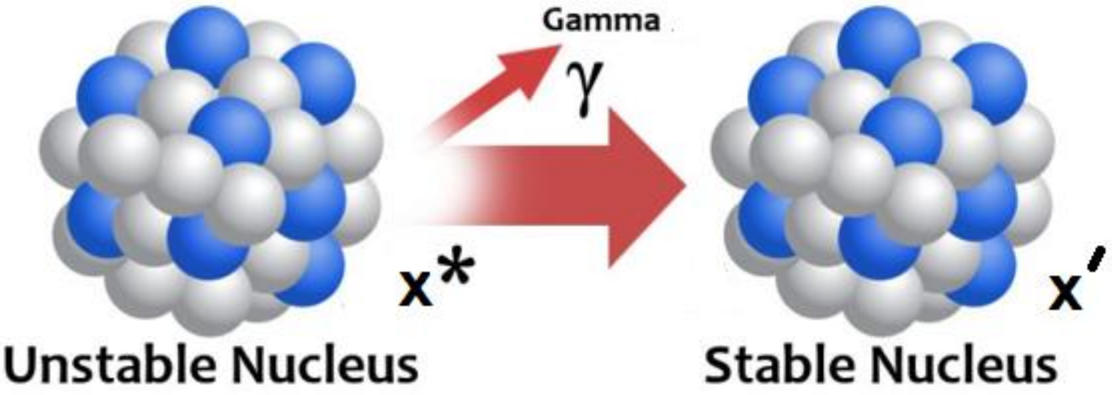


The general notation for B-Decay is therefore:

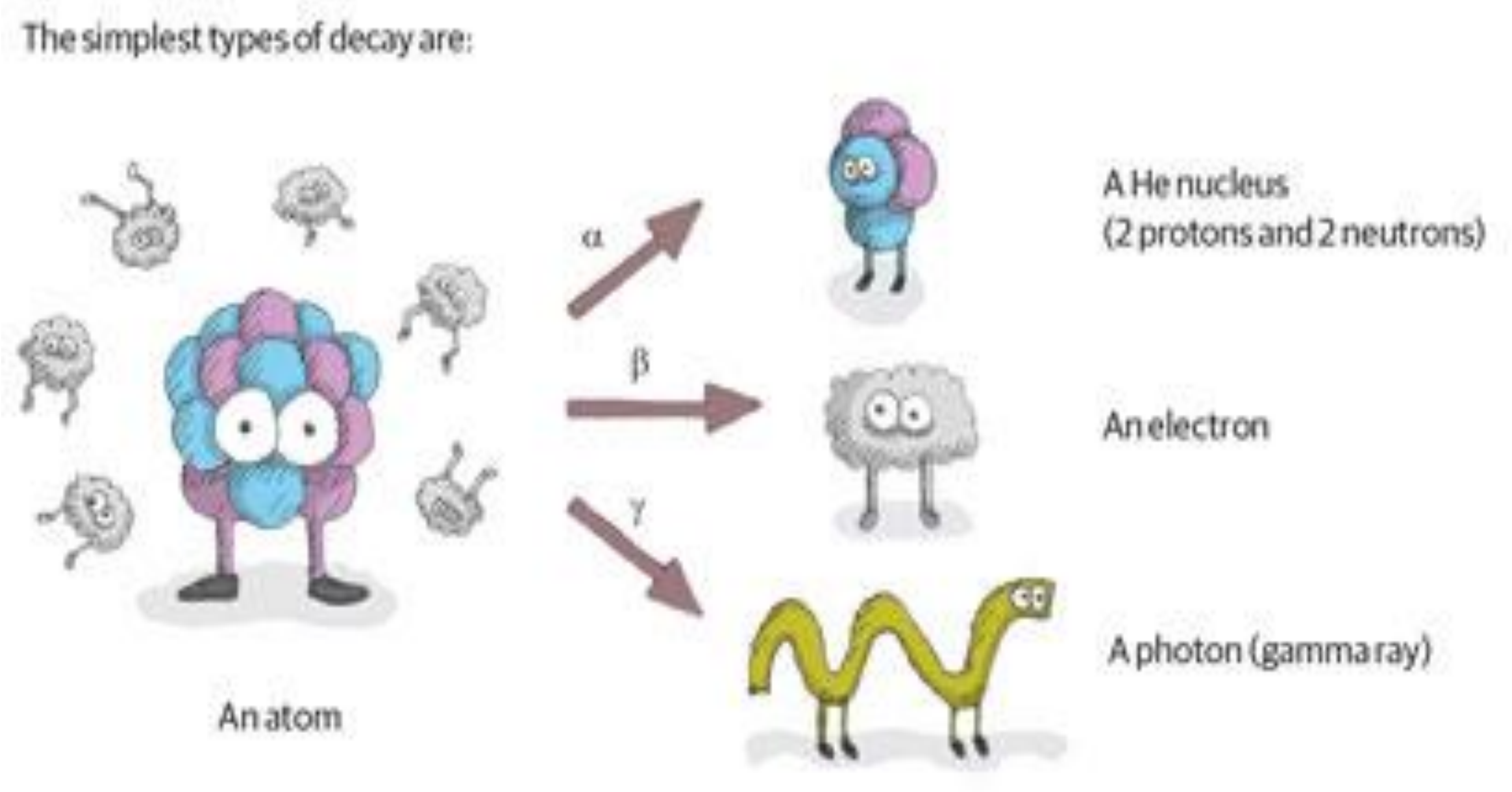
Parent Element **Daughter Element** **γ ray**

$$ {}^{A}_{Z}X^{*} \xrightarrow{\text{Relaxation}} {}^{A}_{Z}X' + {}^{0}_{0}\gamma $$

The * in the reaction denotes an excited nuclear state.



Excited atoms emit 3 things…alpha, beta *particles* and gamma *rays*



The simplest types of decay are:

Energy Level of Each Radioactive Decay

In terms of the energy associated with each type of radiation:

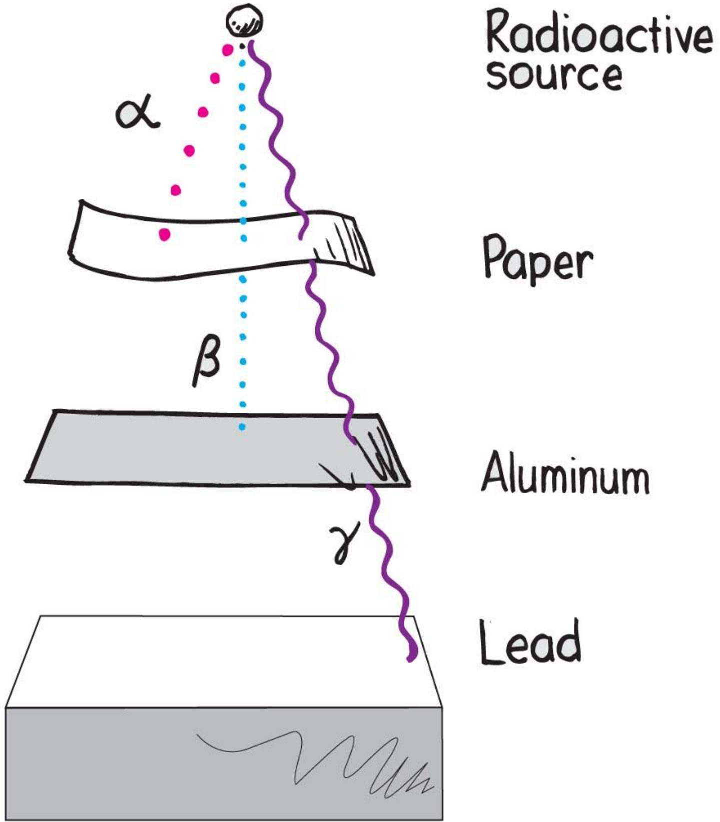
Increasing energy →

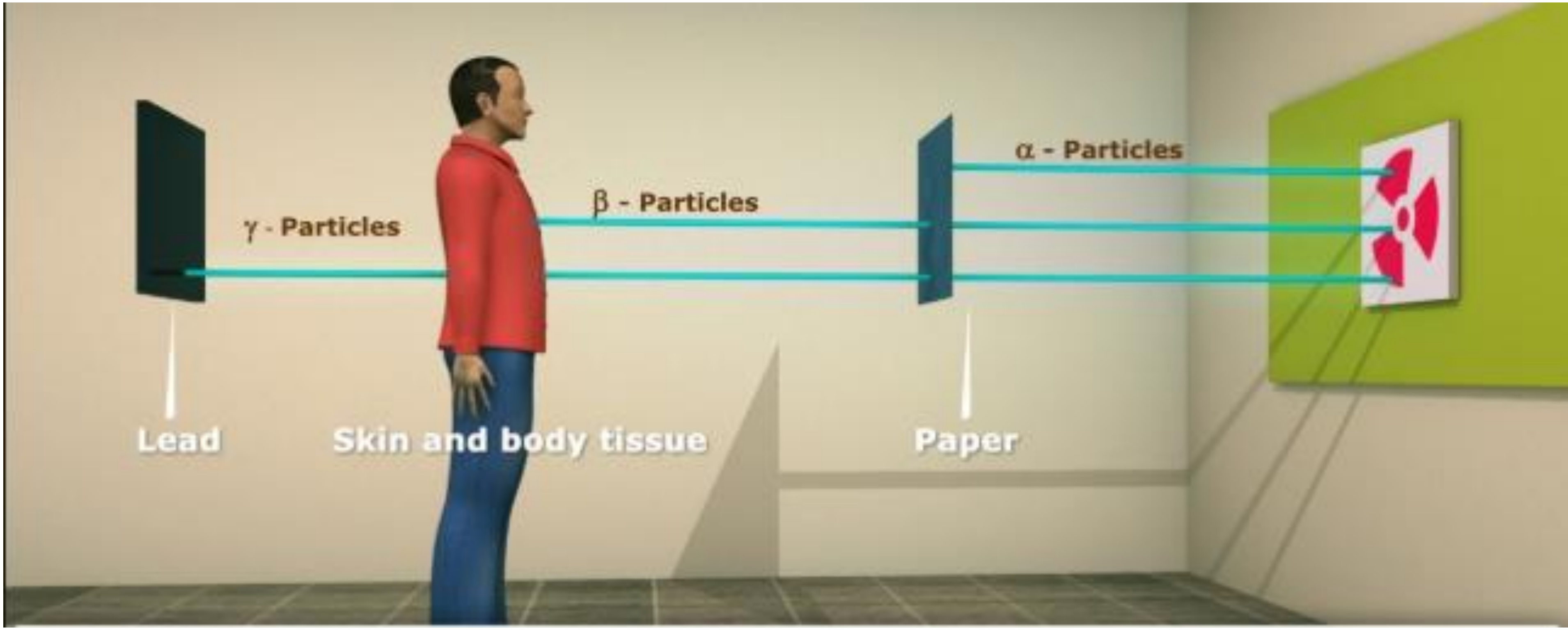
α β γ

Good news...............................Bad news

Penetrating Ability of Each Radioactive Decay

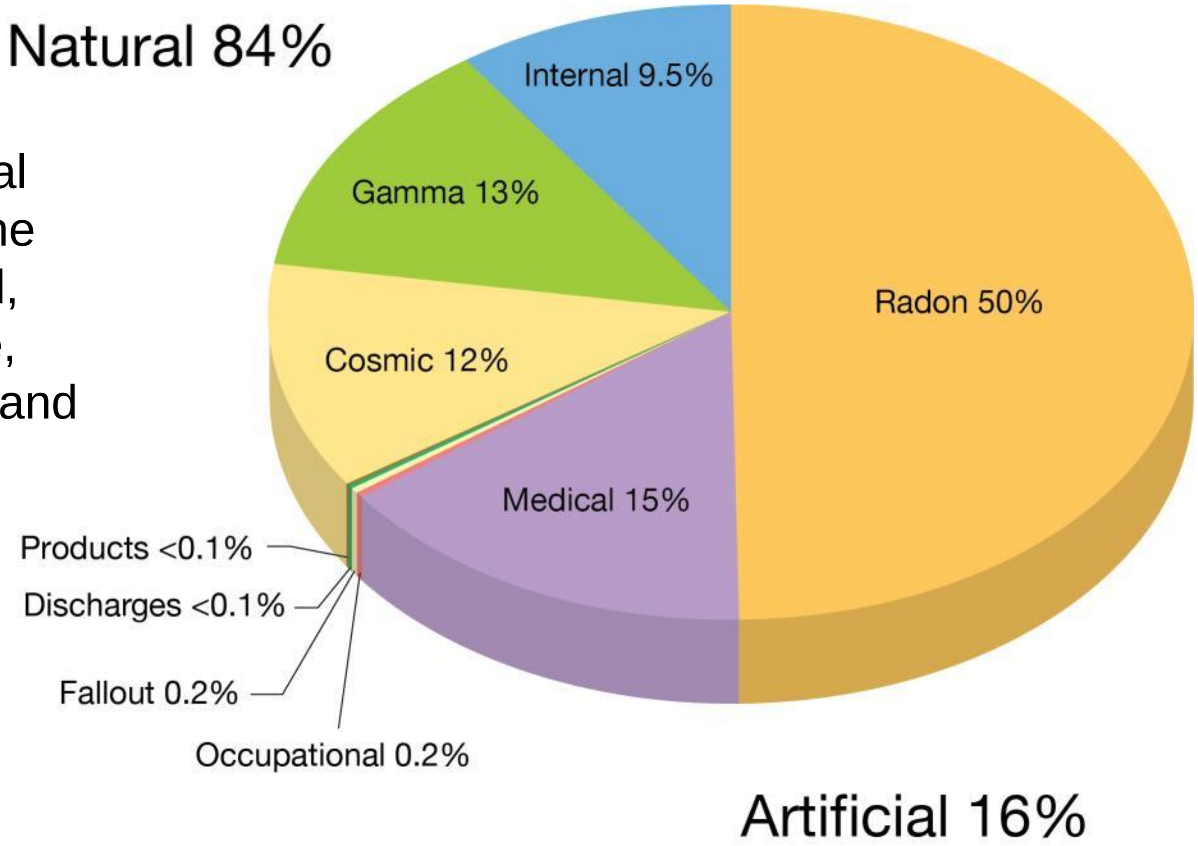
A piece of paper can stop alpha rays. Beta particles can be stopped by a sheet of aluminum. Even lead may not stop gamma rays.




α - Particles
β - Particles
γ - Particles
Lead
Skin and body tissue
Paper

Radiation is found naturally and in artificially produced sources.

The components of the natural radioactive background are the natural radioactivity of ground, natural activity of atmosphere, natural radioactivity of water, and cosmic radiation.



The artificial sources of radiation that have currently the highest impact on the environment and population are as follows:

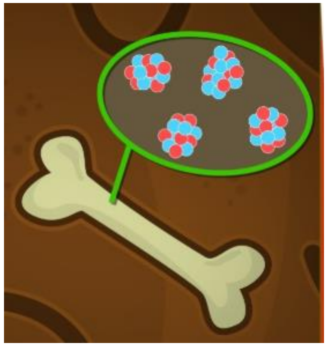
medicine sources of ionization radiation,
nuclear explosions,
consumer products,
nuclear power plants and their fuel cycle.

Applications Of Radioactivity

Medicine: medical specialty that involves the use of radioactive isotopes in the diagnosis and treatment of disease.

Energy Industry: Power generation based on the release of the fission energy of uranium

Science: The isotope carbon-14 is used by archeologists to determine age.



Household: Radioactive isotopes are even used in smoke alarms.

Example 1:

A) Name the type of decay.

B)Determine the value of x and y in each nuclear equation where P = parent and D = daughter.

a) $^{212}_{82}\mathrm{P} \rightarrow \, ^{212}_{x}\mathrm{D} + \, ^{0}_{-1}\mathrm{e}$

b) $^{210}_{84}\mathrm{P} \rightarrow \, ^{y}_{x}\mathrm{D} + \, ^{4}_{2}\mathrm{He}$

c) $^{227}_{89}\mathrm{P} \rightarrow \, ^{227}_{90}\mathrm{D} + x$

d) $^{226}_{88}\mathrm{P} \rightarrow \, ^{y}_{x}P + \gamma$

Ex - Determine the value of x and y in each nuclear equation where P = parent and D=daughter. Name the type of decay.

a) $${}^{212}_{82}\mathrm{P} \rightarrow {}^{212}_{x}\mathrm{D} + {}^{0}_{-1}\mathrm{e}$$

Since a β– particle is produced, this is **β– decay**

The atomic number of the daughter must be **x = 83**, since it increases by 1 for β– decay.

b) $${}^{210}_{84}\mathrm{P} \rightarrow {}^{y}_{x}\mathrm{D} + {}^{4}_{2}\mathrm{He}$$

Since an α– particle (helium nuclei) is produced, this is **α– decay**

The atomic mass number of the daughter must be y = 210 – 4 = **216.**

The atomic number of the daughter must be x = 84 – 2 = **82**.

c) $${}^{227}_{89}\mathrm{P} \rightarrow {}^{227}_{90}\mathrm{D} + x$$

A, the unified atomic mass, did not change, but the number of protons or positive charges increased by 1.

Therefore, **a neutron has decayed into a proton**. This means that **an electron was emitted from the parent nucleus.** This is **β- decay.**

x = ${}^{0}_{-1}\mathrm{e}$

d) $${}^{226}_{88}\mathrm{P} \rightarrow {}^{y}_{x}P + \gamma$$

This is **gamma radiation.**

With the emission of a gamma ray the parent nucleus does not change.

That is, the atomic number and atomic mass number stay the same.

x = 88 and y = 226.

e) $^{214}_{83}P \rightarrow {}^{x}_{y}D + {}^{0}_{-1}e$

f) $^{x}_{y}P \rightarrow {}^{222}_{86}D + {}^{4}_{2}He$

g) $^{215}_{84}P \rightarrow {}^{211}_{82}D + x$

h) $^{3}_{1}P \rightarrow x + \gamma$

e) $^{214}_{83}P \rightarrow {}^{x}_{y}D + {}^{0}_{-1}e$

Since a β− particle is produced, this is **β− decay**

The atomic number of the daughter must be **y = 84**, since it increases by 1 for β− decay.

The unified *A*, the unified atomic mass, did not change so **x = 214**

f) $^{x}_{y}P \rightarrow {}^{222}_{86}D + {}^{4}_{2}He$

The α-particle, $^{4}_{2}He$, tells us that this is **α decay.**

x = 224 + 4 = **226**; *y* = 86 + 2 = **88**.

g) $^{215}_{84}P \rightarrow {}^{211}_{82}D + x$

A decreases by 4 and *Z* decreases by 2.

Therefore the emitted particle (*x*) must be an α-particle $^{4}_{2}He$

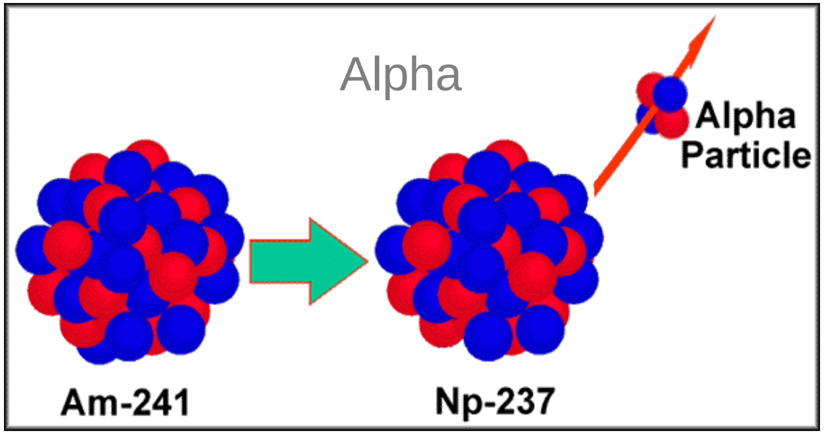
This is **α decay**

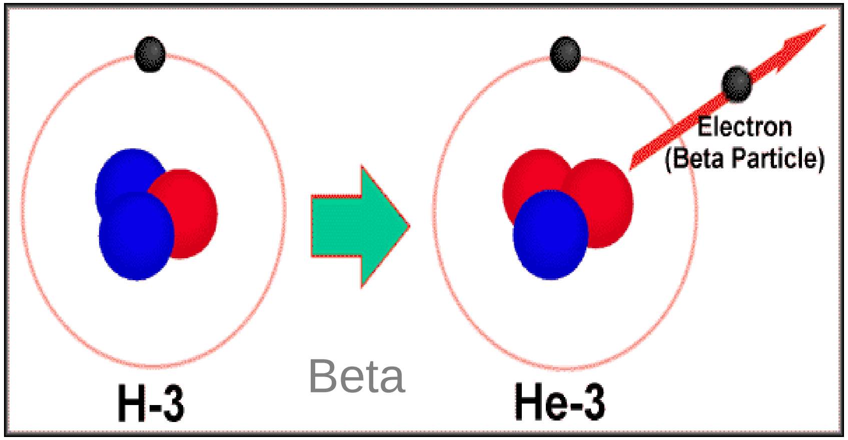
h) $^{3}_{1}P \rightarrow x + \gamma$

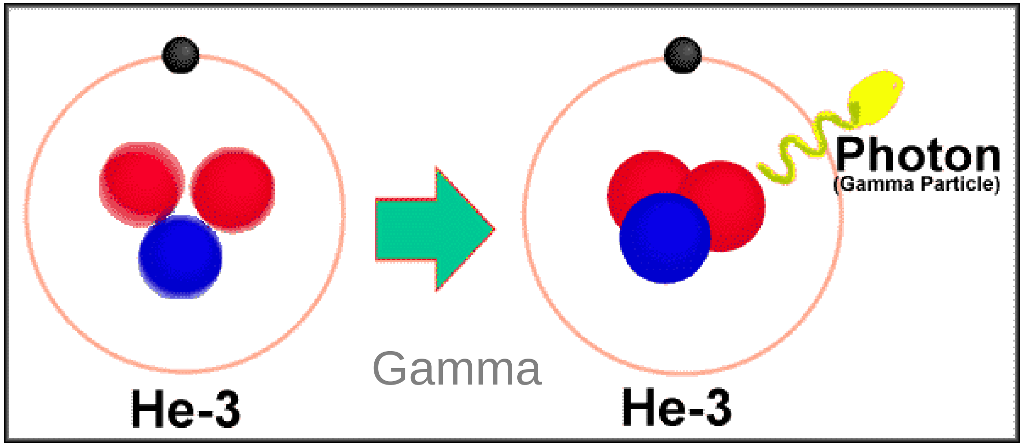
This is **gamma radiation**.

Because a gamma ray has no mass and no charge, the *A* and *Z* numbers of the parent nucleus do not change. $x = {}^{3}_{1}P$

Three Common Types of Radioactive Emissions

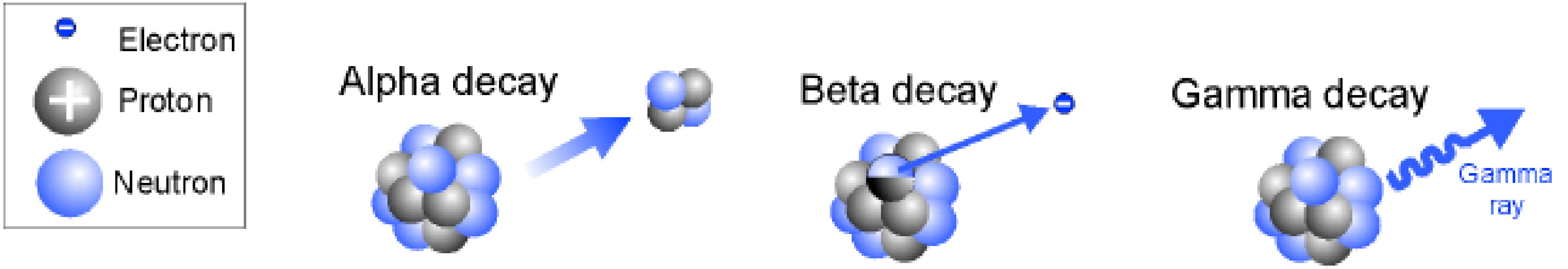






Radioactivity Summary

- In alpha decay, the nucleus ejects two protons and two neutrons.
- Beta decay occurs when a neutron in the nucleus splits into a proton and an electron.
- Gamma decay is not truly a decay reaction in the sense that the nucleus becomes something different.

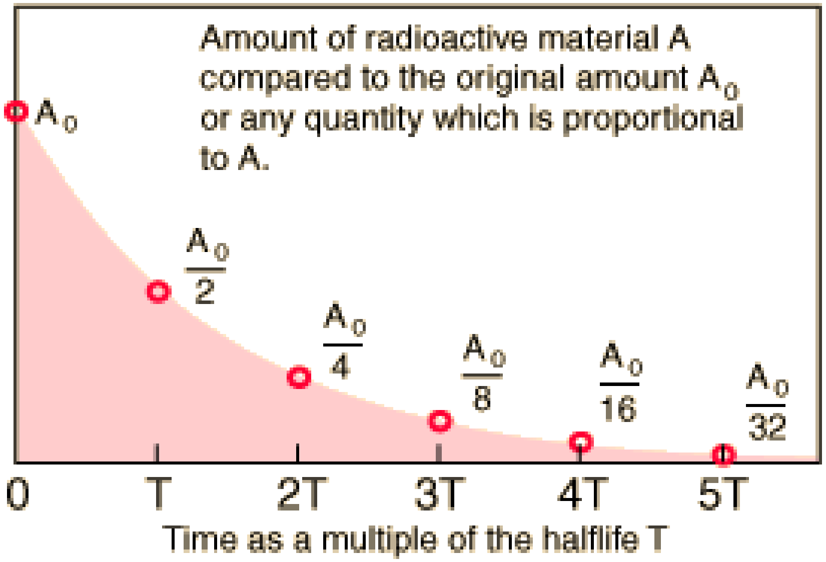


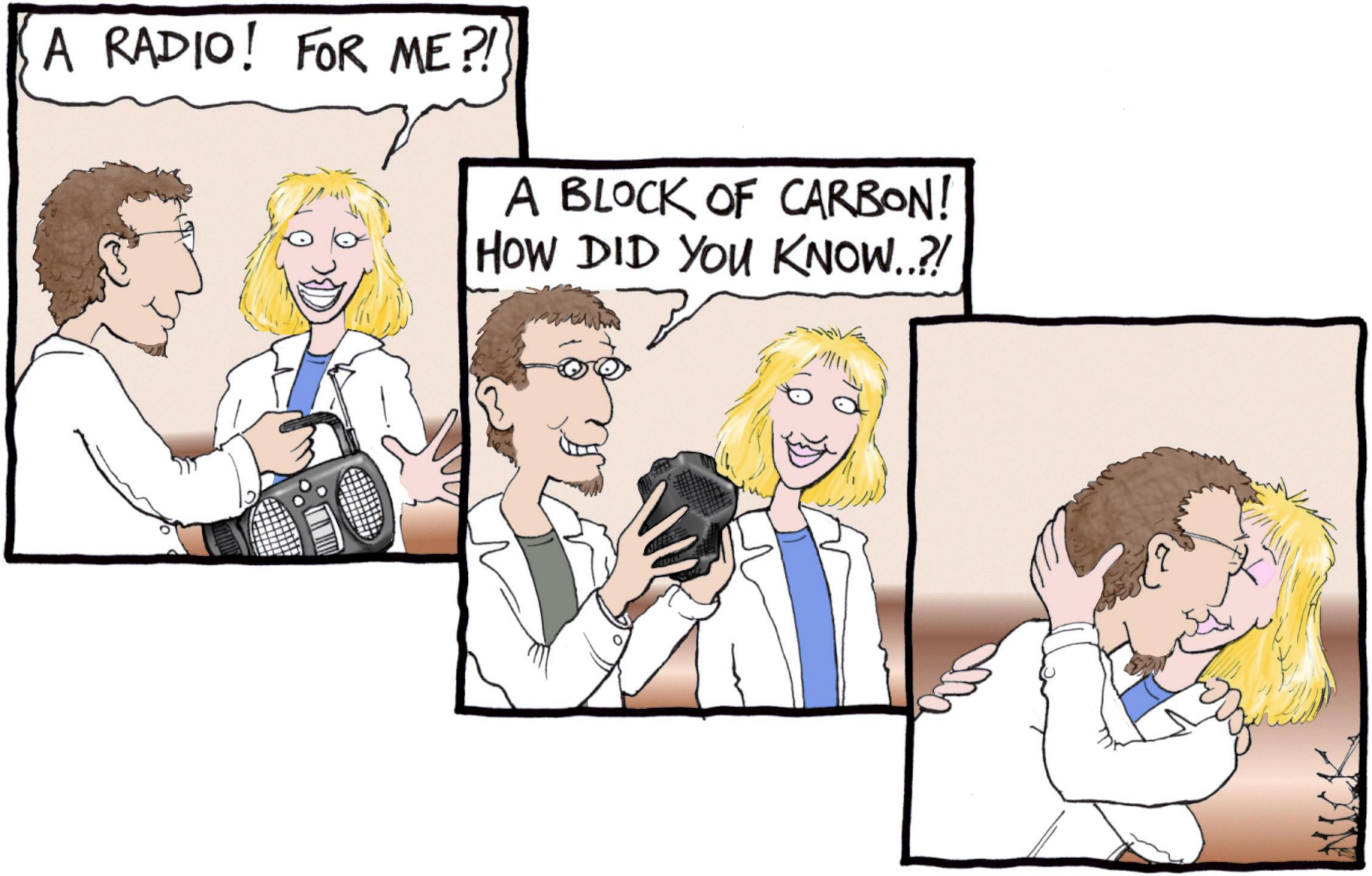
Protons	Decrease by 2	Increase by 1	Unchanged
Neutrons	Decrease by 2	Decrease by 1	Unchanged

Physics 2204

UNIT 3: Section 13

Radioactive Half Life





The radiocarbon dating technique.

Half Life Bank Account

Given that the half-life of your bank account is 5 days, and the original amount is $1280, determine the number of dollars in your account after 20 days.

Since 20 days represents 4 half-lives, divide 1280 by 2 repeatedly 4 times:

1280 ÷ 2 = 640; 640 ÷ 2 = 320; 320 ÷ 2 = 160; and 160 ÷ 2 = 80.

After 20 days the amount in the account is $80.00.

Here's a short-cut: dividing by 2 four times is the same as multiplying by ½ four times . That is:

$$\tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} \times \tfrac{1}{2} = \frac{1}{2^4} = \frac{1}{16} \qquad \$1280 \times \frac{1}{16} = \$80$$

So, After 20 days, $80 remain.

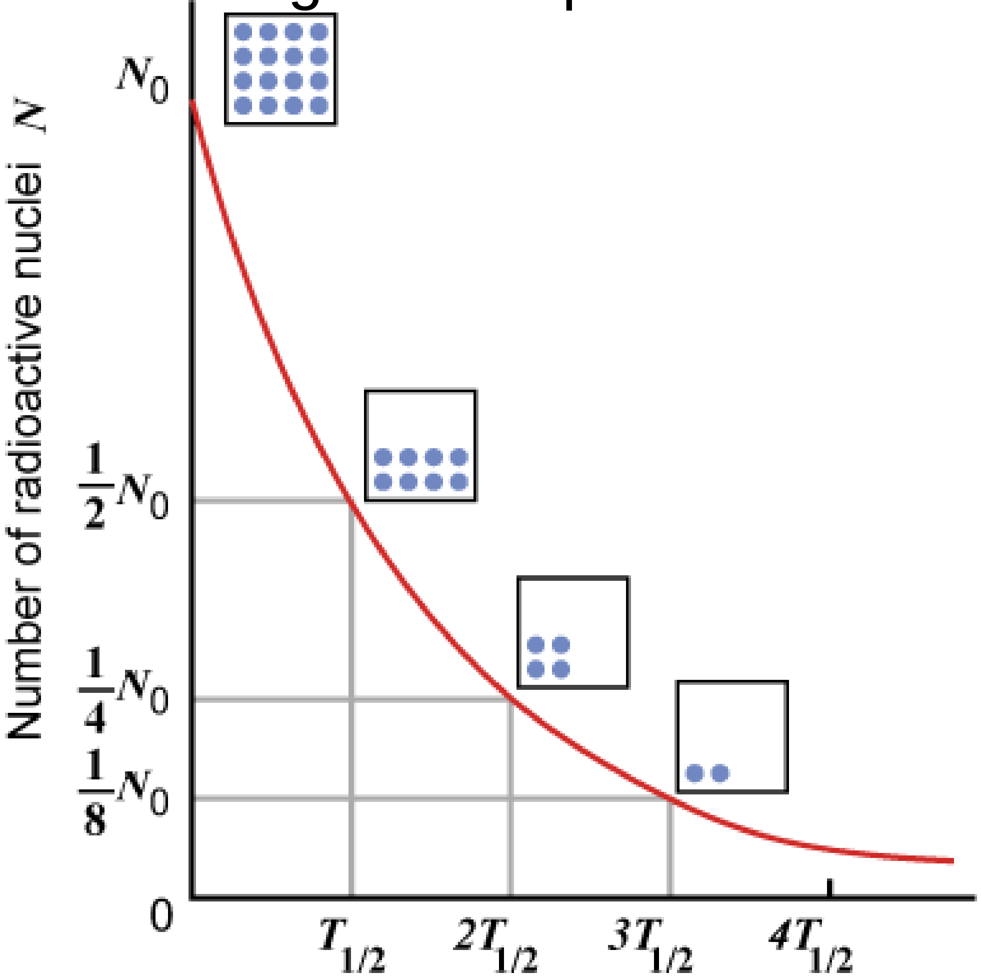
Graphical Representation of Half-Life – Exponential Decay

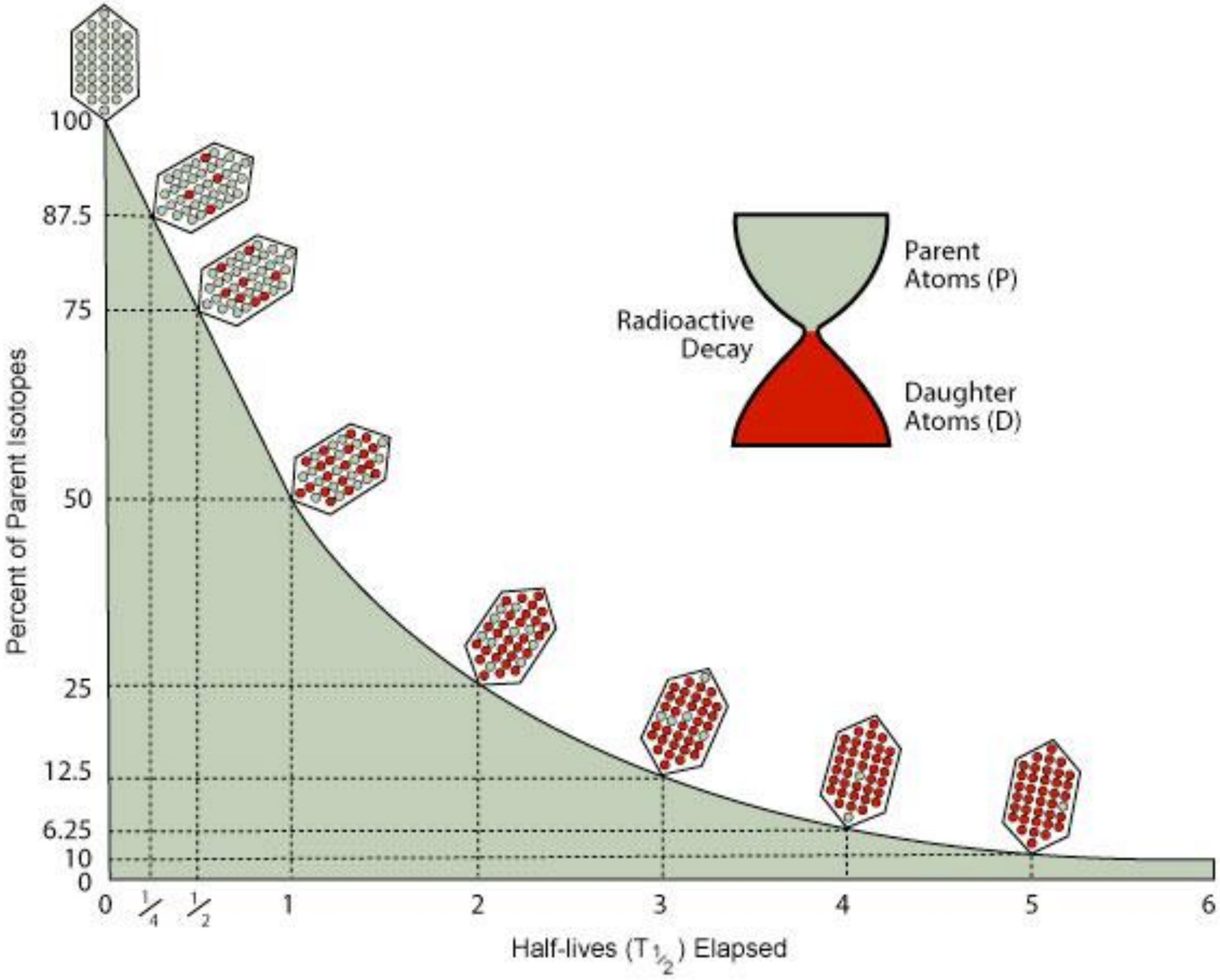
Half Life refers to the time for half of the radioactive nuclei in a given sample to undergo decay. After one half life there is 1/2 of original sample left. After two half-lives, there will be 1/2 of the 1/2 = 1/4 the original sample.

- The horizontal axis shows time – it is measured in number of half-lives.

- The vertical axis shows the amount or material, or number of radioactive nuclei remaining after decay. (represented by blue dots in the squares).

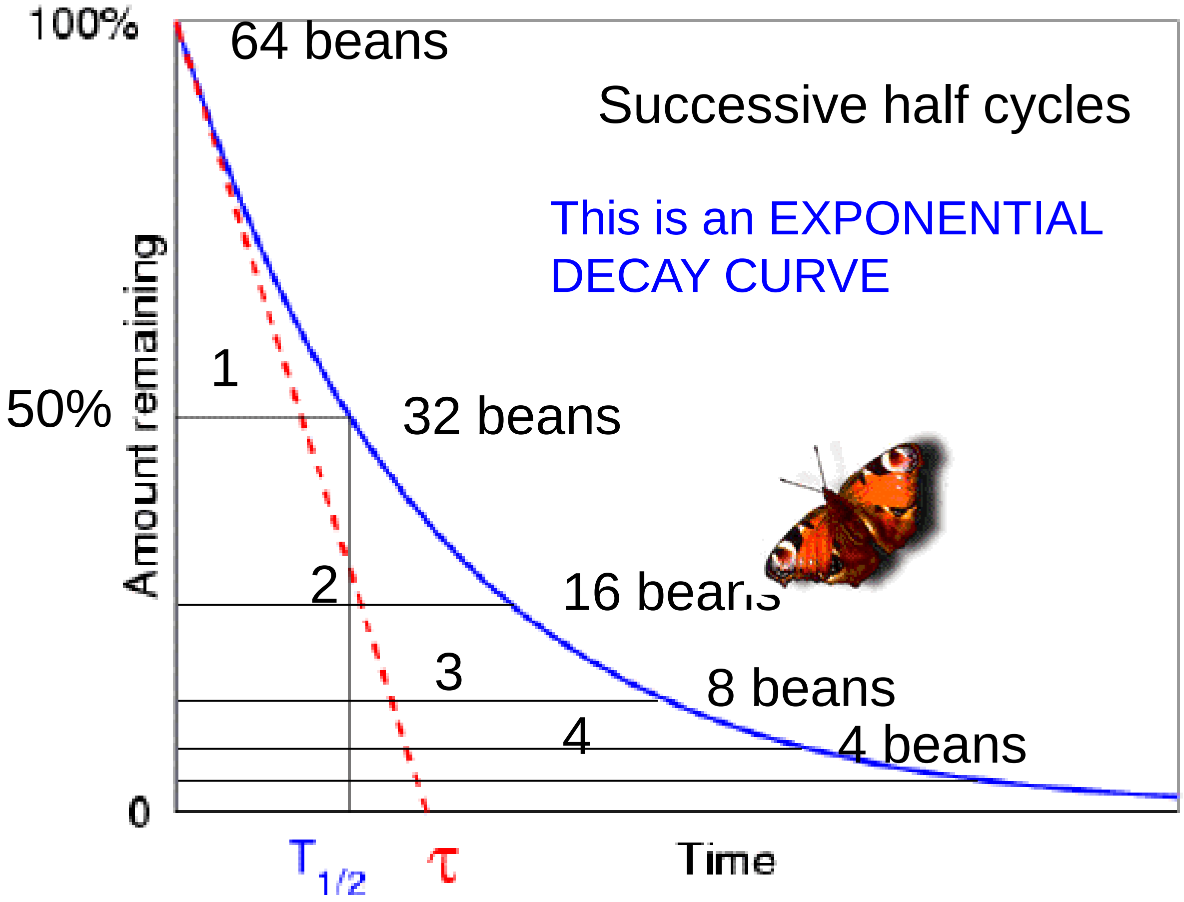
- This is an example of an exponential graph.




100
87.5
75
50
25
12.5
6.25
10
0
Percent of Parent Isotopes
0
1/4
1/2
1
2
3
4
5
6
Half-lives (T 1/2) Elapsed
Parent Atoms (P)
Radioactive Decay
Daughter Atoms (D)

Beanium Decay

What does the graph of radioactive decay look like?



Successive half cycles

This is an EXPONENTIAL DECAY CURVE

Common Radioactive Isotopes

Isotope	*Half-Life*	*Radiation Emitted*
Carbon-14	5,730 years	β, γ
Radon-222	3.8 days	α
Uranium-235	7.0 x 108 years	α, γ
Uranium-238	4.46 x 109 years	α

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Measuring Radioactivity

Instead of measuring number or mass of nuclei present, radioactivity can be measured by number of nuclei decaying per second, known as the activity. The unit **becquerels** (Bq) is for decays per second or kilobecquerels (kBq) or megabecquerels (mBq). One becquerel is 1 count/sec or 1/s or s-1.

For example, an activity 1.5 kBq means that the recording device detects 1500 atoms decaying in one second. One such device is the geiger counter, invented by Hans Geiger

Geiger counter is used to measure the activity of a radioactive material. It is a type of radiation detector invented to measure x-rays and other ionizing radiation, since they are invisible to the naked eye. It detects radiation such as alpha particles, beta Particles and gamma rays It was invented by Hans Geiger

Example 1:

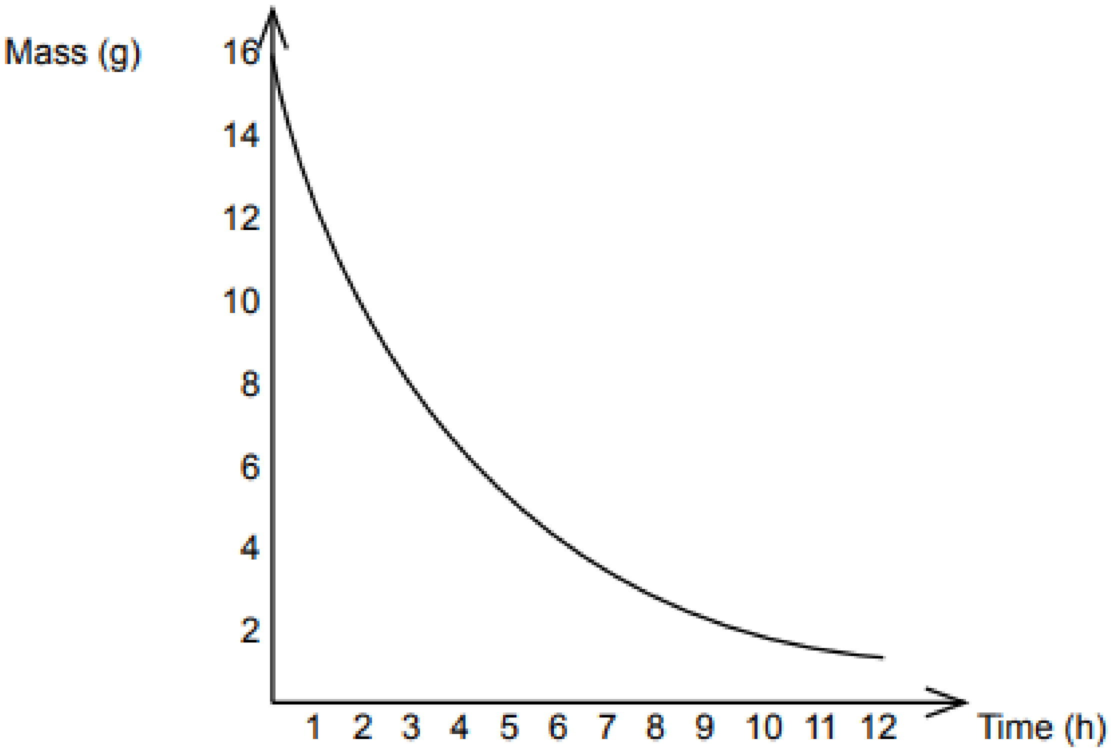
A radioactive chemical has an activity of 10,000Bq. What is the activity of this chemical after 2 half-lives have passed?

Example 2:

A 10.0 g sample of radioactive tracer iodine-123 is stored on a hospital shelf. Its half-life is 12 hours. How much radioactive material is left after 5.0 days?

Example 3:

Determine the half-life from the decay of the radioactive element represented in the graph below.



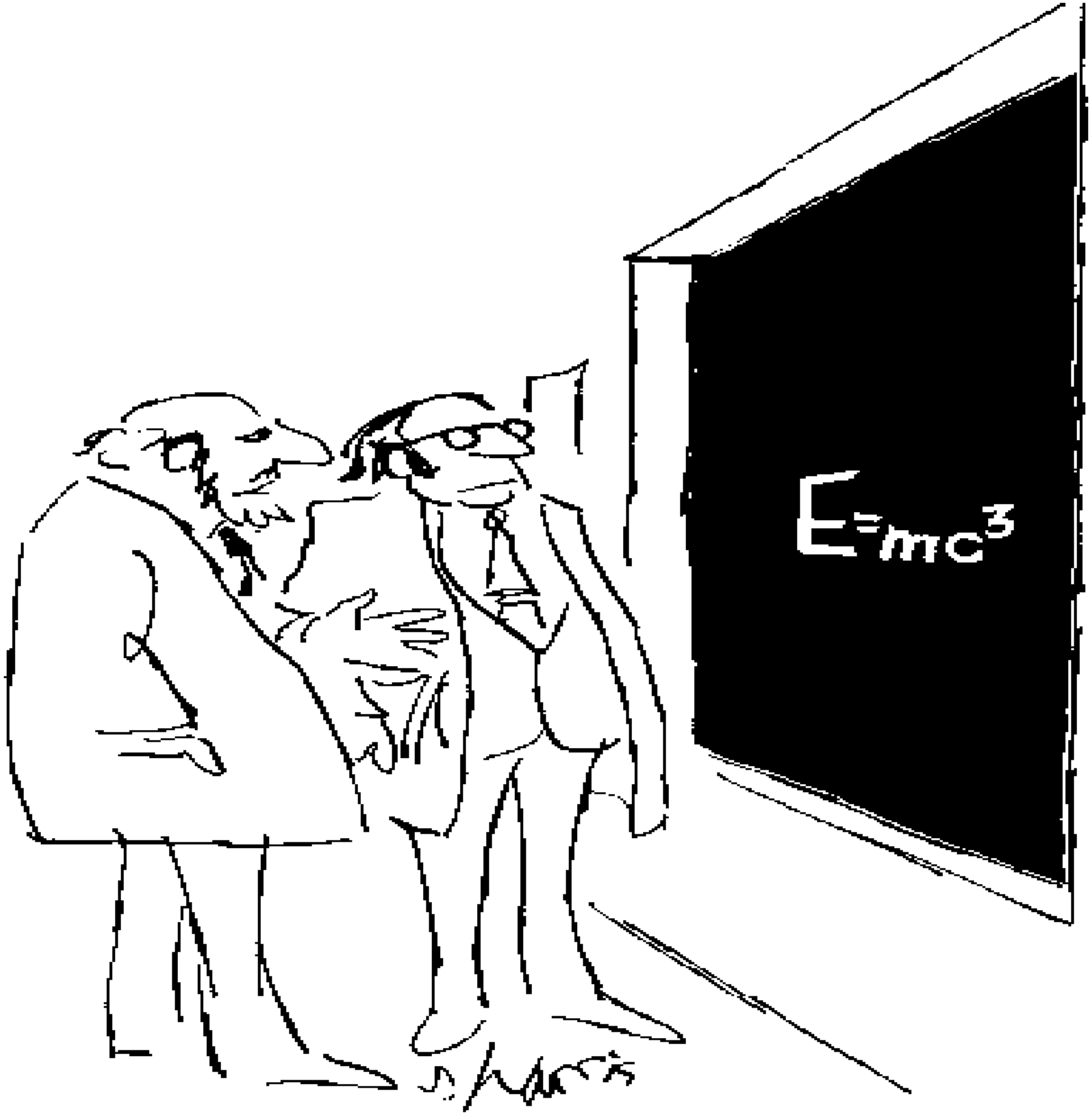
Example 4:

The number of radioactive nuclei in a particular sample decreases over 15 days to 1/16 of the original number. What is the half-life of these nuclei?

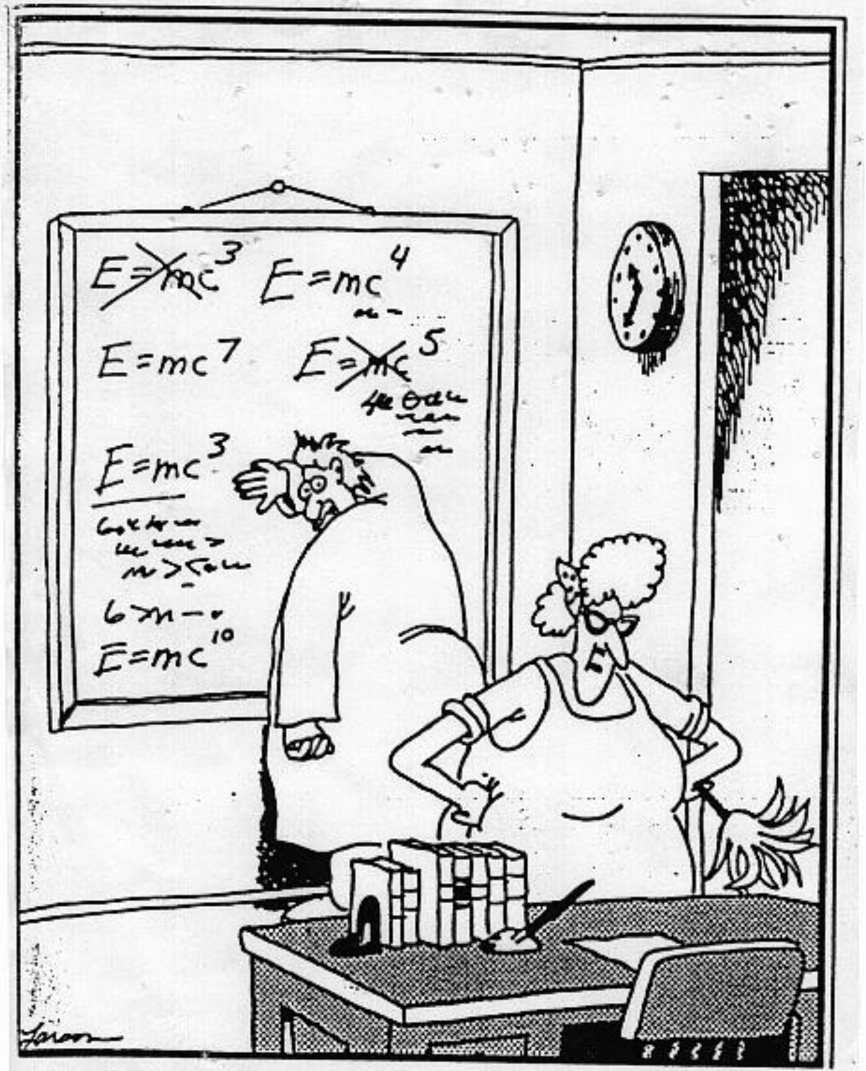
Physics 2204

UNIT 3: Topic 14

Mass - Energy Equivalence Equation

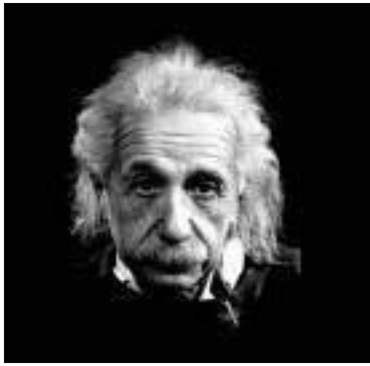


"These days *everything* is higher."



"*Now* that desk looks better. Everything's squared away, yessir, squaaaaaared away."

$E = mc^2$: The Equivalence of Matter and Energy



Einstein’s most famous contribution is the about the equivalence of matter and energy — **that a loss or gain in mass can also be considered a loss or gain in energy.**

$$E = m \cdot c^2$$

E = the energy equivalent to the mass (in joules),

m = mass difference (in kilograms), and

c = the speed of light in a vacuum (in meters per second).

Don’t make plans for the end of the sun

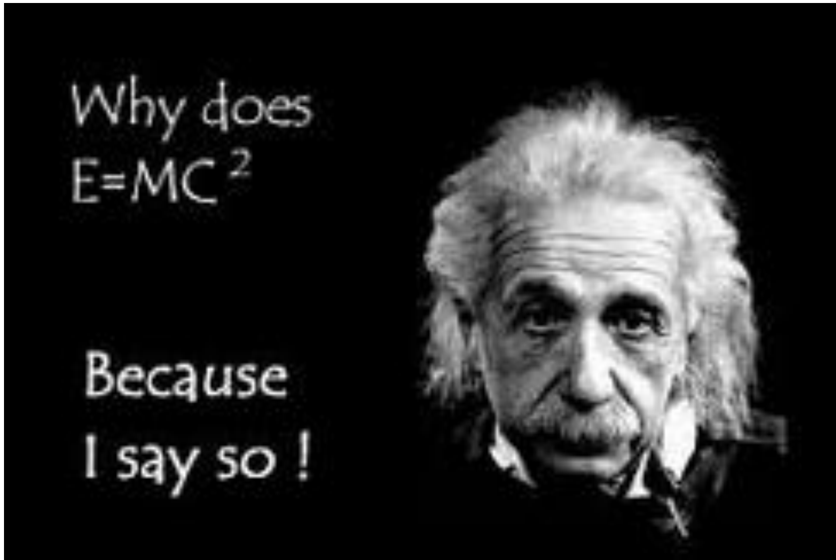
The sun radiates power at 3.92 x 10^{26} Watts. So, in one second, it radiates 3.92 x 10^{26} Joules of energy. This translates into the sun losing about *4.36 billion kilograms of mass per second* — whoa! That’s about 4.79 million tons of matter lost every second. You can almost hear solar scientists going nuts. Surely, at that rate, there will be no more sun left in a few weeks. They cry out, “Our mortgages! We’ll have to get new jobs when the sun goes out!” What they shouldn’t forget is that the sun has a mass of 1.99 x 10^{30} kg. Even at 4.36 x 10^{9} kg of mass lost per second, it will still last for a while. How long? If radiating away mass were the only physical mechanism at work, the sun would last 1.99 x 10^{30} / 4.36 x 10^{9} = 4.56 x 10^{20} seconds. That’s about 1.44 x 10^{13} years, or 144 billion centuries.

A huge amount of energy from a small amount of mass. Every process that releases energy is accompanied by an equivalent loss of mass. Every process that absorbs energy results in a gain of mass. The mass changes accompanying chemical reactions are too small to measure but mass changes due to nuclear reactions can be measured using a mass spectrometer. The following process releases energy (how do you know?):

The mass-energy equivalency formula can be used to calculate:

1) Energy of a Fission Reaction

2) Energy of a Fusion Reaction



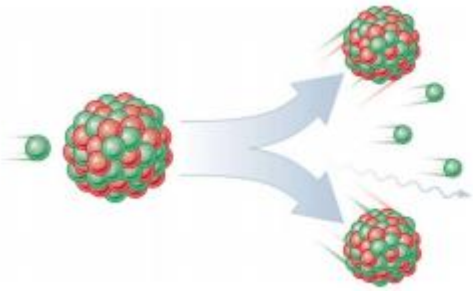
1) Fission Reaction

Fission = the splitting of a heavy nucleus into two nuclei with smaller mass numbers. This process is induced by absorption of a neutron by the reactant nucleus, and results in the release of energy and an additional 2 or 3 neutrons as products. For example 3 of the many possible outcomes of uranium-235 fission are:

$${}^{1}_{0}n+{}^{235}_{92}U\rightarrow{}^{90}_{38}Sr+{}^{143}_{54}Xe+3\,{}^{1}_{0}n$$

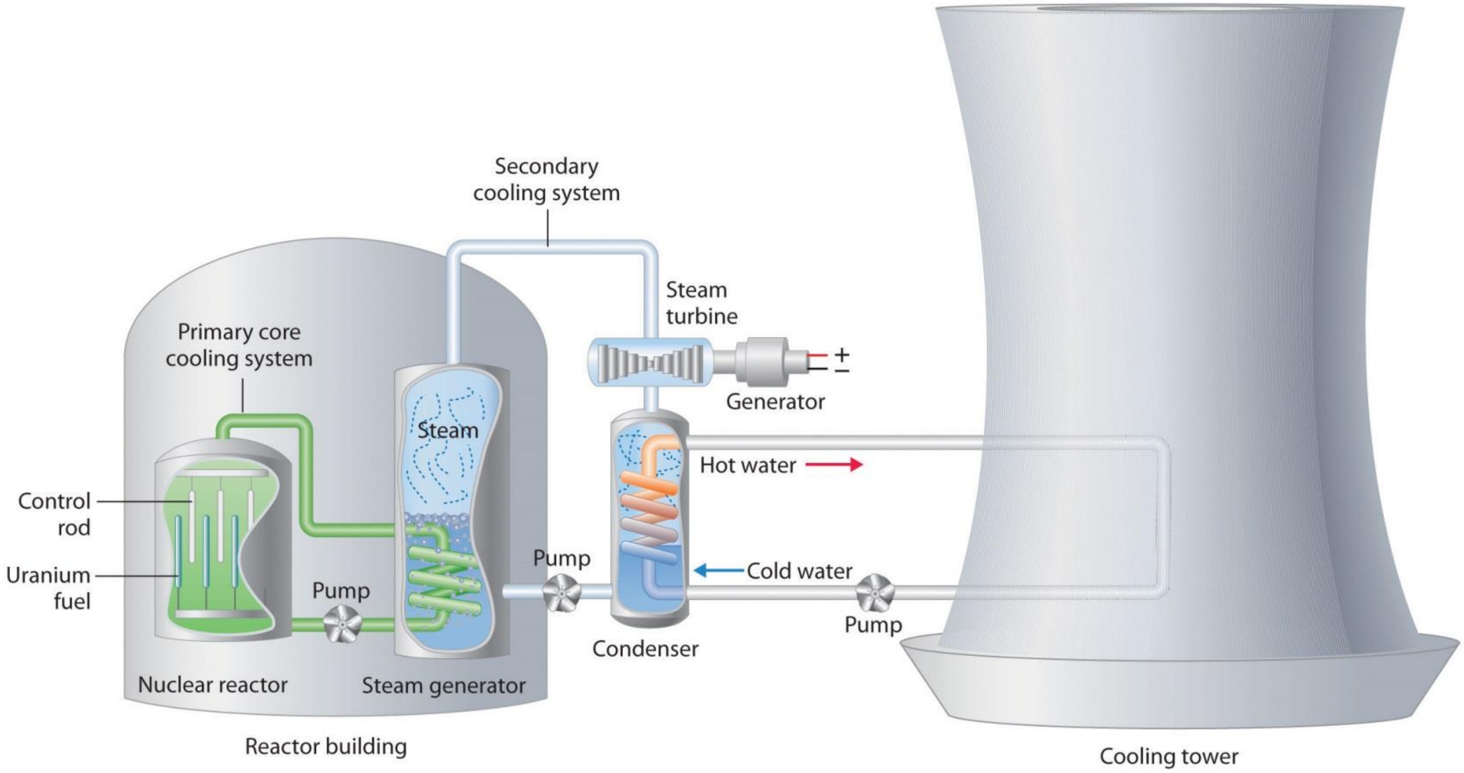
$${}^{1}_{0}n+{}^{235}_{92}U\rightarrow{}^{137}_{52}Te+{}^{97}_{40}Zr+2\,{}^{1}_{0}n$$

$${}^{1}_{0}n+{}^{235}_{92}U\rightarrow{}^{142}_{56}Ba+{}^{91}_{36}Kr+3\,{}^{1}_{0}n$$



Energy OF Fission

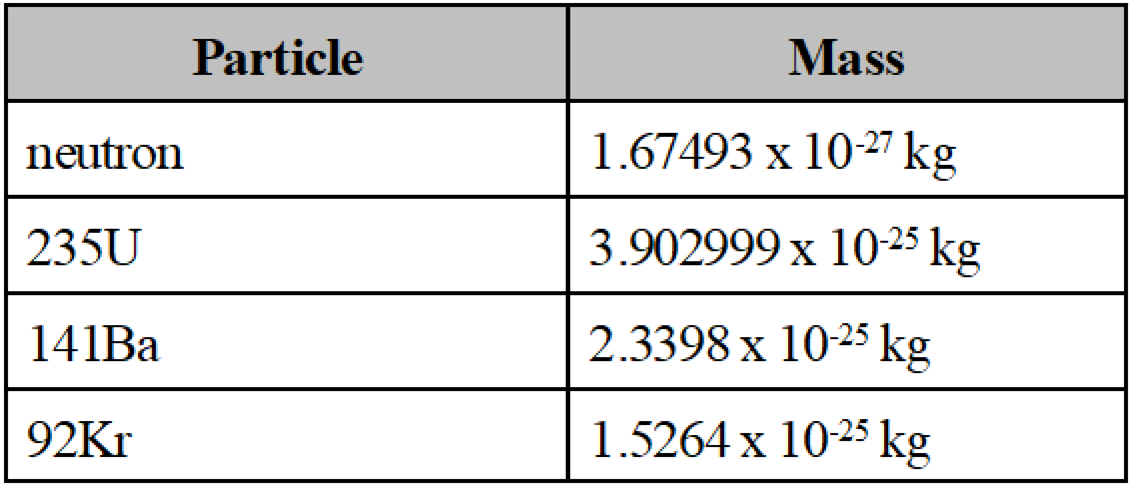
Fission is used to create energy in a nuclear reactor. We have learned about natural radioactive decay through α , β, and γ radiation. However, Fission, however, occurs in a reactor site.



Example 1: Fission Reaction

For the reactions shown below,

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3(^{1}_{0}n)$$



Particle	Mass
neutron	1.67493×10^{-27} kg
235U	3.902999×10^{-25} kg
141Ba	2.3398×10^{-25} kg
92Kr	1.5264×10^{-25} kg

calculate:

A) Mass difference

B) Energy released in the reaction

2) Fusion Reaction

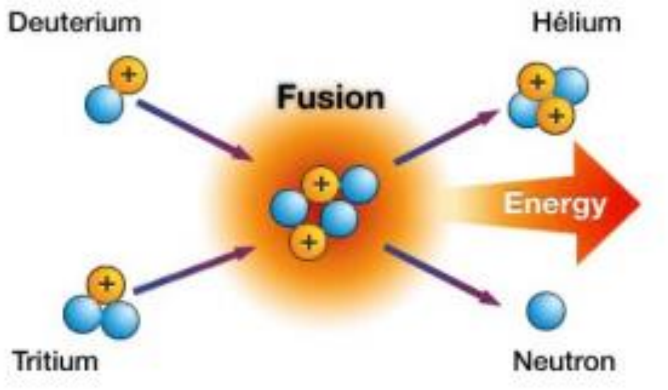
Fusion the combining of two light nuclei to form a heavier, more stable nucleus. For example, the following reactions (among others) take place in the sun:

$$ {}^1_1H + {}^1_1H \rightarrow {}^2_1H + {}^0_1e $$

$$ {}^1_1H + {}^2_1H \rightarrow {}^3_2He $$

$$ {}^3_2He + {}^1_1H \rightarrow {}^4_2He + {}^0_1e $$

$$ {}^3_2He + {}^3_2He \rightarrow {}^4_2He + 2{}^1_1H $$

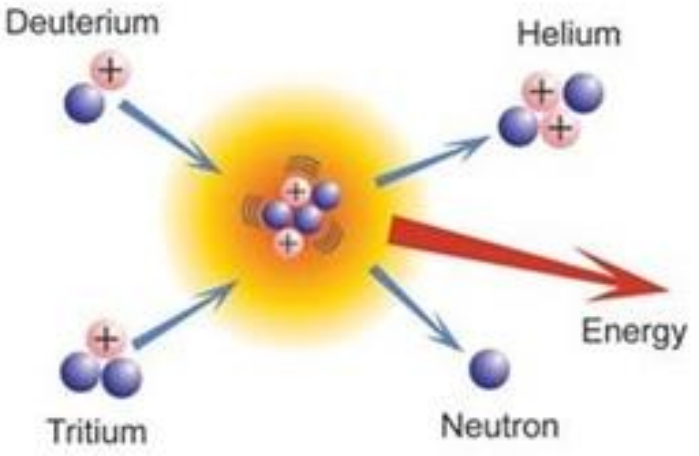


Because of the large binding energies involved in a nucleus, both fission and fusion involve energy changes of more than a million times larger than those energy changes associated with chemical reactions.

Energy and Fusion.

It is believed that in the sun the temperatures and pressures are so great that hydrogen nuclei fuse into helium nuclei. The helium nucleus is lighter than the sum of the separate nuclei before the fusing. The difference in mass is converted into energy according to the expression $E = mc^2$.

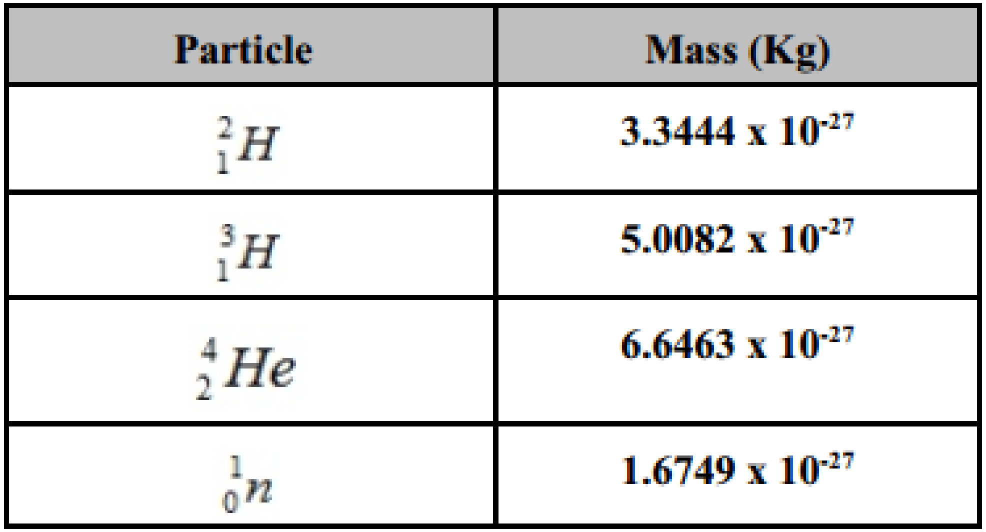
An even simpler example of fusion involves a neutron fusing with hydrogen-1 to form the isotope hydrogen-2 plus gamma radiation. Another name for hydrogen-2 is deuterium. The reaction looks like this:



Example 2: Fusion Reaction

Calculate the energy produced in the reaction below.

$$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + \text{energy}$$

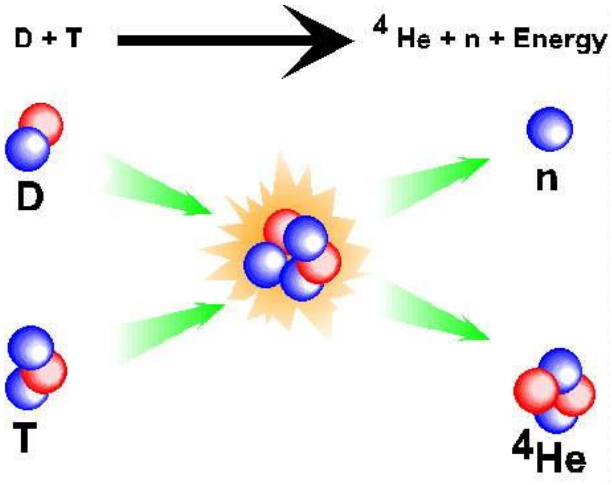


Particle	**Mass (Kg)**
$^{2}_{1}H$	**3.3444 x 10^{-27}**
$^{3}_{1}H$	**5.0082 x 10^{-27}**
$^{4}_{2}He$	**6.6463 x 10^{-27}**
$^{1}_{0}n$	**1.6749 x 10^{-27}**

How is that energy is produced in both processes?

The enormous energy results when there is a mass difference between the original and the end products.

nuclear fusion the single product after the fusion is lighter than the two nuclei that came together.

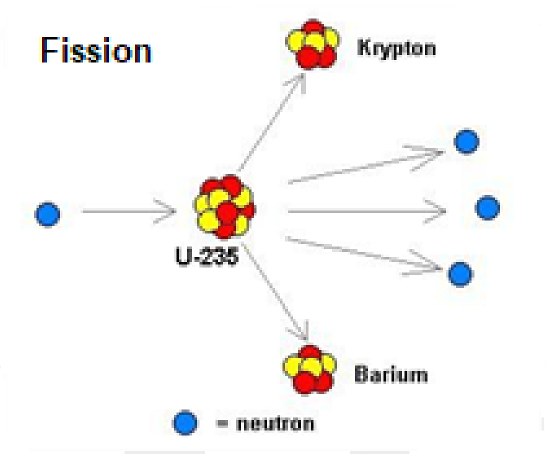


- So, **in both fission and fusion there is a mass difference.** Using $E = mc^2$, we can calculate the energy equivalence of this mass difference.

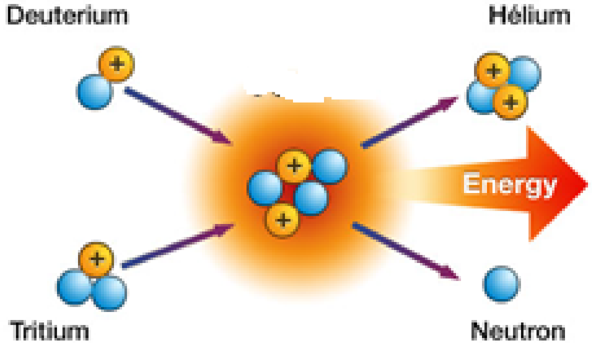
Comparing Fission and Fusion

- In nuclear fission, a large nucleus splits into two smaller ones and in nuclear fusion two small nuclei join to make one larger one.

Fission



Fusion



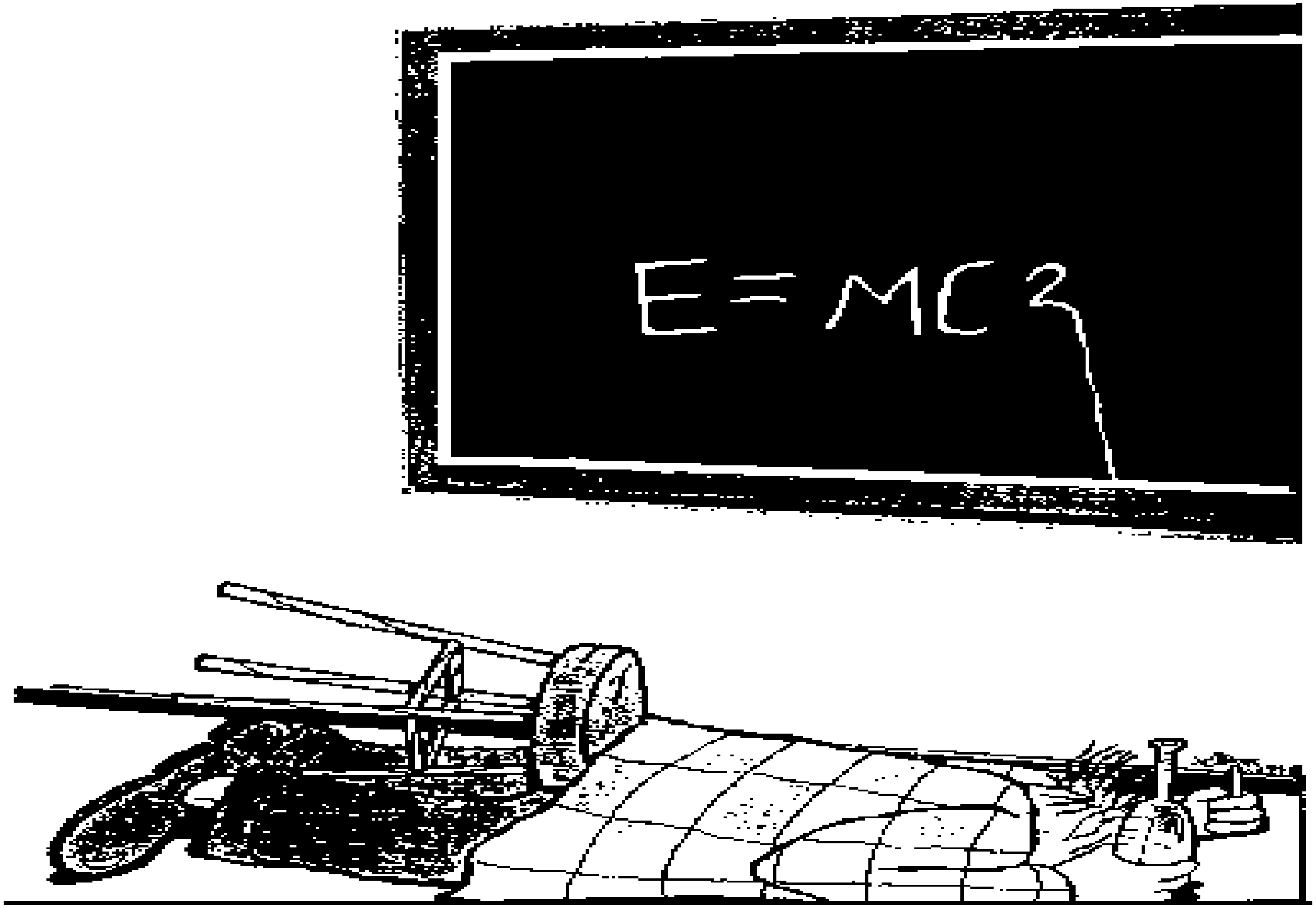
- Fusion and fission are alike in one important way. Both processes produce enormous amounts of energy. In fact fusion produces about 4 times as much energy as fission.

Why it is fission and not fusion that has been developed commercially.

You may be wondering why it is fission and not fusion that has been developed commercially. The reason is that it is much easier to achieve nuclear fission than nuclear fusion. This is because in order to make nuclei fuse, the repelling positive electric force on the protons must be overcome. One way to do this is to make the nuclei move very fast towards each other. And one way to make them move fast is to increase their temperature. Therein lies the problem. The temperatures required are similar to the temperatures in the stars and in our sun. That's in the order of a millions of degrees!! Such temperatures are difficult to achieve on earth.

Strategy For Mass - Energy Equivalence

- \- Calculate the mass before and after.
- \- Find mass difference.
- \- Find the energy equivalence of this mass difference using $E=mc^2$



Early in his carrer, Einstein discovered the hazards of drinking and deriving.

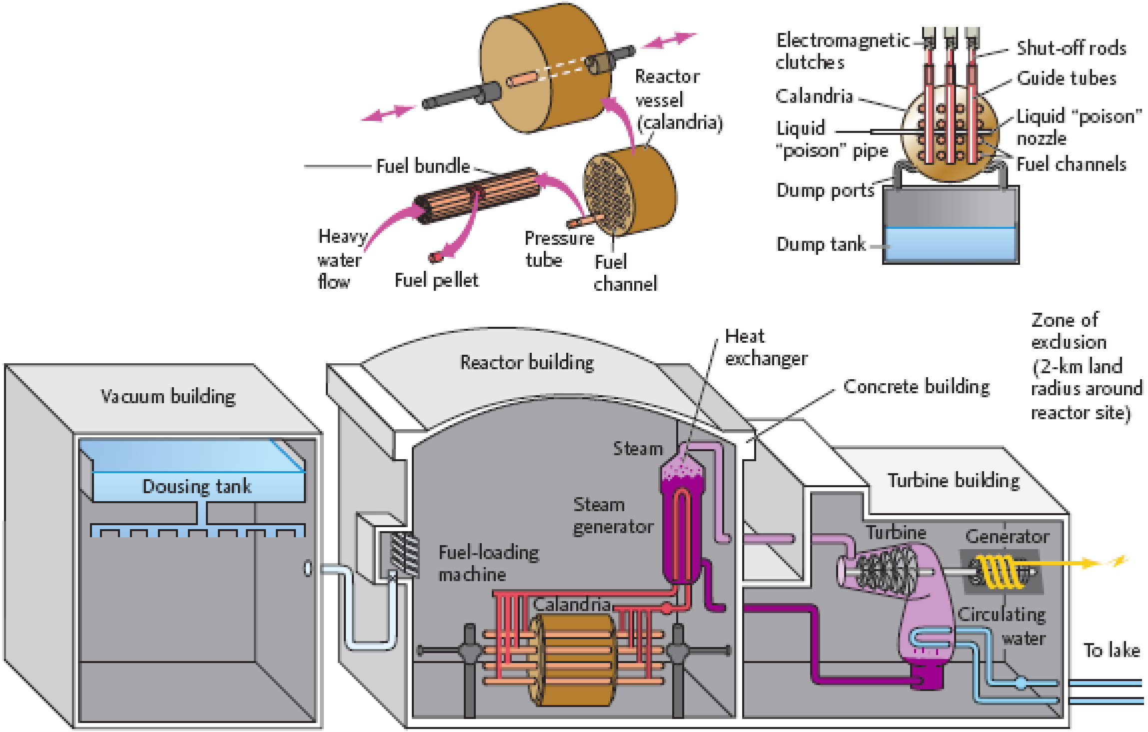
Physics 2204

UNIT 3: Topic 15

Energy Production

Nuclear Fission Energy Production

CANadian Deuterium Uranium reactor **(CANDU)** gets energy from the fission of Uranium which occurs in its many fuel bundles.



Calandria is the reactor core that contains a moderator, and the nuclear fuel to achieve nuclear fission.

Nuclear fuel (natural uranium 235) is a material that can be consumed to derive nuclear energy

Moderator is a medium which reduces the velocity of fast neutrons.

Deuterium (Heavy water) is used as a moderator. Heavy water is chemically and physically identical to regular water, with the exception that the extra neutron in each atom of hydrogen makes it more dense.

Control Rods (shut off Rods)control the distribution of power in the reactor and can be used to shutdown the reactor.

Critical Mass: the minimum mass of nuclear material needed for a self –sustaining chain reaction to occur

Controlled Nuclear Fission Reactions

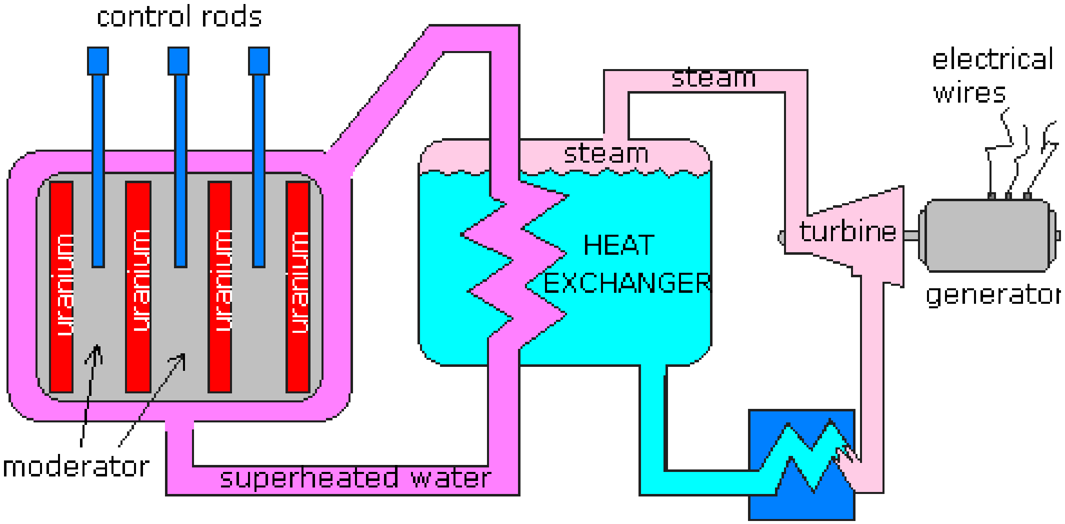


Diagram of a nuclear fission power plant (adapted from Conceptual Physics by Paul G. Hewitt)

The moderator slows down the neutrons so that the uranium atoms in the fuel rods will capture the neutrons and go through the fission process. The fission process produces enormous heat which superheats the water that surrounds the core. The superheated water is piped to a heat exchanger where it causes more water to boil and give off steam. The steam causes the blades of the turbine to spin. The turbine is connected via a shaft to the generator and electricity is produced. The steam is recycled via a condenser where it is converted back to water. The control rods are made of a material that can absorb neutrons. Consequently, the nuclear reaction can be controlled by raising and lowering the control rods.

CANDU Safety Systems

1)Moderator Dump -The heavy water moderator passes through the calandria by gravity. If no more heavy water is ‘poured’, the reactions stop because there is no moderator slowing down neutrons

2)Cadmium Control Rods - Cadmium rods, which absorb neutrons, can be lowered into the core remotely to control the reactions. These rods are dropped from electromagnetic clutches and stop the reactions, if there is a power outage.

3) Moderator “Poison” - A neutron-absorbing solution can be injected into the moderator. This stops the chain reactions, while also cooling the core.

Nuclear Energy Debate

Reasons for Nuclear Energy

1)The demand for electricity will keep increasing, so the way in which we generate electricity must be able to keep up

2)Uranium, the fuel for nuclear fission, is indigenous to which frees us from depending on expensive importing of oil and natural gas.

3)Everything we do involves risk , and there is certainly no way to generate the power that we need risk free. The safety of CANDU reactors has been proven and is a technology that is available now

4)Compared to burning coal, CANDU reactors are much more environmentally friendly.The highly radioactive waste that is produced does not take up much volume

5) High capital costs at the outset will be more than offset by a plenitude of safe and inexpensive power for years to come.

Reasons Against Nuclear Energy

1) Energy conservation and efficiency improvements could reduce the growth rate for electricity demand while at the same
creating jobs

2) Uranium mining in Canada disturbs buried radioactive material. Exposed radioactive material is called **radioactive tailings.** It leaches into the soil and groundwater, causing radioactive contamination of sensitive ecosystems

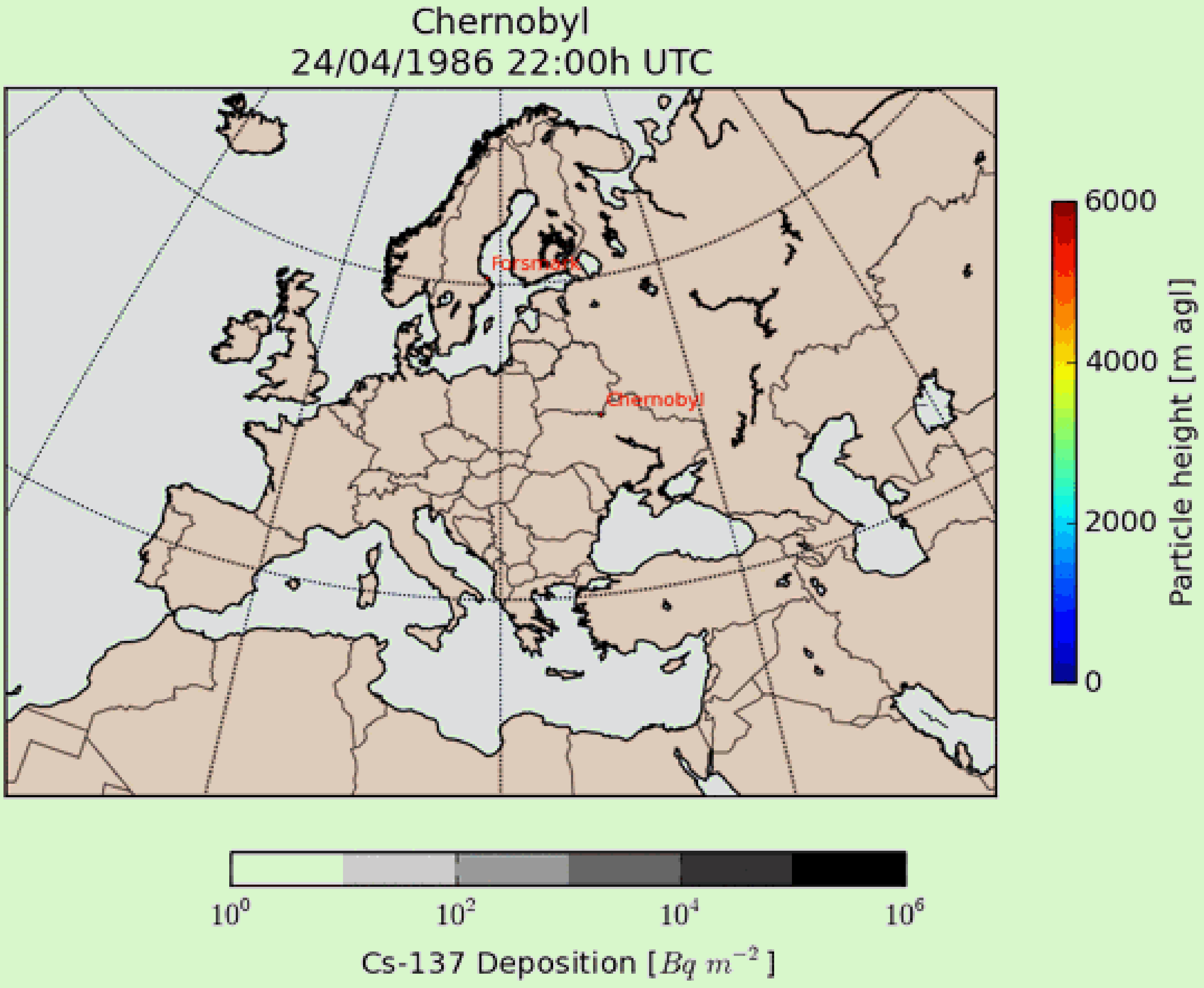
3) Any safety record has been based on limited operational experience. Any health and environmental effects may take years to manifest themselves, when they do, the result is long term and catastrophic

4) The nature of the effects of exposure to radioactive isotopes means that any negative health and environmental effects will not be realized for years. No permanent and safe methods for the disposal of long-lived high-level radioactive have been employed as of yet

5) Nuclear power is very centralized and capital cost intensive. Quite often, the costs may be hidden due to various government subsidies


1.8 MW
ZERO EMISSIONS
450 MW X 6 = 2700 MW
ZERO EMISSIONS
ANY QUESTIONS?

Met Office


Chernobyl
24/04/1986 22:00h UTC
Forsmark
Chernobyl
6000
4000
2000
0
Particle height [m agl]
10^0
10^2
10^4
10^6
Cs-137 Deposition [$Bq\ m^{-2}$]