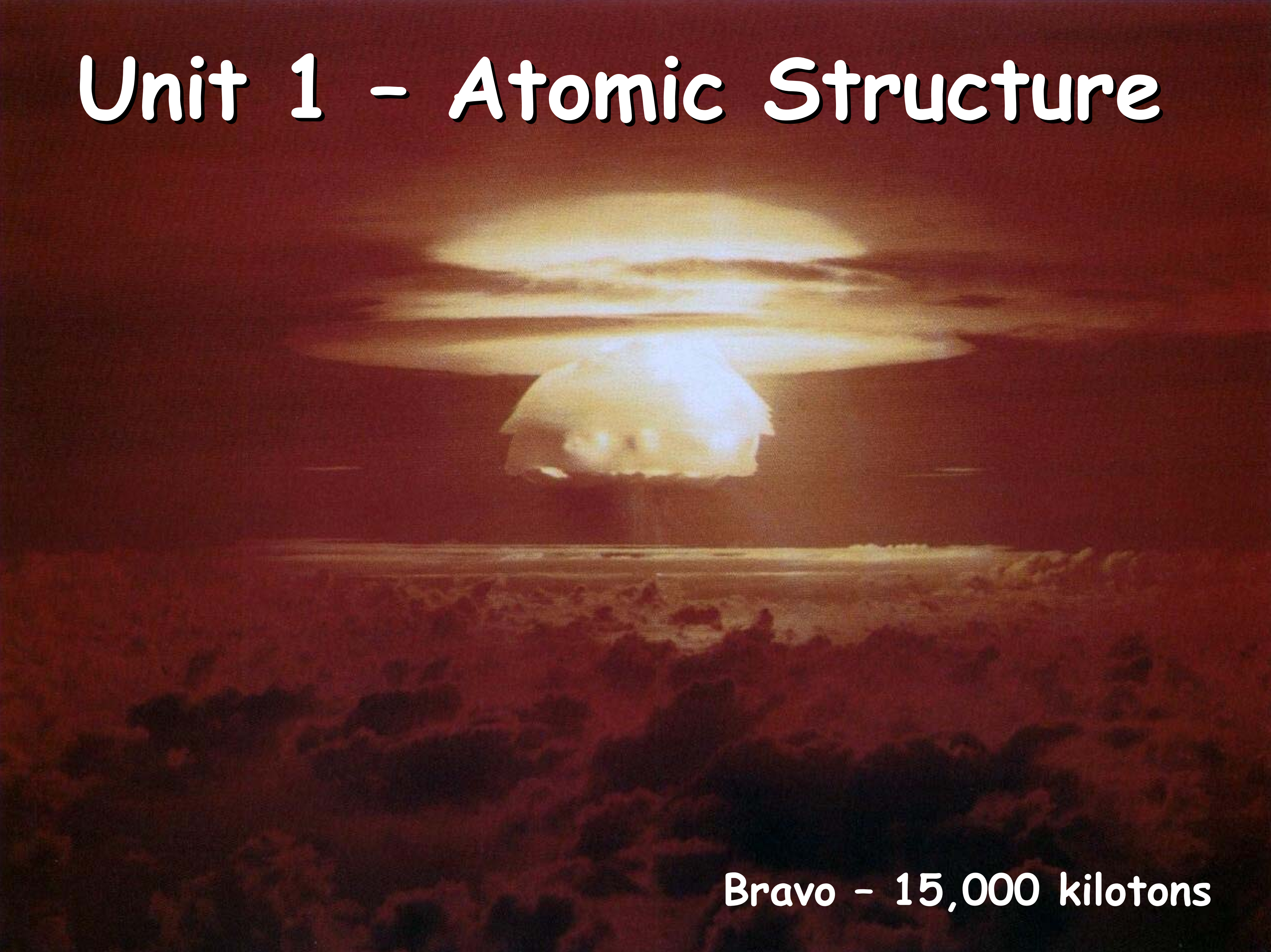
Unit 1 – Atomic Structure



Bravo – 15,000 kilotons

Modern Atomic Theory

- All matter is composed of atoms

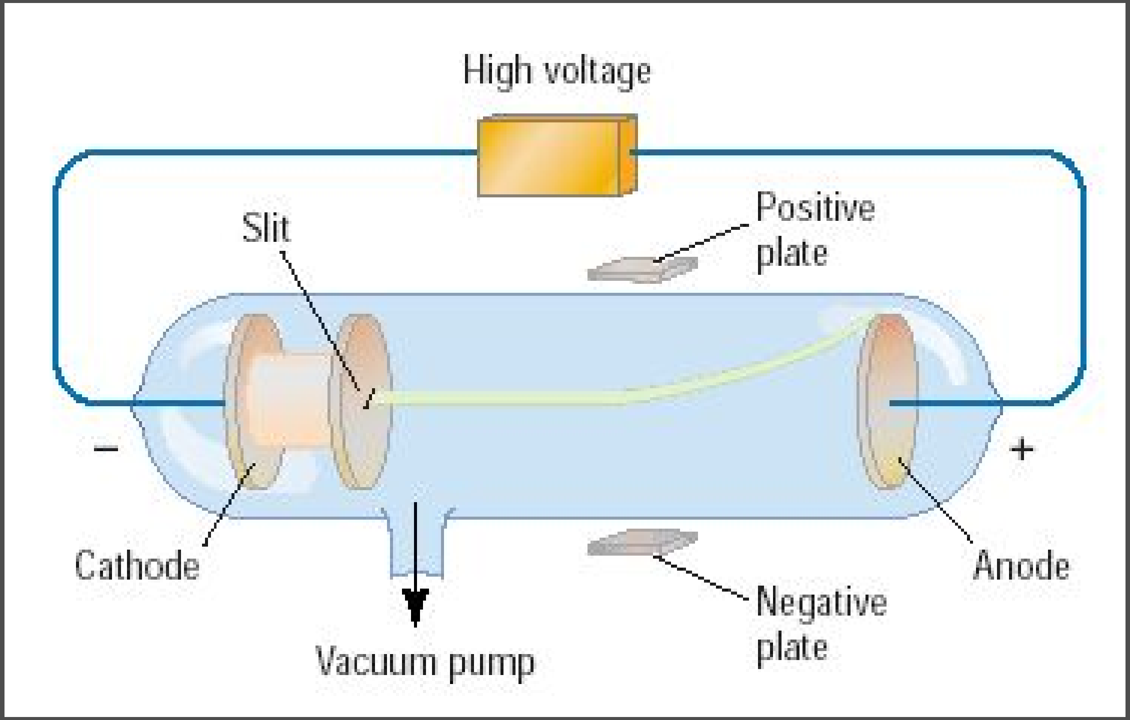
- Atoms cannot be subdivided, created, or destroyed in ordinary chemical reactions. However, these changes CAN occur in nuclear reactions!

- Atoms of an element have a characteristic average mass which is unique to that element.

- Atoms of any one element differ in properties from atoms of another element

Discovery of the Electron

In 1897, J.J. Thomson used a cathode ray tube to deduce the presence of a negatively charged particle.

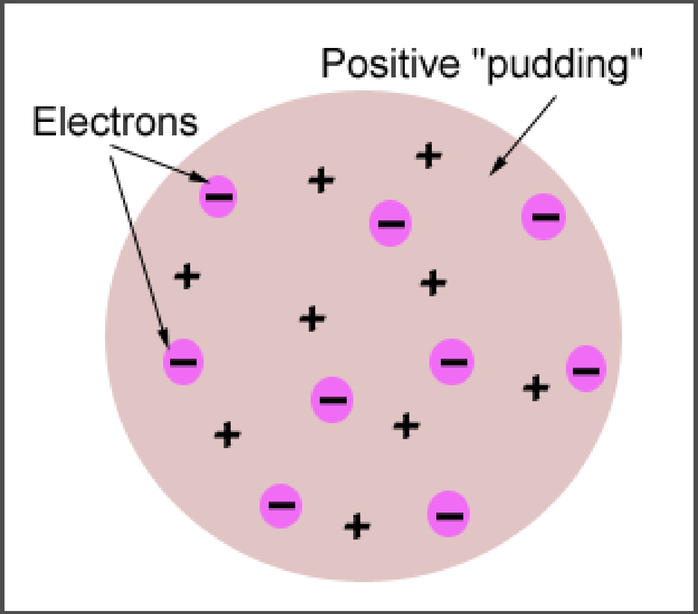


Cathode ray tubes pass electricity through a gas that is contained at a very low pressure.

Conclusions from the Study of the Electron

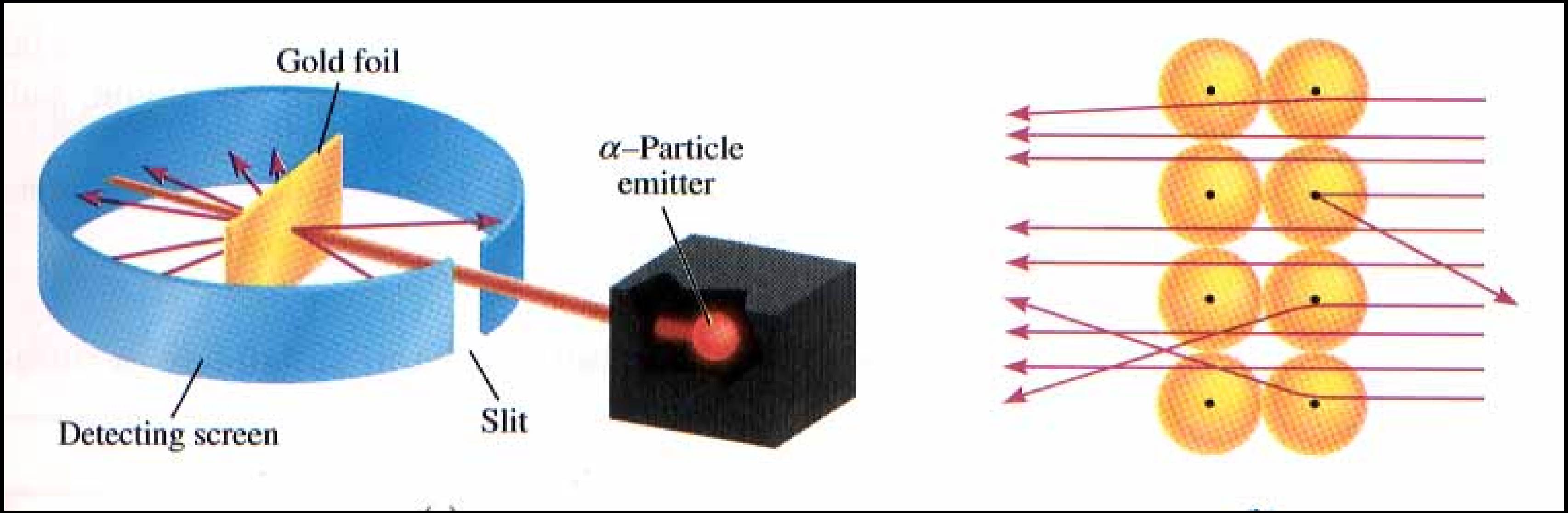
- Cathode rays have identical properties regardless of the element used to produce them. All elements must contain identically charged electrons.
- Atoms are neutral, so there must be positive particles in the atom to balance the negative charge of the electrons
- Electrons have so little mass that atoms must contain other particles that account for most of the mass

Thomson's Atomic Model



Thomson believed that the electrons were like plums embedded in a positively charged "pudding," thus it was called the "plum pudding" model.

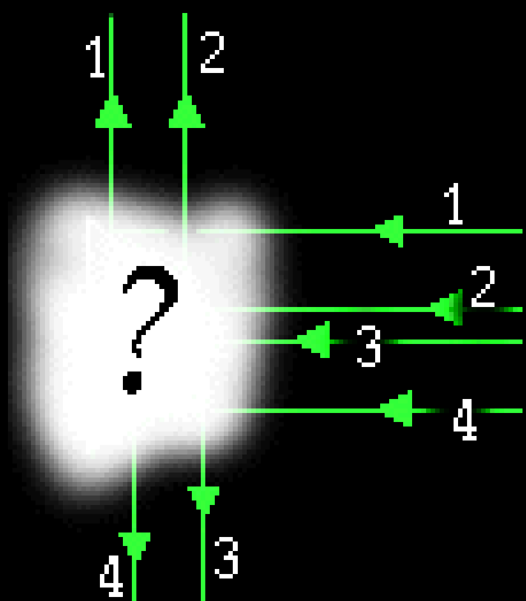
Rutherford's Gold Foil Experiment

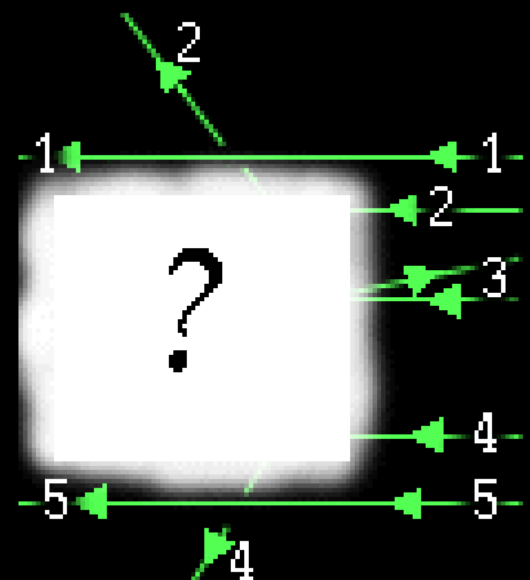


- Alpha particles are helium nuclei
- Particles were fired at a thin sheet of gold foil
- Particle hits on the detecting screen (film) are recorded

Try it Yourself!

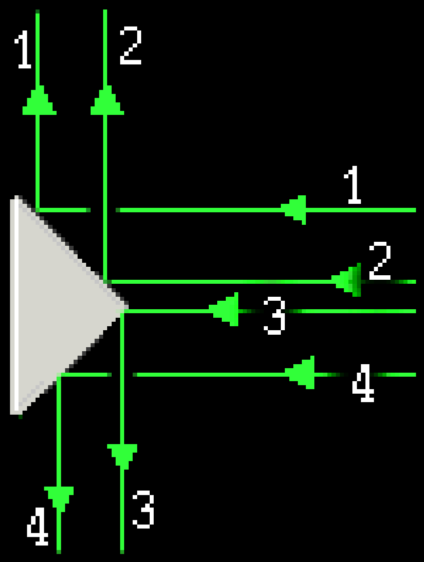
In the following pictures, there is a target hidden by a cloud. To figure out the shape of the target, we shot some beams into the cloud and recorded where the beams came out. Can you figure out the shape of the target?



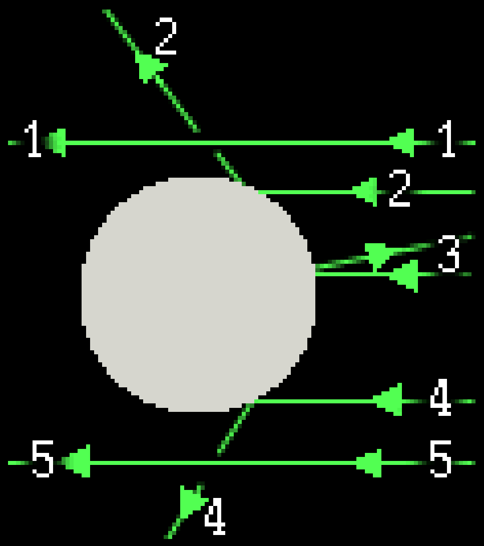


The Answers

Target #1

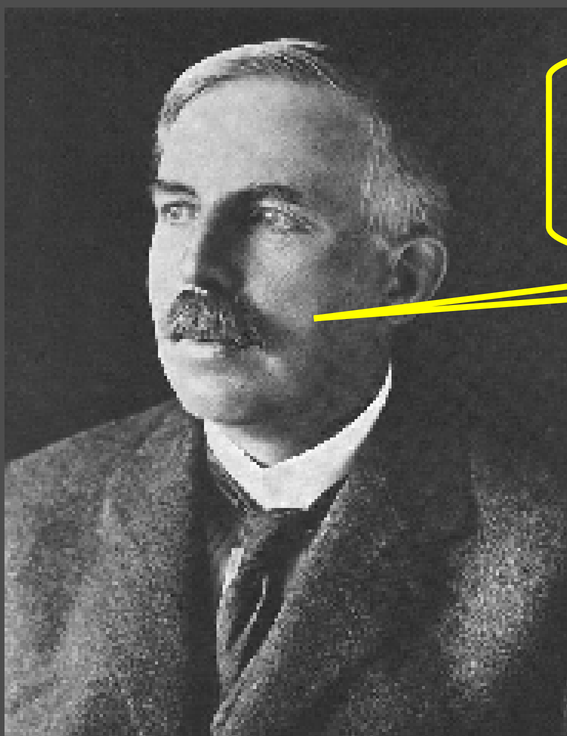


Target #2



Rutherford's Findings

- Most of the particles passed right through
- A few particles were deflected
- VERY FEW were greatly deflected



"Like howitzer shells bouncing off of tissue paper!"

Conclusions:

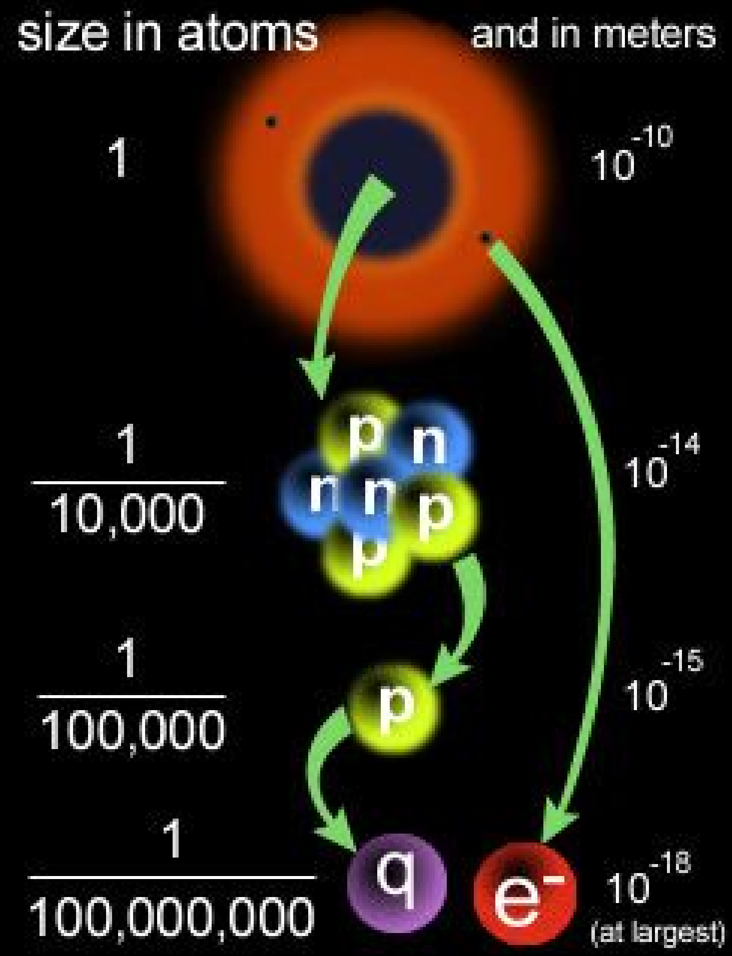
- The nucleus is small
- The nucleus is dense
- The nucleus is positively charged

Atomic Particles

Particle	Charge	Mass #	Location
Electron	-1	0	Electron cloud
Proton	+1	1	Nucleus
Neutron	0	1	Nucleus

The Atomic Scale

- Most of the mass of the atom is in the nucleus (protons and neutrons)
- Electrons are found outside of the nucleus (the electron cloud)
- Most of the volume of the atom is empty space



"q" is a particle called a "quark"

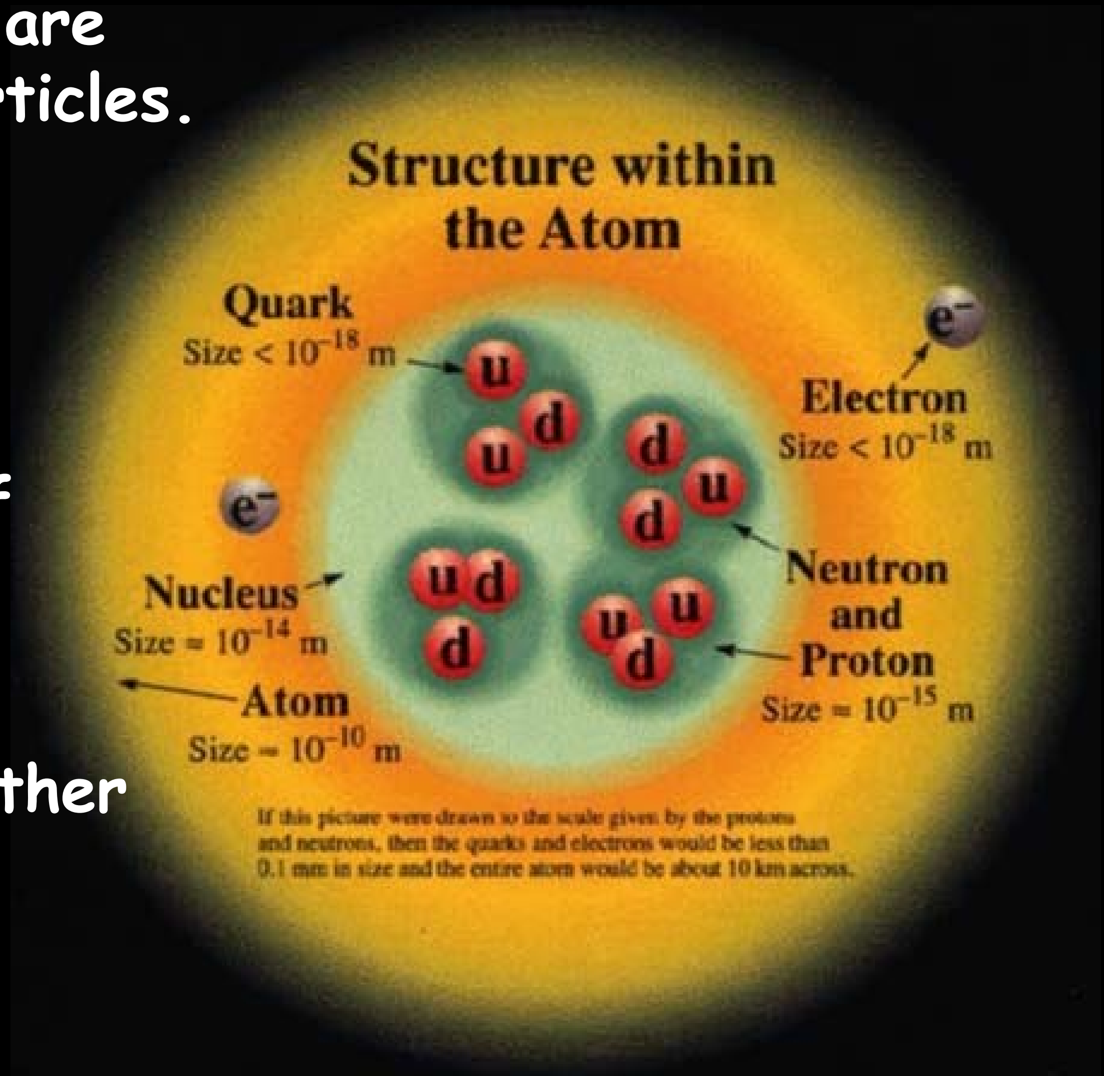
About Quarks…

Protons and neutrons are <u>NOT</u> fundamental particles.

Protons are made of two “up” quarks and one “down” quark.

Neutrons are made of one “up” quark and two “down” quarks.

Quarks are held together by “gluons”



Atomic Number

Atomic number (Z) of an element is the number of protons in the nucleus of each atom of that element.

Element	# of protons	Atomic # (Z)
Carbon	6	6
Phosphorus	15	15
Gold	79	79

Mass Number

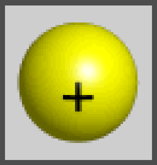
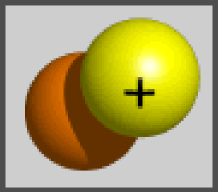
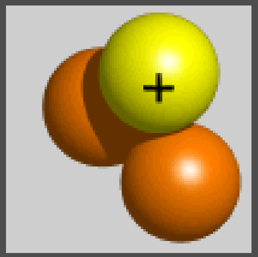
Mass number is the number of protons and neutrons in the nucleus of an isotope.

$$\text{Mass \#} = p^{+} + n^{0}$$

Nuclide	p^+	n^0	e^-	Mass #
Oxygen - 18	8	10	8	18
Arsenic - 75	33	42	33	75
Phosphorus - 31	15	16	15	31

Isotopes

Isotopes are atoms of the same element having different masses due to varying numbers of neutrons.

Isotope	Protons	Electrons	Neutrons	Nucleus
Hydrogen–1 (protium)	1	1	0	
Hydrogen-2 (deuterium)	1	1	1	
Hydrogen-3 (tritium)	1	1	2	

Atomic Masses

Atomic mass is the average of all the naturally isotopes of that element.

Carbon = 12.011

Isotope	Symbol	Composition of the nucleus	% in nature
Carbon-12	^{12}C	6 protons 6 neutrons	98.89%
Carbon-13	^{13}C	6 protons 7 neutrons	1.11%
Carbon-14	^{14}C	6 protons 8 neutrons	<0.01%

The Mole

1 dozen = 12

1 gross = 144

1 ream = 500

1 mole = 6.02×10^{23}

There are exactly 12 grams of carbon-12 in one mole of carbon-12.

Avogadro's Number

6.02×10^{23} is called "Avogadro's Number" in honor of the Italian chemist Amadeo Avogadro (1776-1855).

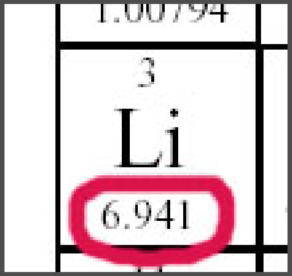
Amadeo Avogadro

I didn't discover it. Its just named after me!

Calculations with Moles:

Converting moles to grams

How many grams of lithium are in 3.50 moles of lithium?

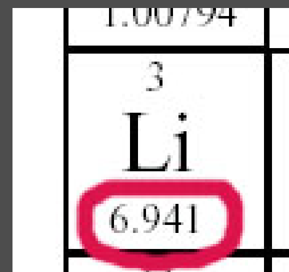


$$\frac{3.50 \text{ mol Li}}{} \times \frac{6.94 \text{ g Li}}{1 \text{ mol Li}} = 45.1 \text{ g Li}$$

Calculations with Moles:

Converting grams to moles

How many moles of lithium are in 18.2 grams of lithium?



18.2 ~~g~~ Li	1 mol Li	=	2.62 mol Li
	6.94 ~~g~~ Li		

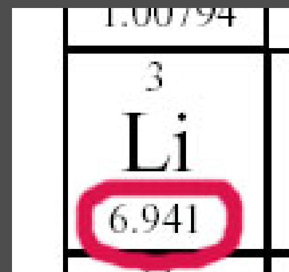
Calculations with Moles:
Using Avogadro's Number

How many atoms of lithium are in 3.50 moles of lithium?

$$\frac{3.50 \text{ mol Li}}{} \left| \frac{6.022 \times 10^{23} \text{ atoms Li}}{1 \text{ mol Li}} \right. = 2.11 \times 10^{24} \text{ atoms Li}$$

Calculations with Moles:
Using Avogadro's Number

How many atoms of lithium are in 18.2 g of lithium?



18.2 ~~g~~ Li	1 ~~mol~~ Li	6.022×10^{23} atoms Li
	6.94 ~~g~~ Li	1 ~~mol~~ Li

$(18.2)(6.022 \times 10^{23})/6.94 = 1.58 \times 10^{24}$ atoms Li

Nuclear Symbols

Mass number
($p^+ + n^o$)

$$^{235}_{92}U$$

Element symbol

Atomic number
(number of p^+)

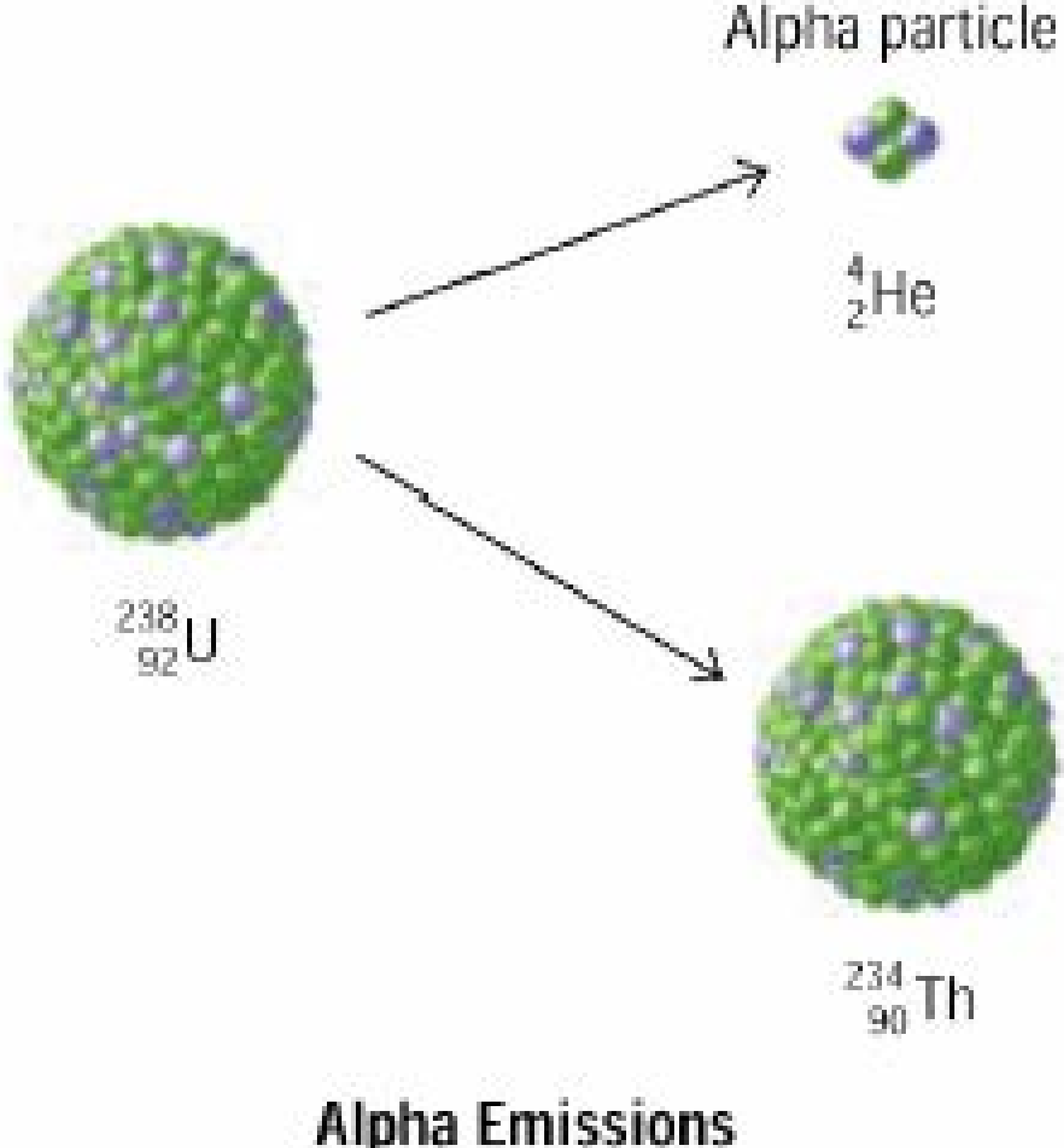
Types of Radioactive Decay

- **alpha production (α): helium nucleus** $^{4}_{2}He^{2+}$

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

- **beta production (β):** $^{0}_{-1}e$

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

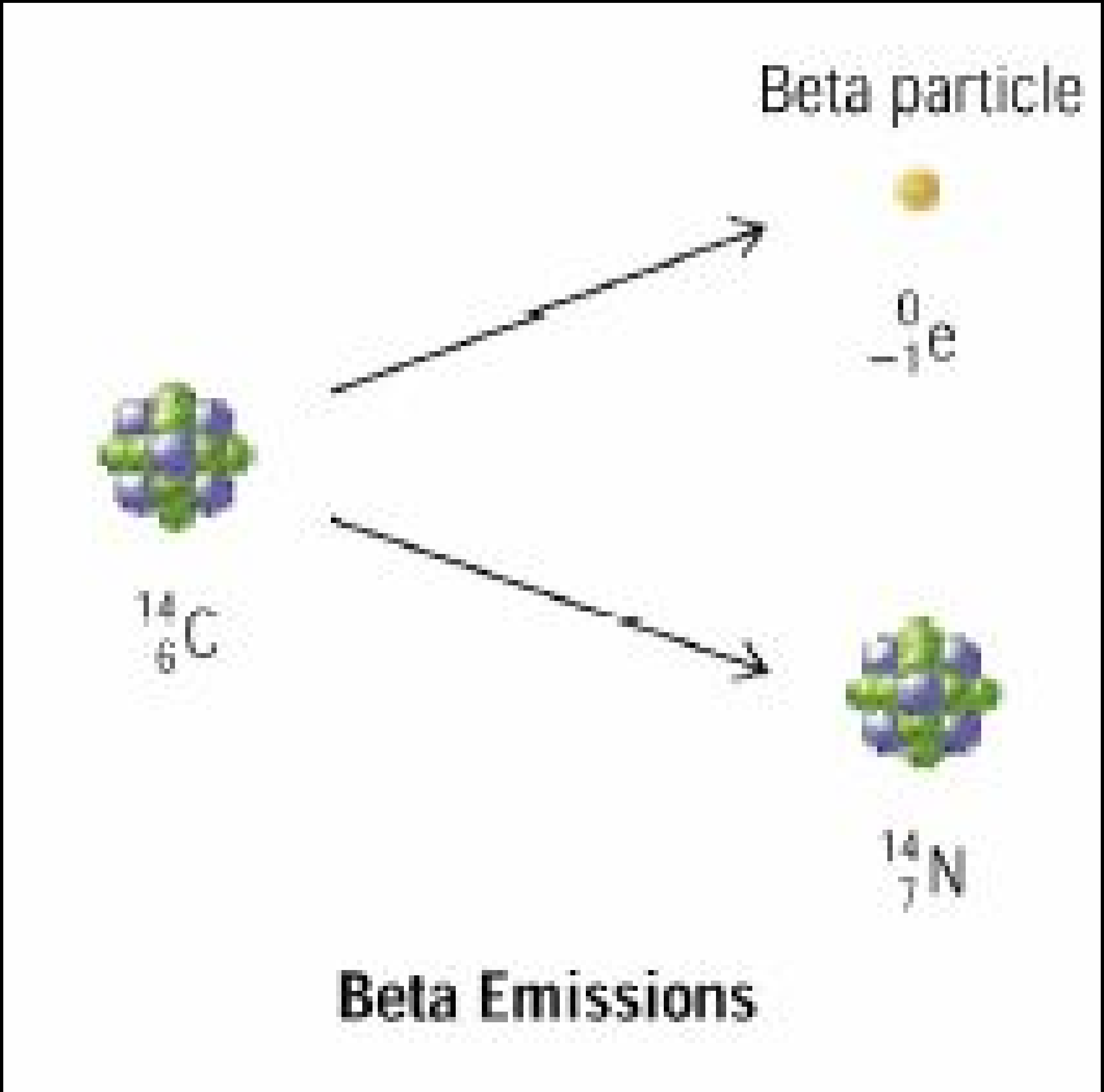


Alpha Radiation

Limited to VERY large nucleii.

Beta Radiation

Converts a neutron into a proton.



Types of Radioactive Decay

- gamma ray production (γ):

$$^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He} + {}^{234}_{90}\text{Th} + 2\,{}^{0}_{0}\gamma$$

- positron production ${}^{0}_{1}\text{e}$:

$$^{22}_{11}\text{Na} \rightarrow {}^{0}_{1}\text{e} + {}^{22}_{10}\text{Ne}$$

- electron capture: (inner-orbital electron is captured by the nucleus)

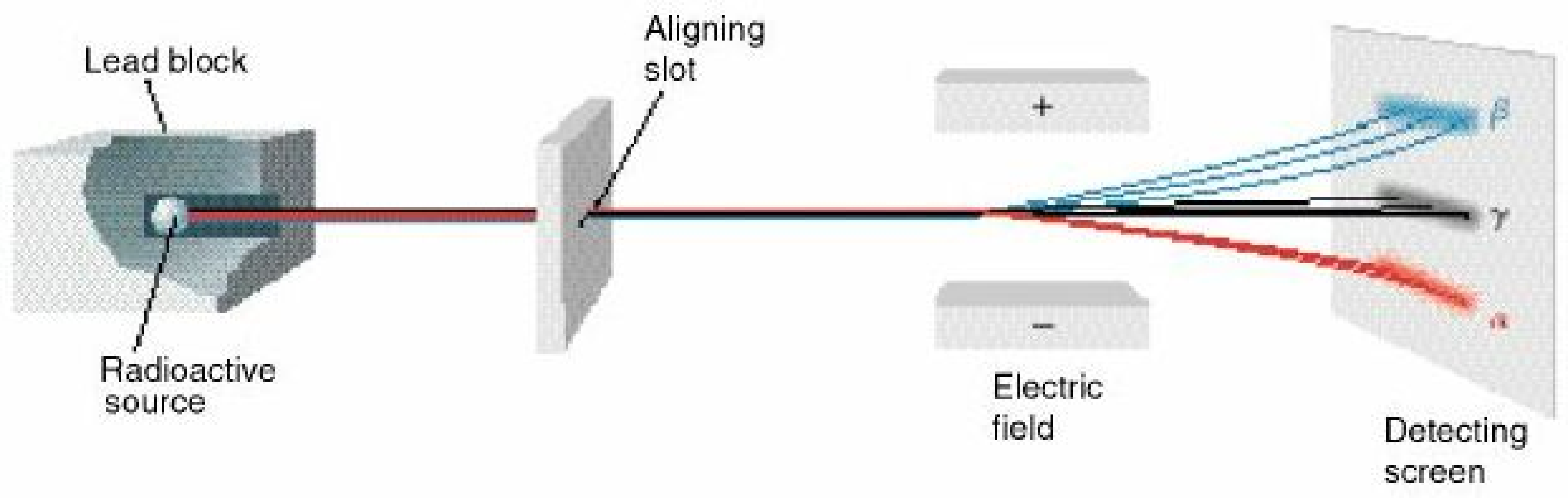
$$^{201}_{80}\text{Hg} + {}^{0}_{-1}\text{e} \rightarrow {}^{201}_{79}\text{Au} + {}^{0}_{0}\gamma$$

Characteristics of Some Ionizing Radiations

Property	Alpha radiation	Beta radiation	Gamma radiation
Composition	Alpha particle (helium nucleus)	Beta particle (electron)	High-energy electro-magnetic radiation
Symbol	α, ${}^{4}_{2}He$	β, ${}^{0}_{-1}e$	γ
Charge	2+	1−	0
Mass (amu)	4	1/1837	0
Common source	Radium-226	Carbon-14	Cobalt-60
Approximate energy	5 MeV*	0.05 to 1 MeV	1 MeV
Penetrating power	Low (0.05 mm body tissue)	Moderate (4 mm body tissue)	Very high (penetrates body easily)
Shielding	Paper, clothing	Metal foil	Lead, concrete (incompletely shields)

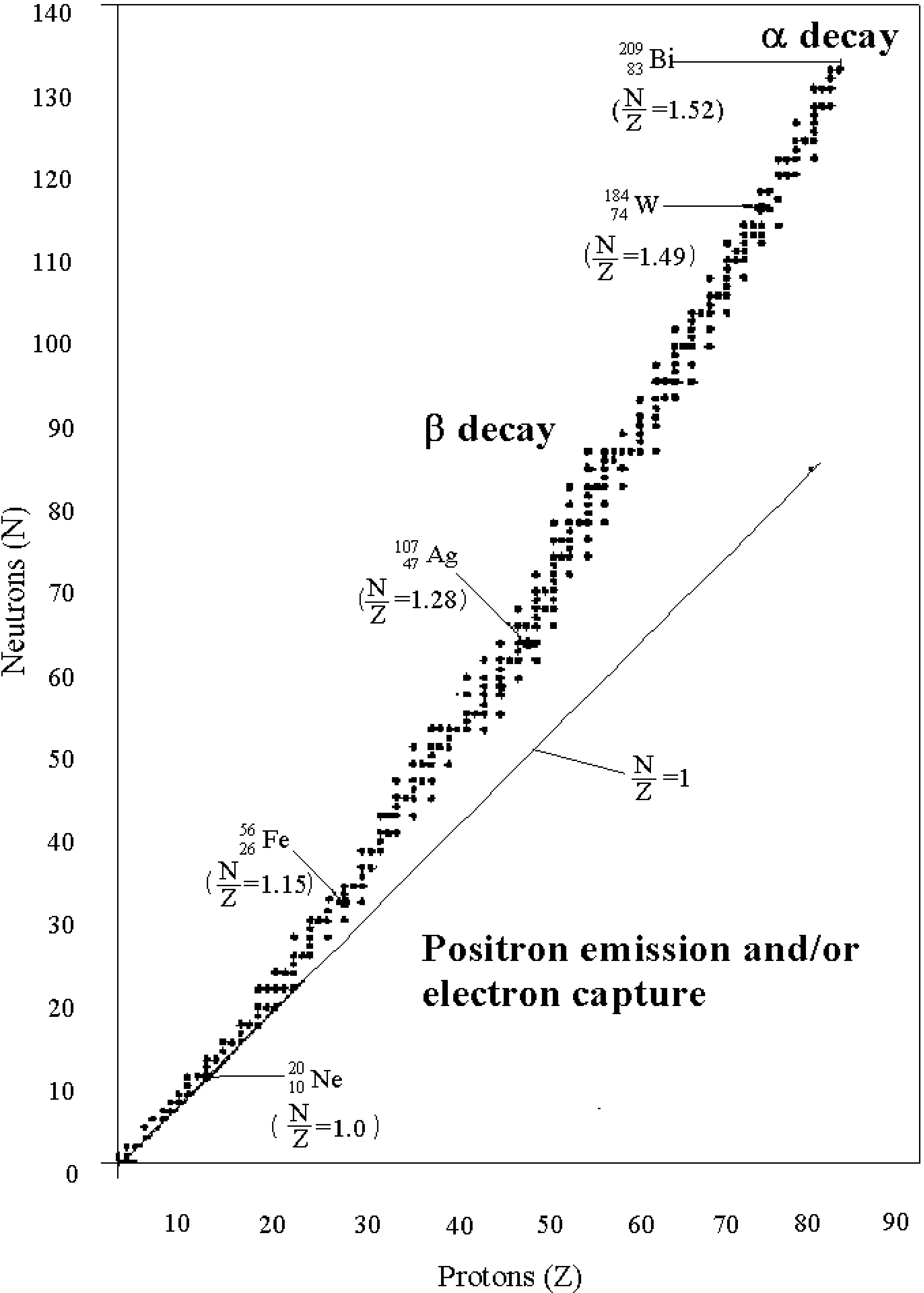
*(1 MeV = 1.60×10^{-13} J)

Deflection of Decay Particles



Opposite charges___attract___ each other.

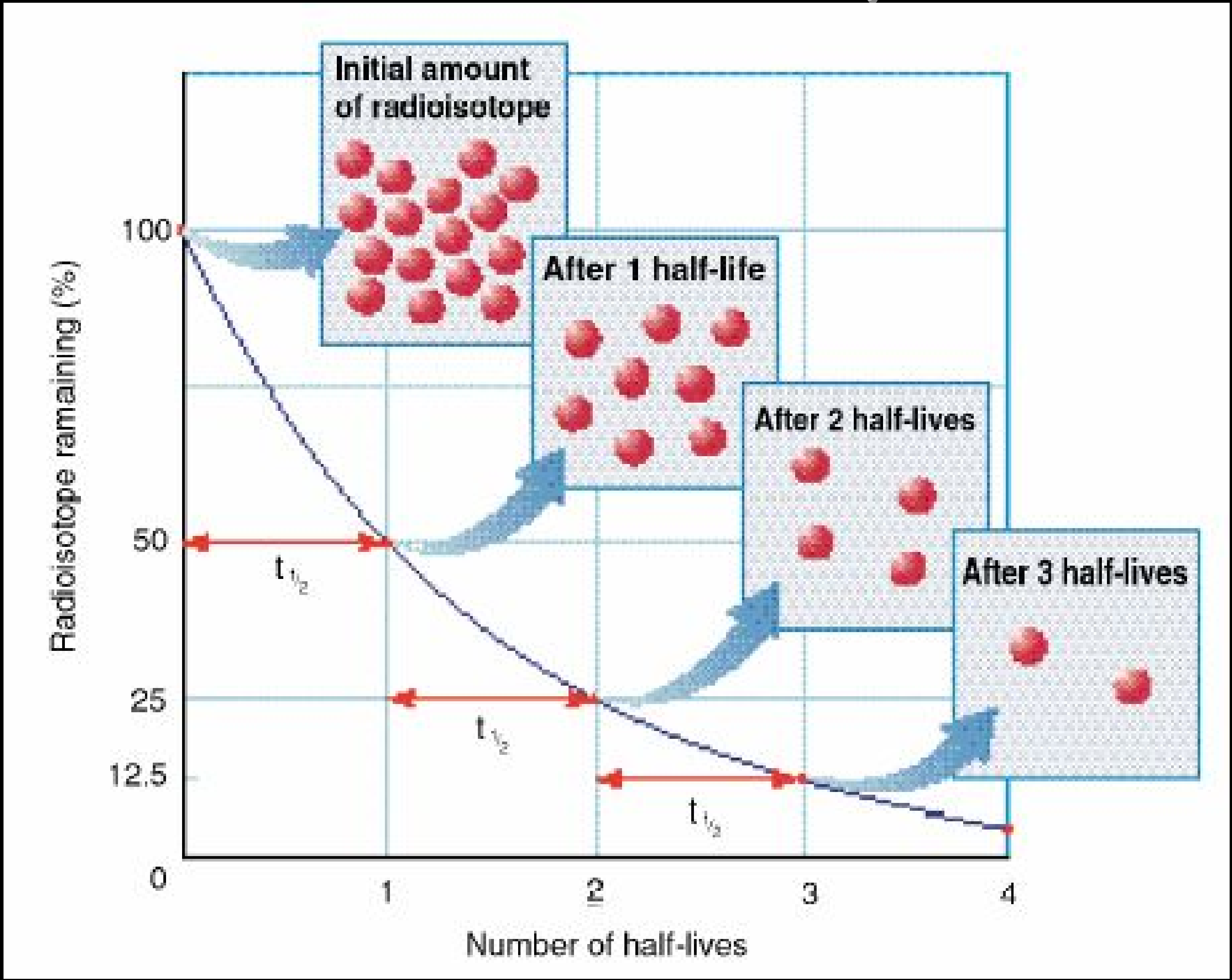
Like charges___repel___ each other.



Nuclear Stability

Decay will occur in such a way as to return a nucleus to the band (line) of stability.

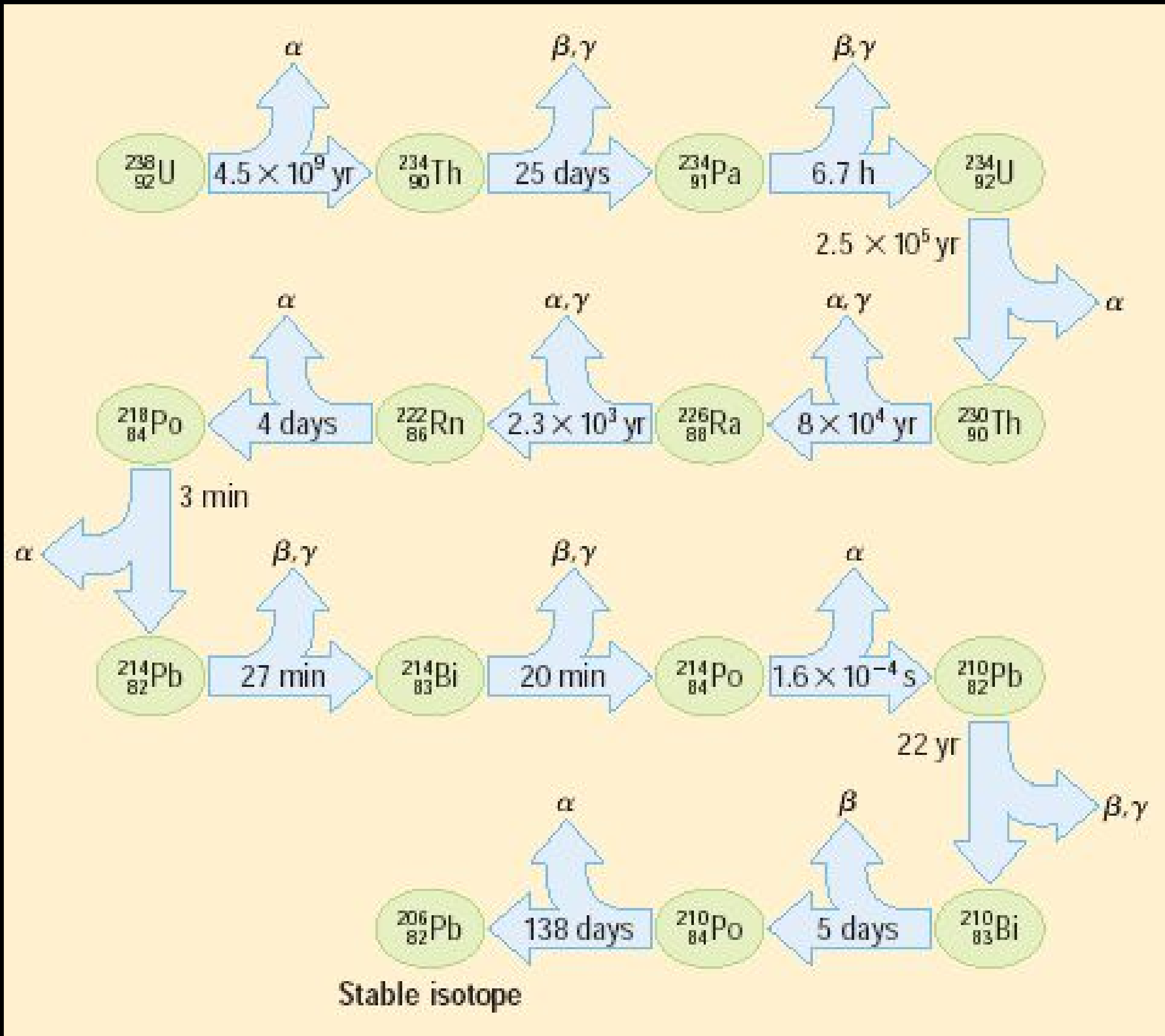
Half-life Concept



Sample Half-Lives

Half-Lives and Radiation of Some Naturally Occurring Radioisotopes		
Isotope	**Half-life**	**Radiation emitted**
Carbon-14	5.73×10^3 years	β
Potassium-40	1.25×10^9 years	β, γ
Radon-222	3.8 days	α
Radium-226	1.6×10^3 years	α, γ
Thorium-230	7.54×10^4 years	α, γ
Thorium-234	24.1 days	β, γ
Uranium-235	7.0×10^8 years	α, γ
Uranium-238	4.46×10^9 years	α

A radioactive nucleus reaches a stable state by a series of steps



A Decay Series

Nuclear Fission and Fusion

- **Fusion**: Combining two light nuclei to form a heavier, more stable nucleus.

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

- **Fission**: Splitting a heavy nucleus into two nuclei with smaller mass numbers.

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

Energy and Mass

Nuclear changes occur with small but measurable losses of mass. The lost mass is called the mass defect, and is converted to energy according to Einstein's equation:

$$\Delta E = \Delta mc^2$$

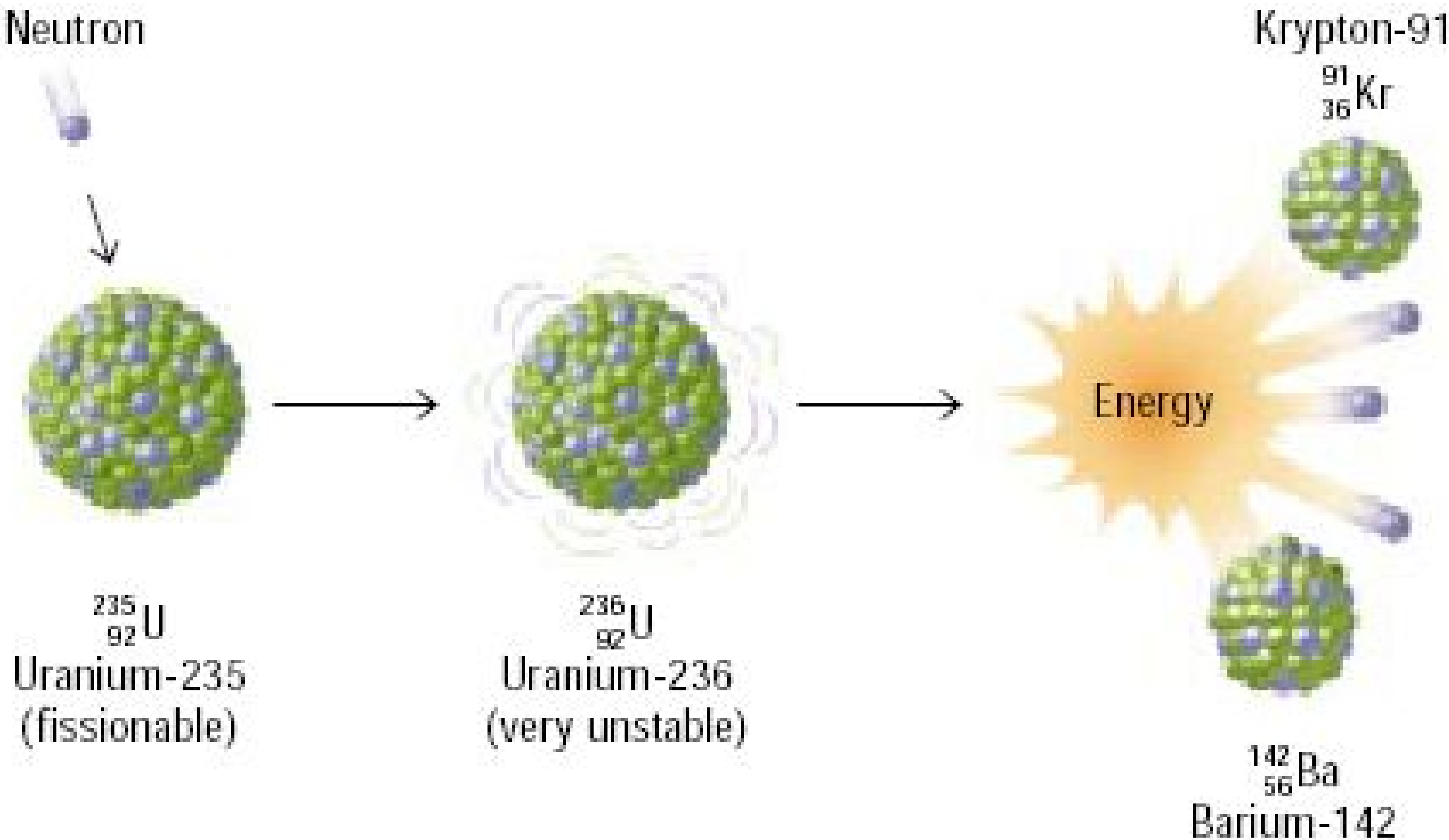
Δm = mass defect

ΔE = change in energy

c = speed of light

Because c^2 is so large, ***even small amounts of mass are converted to enormous amount of energy.***

Fission



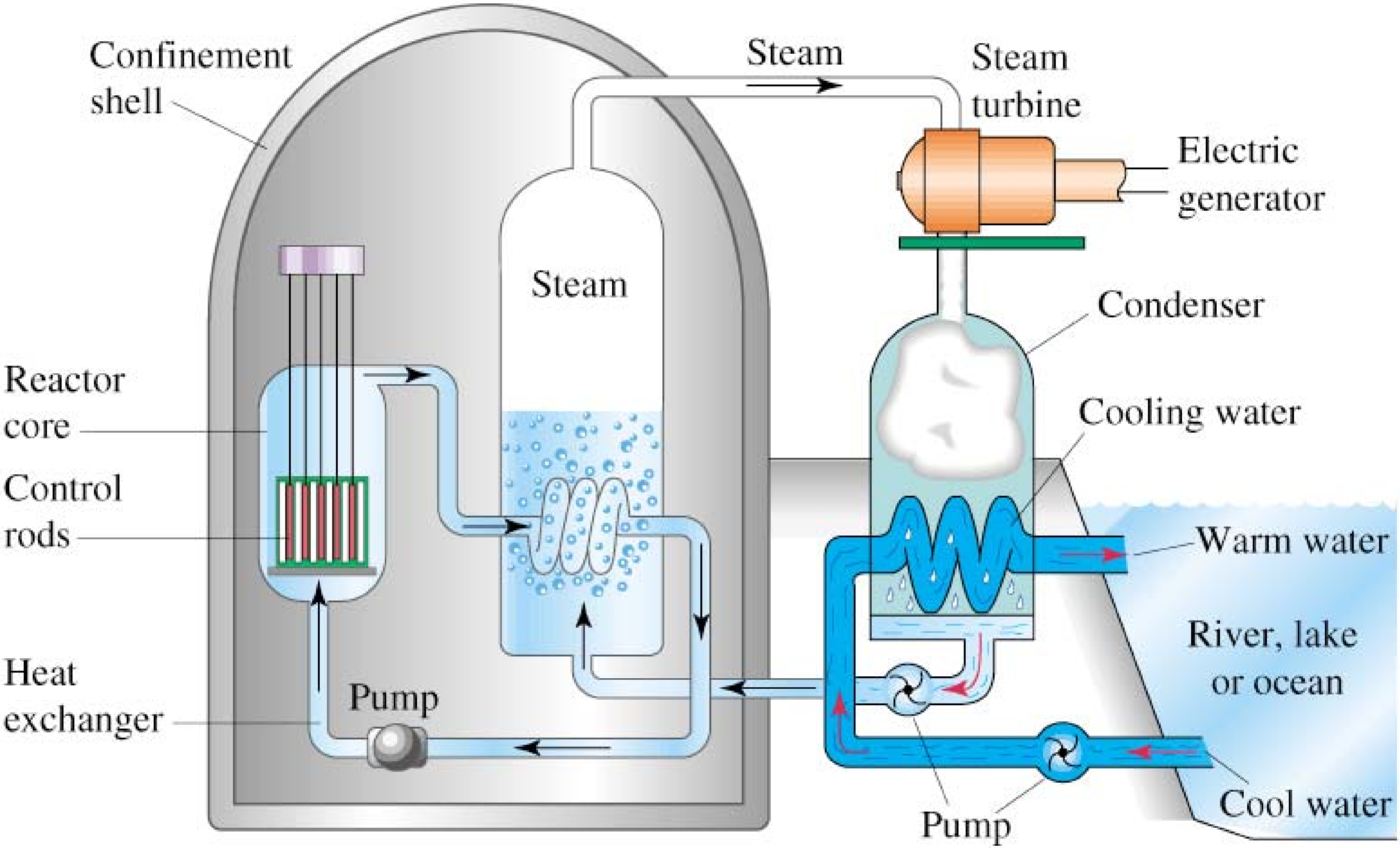
Neutron
Krypton-91
$^{91}_{36}Kr$
Energy
$^{235}_{92}U$
Uranium-235
(fissionable)
$^{236}_{92}U$
Uranium-236
(very unstable)
$^{142}_{56}Ba$
Barium-142

Fission Processes

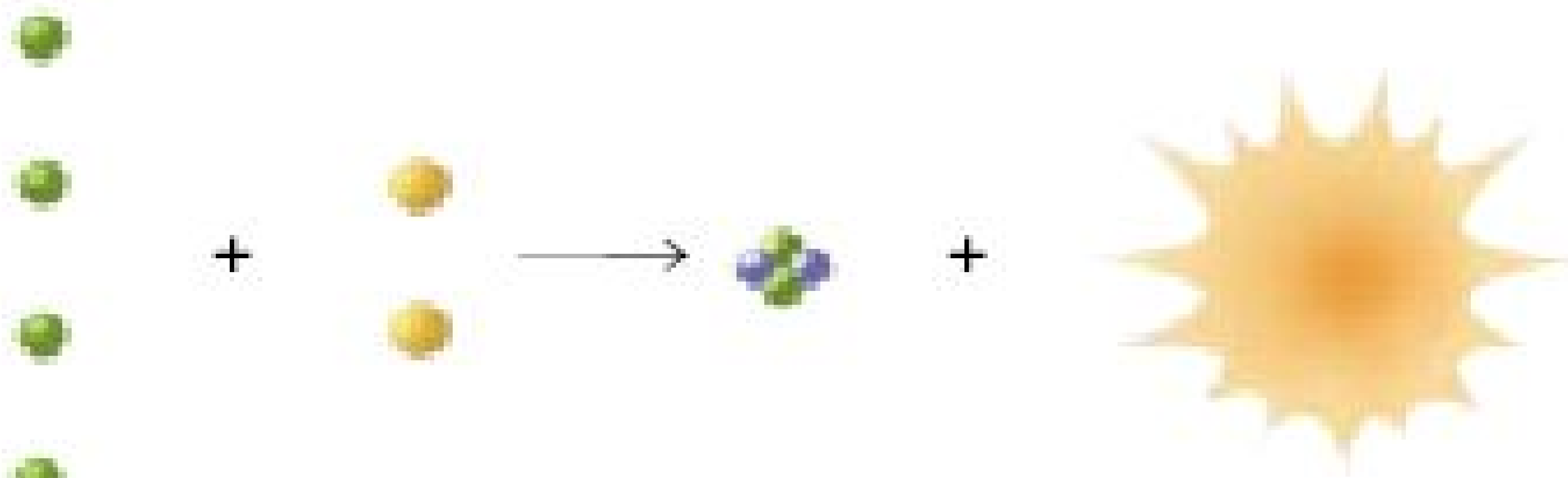
A self-sustaining fission process is called a chain reaction.

Event	Neutrons Causing Fission	Result
subcritical	< 1	reaction stops
critical	= 1	sustained reaction
supercritical	> 1	violent explosion

A Fission Reactor



Fusion



$$4\,{}^{1}_{1}\mathrm{H} + 2\,{}^{0}_{-1}\mathrm{e} \longrightarrow {}^{4}_{2}\mathrm{He} + \text{Energy}$$

Four hydrogen nuclei (protons)	Two beta particles (electrons)	One helium nucleus	Energy