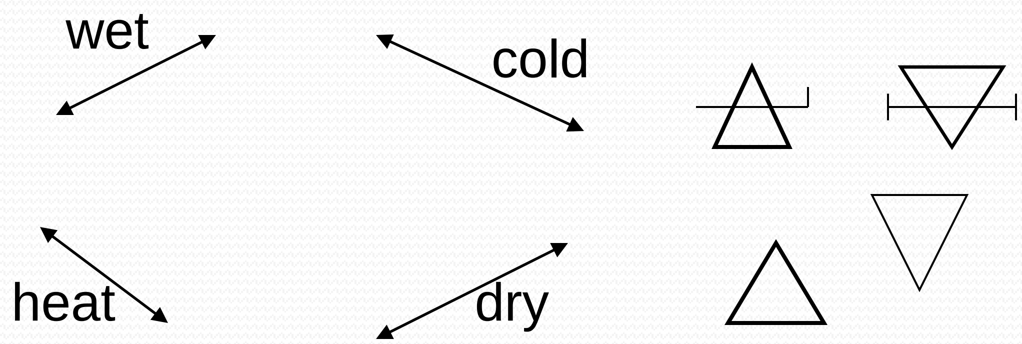
Atom’s Story

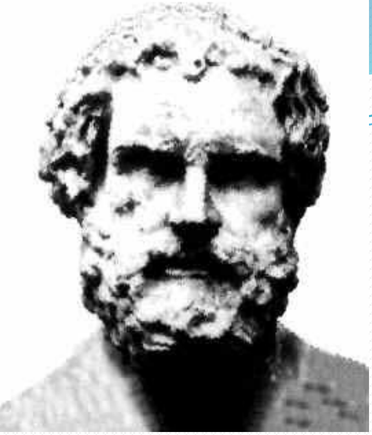
How We Know What We Can’t See Looks Like

Aristotle

- Earth
- Fire
- Water
- Air



- The four elements can change from one to another.



Democritus

400BC

Greek Philosopher

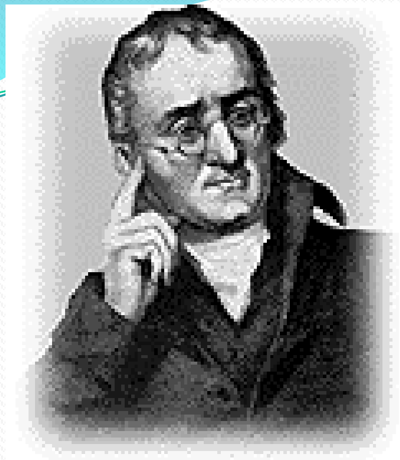
1. Matter is composed of empty space through which atomos move
2. Atomos are solid, homogeneous, **indestructible**, and indivisible.
3. Different kinds of atomos have different shapes and sizes
4. The properties of matter are due to the size shape and movement of atoms
5. Changes in matter result from the changes in the grouping of atomos not from changes in the atoms themselves (atomos cannot change)

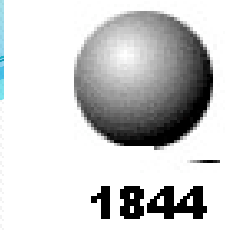
Now you are to take the knowledge known and create the atomic theory.

1. Get a "scrambled atomic theory" worksheet and cut out all the phrases (each line).
2. Piece the phrases together into an organized theory, and tape/glue them to your paper.
3. After you have pieced your theory together, draw a picture that demonstrates each part of the theory that is marked with an *.

(13 mins)

John Dalton





Quaker, School Headmaster, Meteorologist

Atomic Theorist

1. Matter is made of very small particles called “atoms”
2. Atoms cannot be divided, created, or destroyed.
3. Atoms of one kind of element are identical to other atoms of that same element. Atoms of different elements are unlike.
4. Atoms somehow combine in small, whole-number ratios to form chemical compounds.
5. In chemical reactions, atoms are somehow combined, separated, or rearranged.

But now w . .

Can you say:

PROTON?
NEUTRON?
ELECTRON?
QUARK?

1. Matter is made of very s ms”

2. Atoms cannot be divided, created, or destroyed.

3. Atoms of one kind of element are identical to other atoms of that same element. Atoms of different elements are unlike.

4. Atoms somehow combine in small, whole-number ratios to form chemical compounds.

5. In chemical reactions, atoms are somehow combined, separated, or rearranged.

The Law of . . .

Conservation of Mass

Mass can neither be created nor destroyed under ordinary conditions. It can only change forms. *Atoms don't disappear or show up out of nowhere!*

Definite Proportions (or Definite Composition)

Compounds contain the same elements in exactly the same proportions by mass regardless of the size of the sample or source of the compound.

(H_2O is H_2O is H_2O is H_2O is H_2O is H_2O . . .)

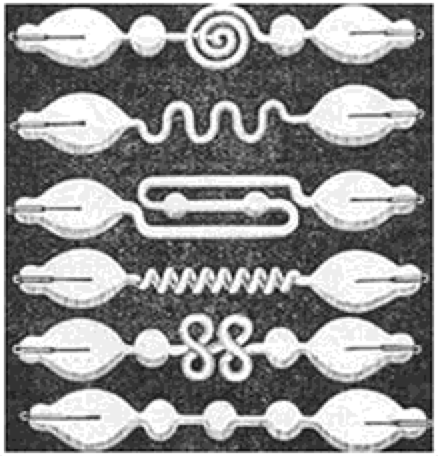
Multiple Proportions

If two or more different compounds are composed of the same two elements, then the ratio of the masses of the second element combined with a certain mass of the first element is always a ratio of small whole numbers.

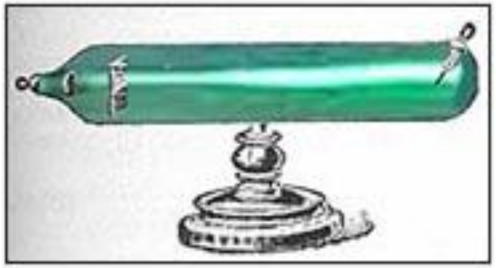
(2 compounds) water (H_2O 2:1) and hydrogen peroxide (H_2O_2 2:2)

carbon dioxide (CO_2 1:2) and carbon monoxide CO (1:1)

J. J. Thomson



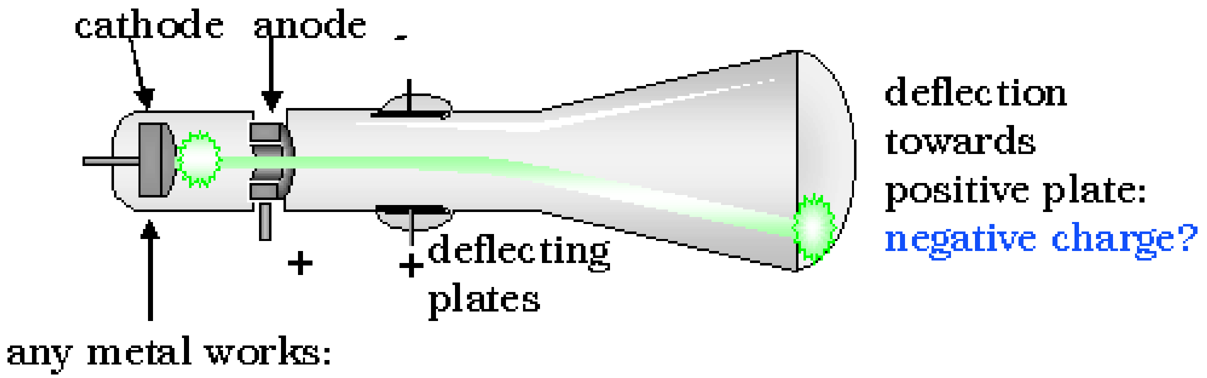
Worked with Cathode Ray Tubes.



He wanted to know what the green glow was. . . . .

Thomson's Experiments

and his conclusions

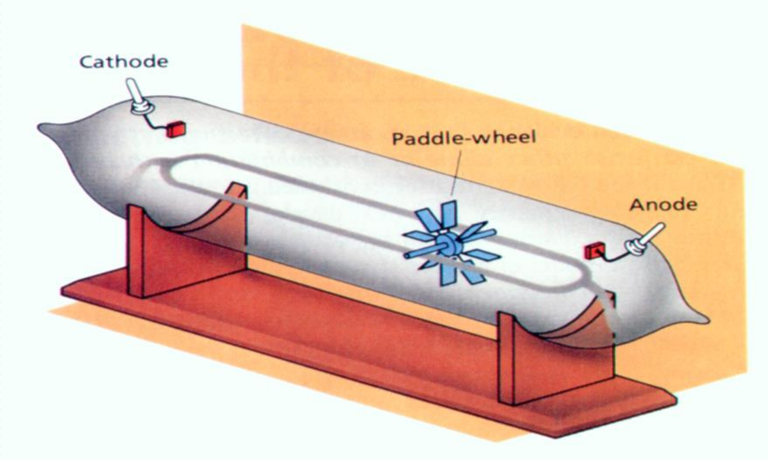


Experiment: What does the beam do in a magnetic/electric field?
The deflecting plates attached to the CRT represent either the magnetic or electric field that Thompson could turn on. No matter which he tried, the beam deflected toward the positive and away from the negative plate.

Conclusion: The beam is composed of

negatively charged particles.

Thomson's Experiments



and his conclusions

Experiment: Can the beam transfer momentum?

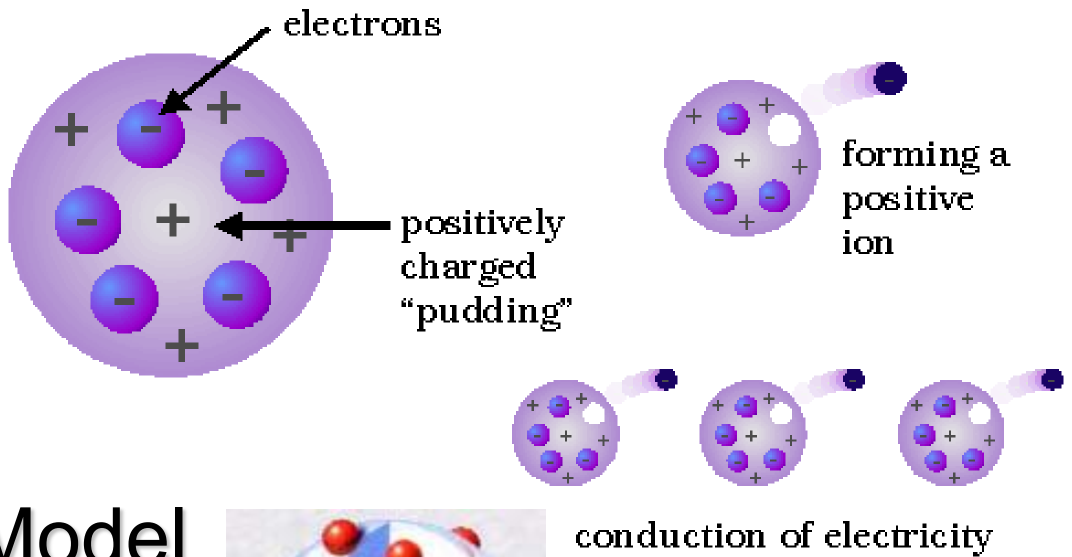
A paddle wheel is mounted inside a CRT and the beam is pointed at it. The beam is able to push the paddle wheel down the tracks.

Conclusion: The particles must be matter (not energy) as they can cause something to physically move.

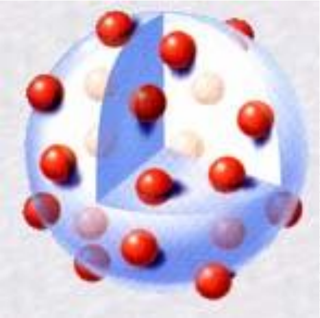
Thomson's New Atom

The 'canal rays' or 'cathode rays' are considered a beam of a very small part of atoms.

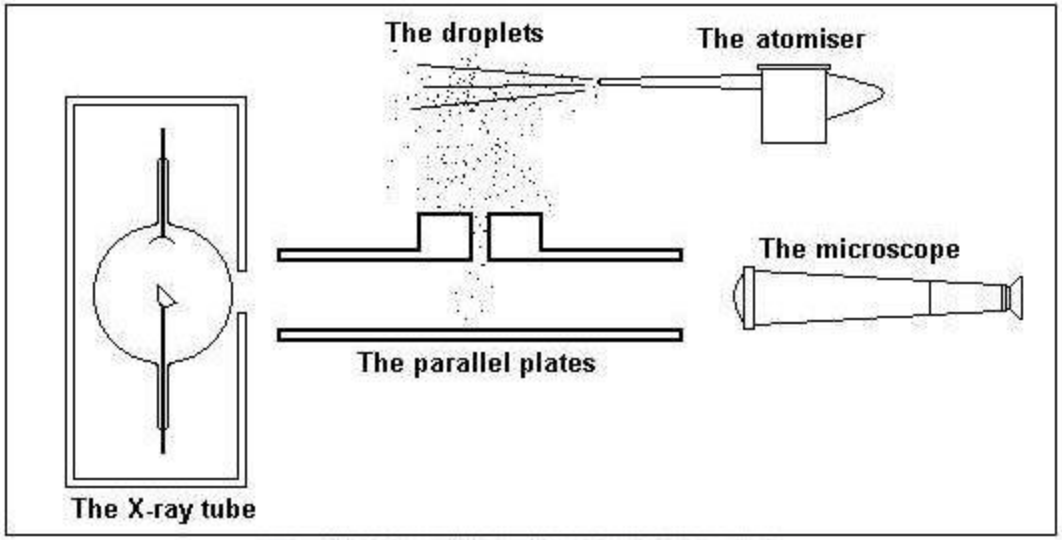
J.J. Thomson saw negative electrons embedded in a 'sea' of positive charge.



The "Plum Pudding" Model



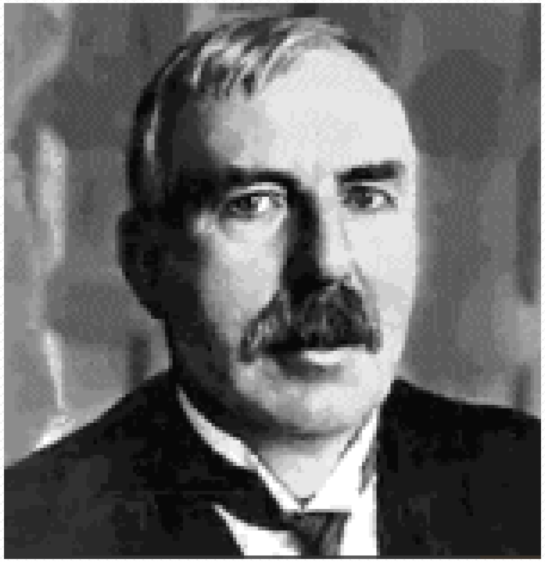
Robert Millikan - 1909



The diagram of the Millikan experiment.

- OIL DROP EXPERIMENT
- Determined the exact charge on an electron to be 1.60 X 10^{-19} C.
- Calculated the mass to be 1/1840 of a H atom.

Experiments continue ~

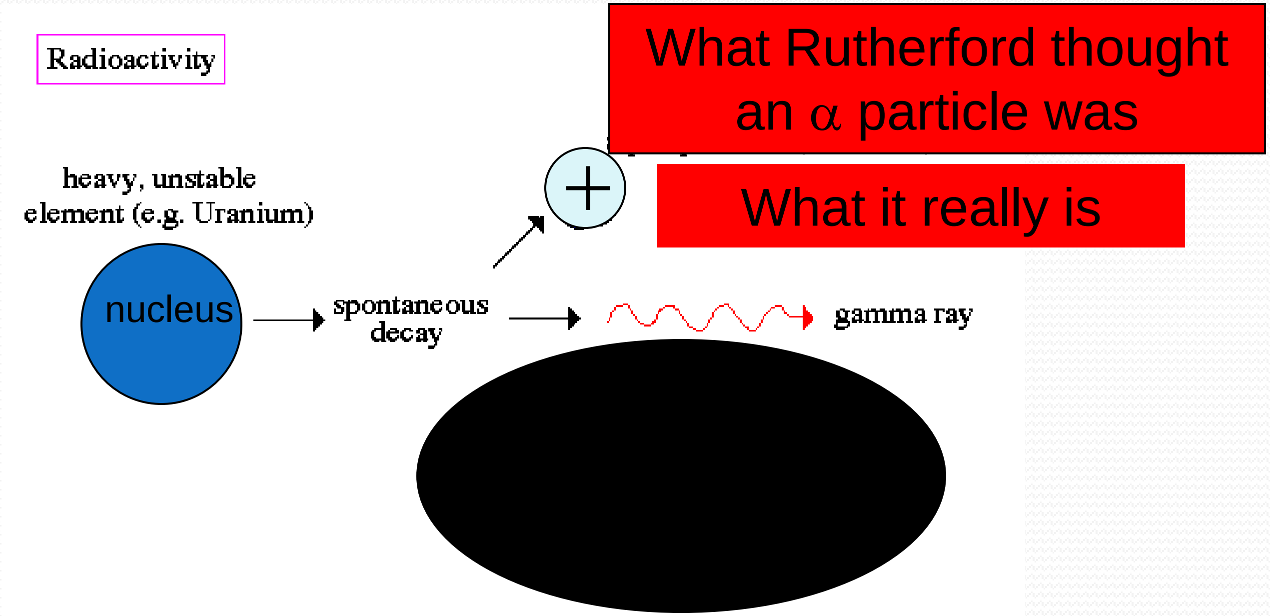


E. Rutherford, a Physics Professor at Cambridge is an expert in radioactive ***Alpha Particles***.

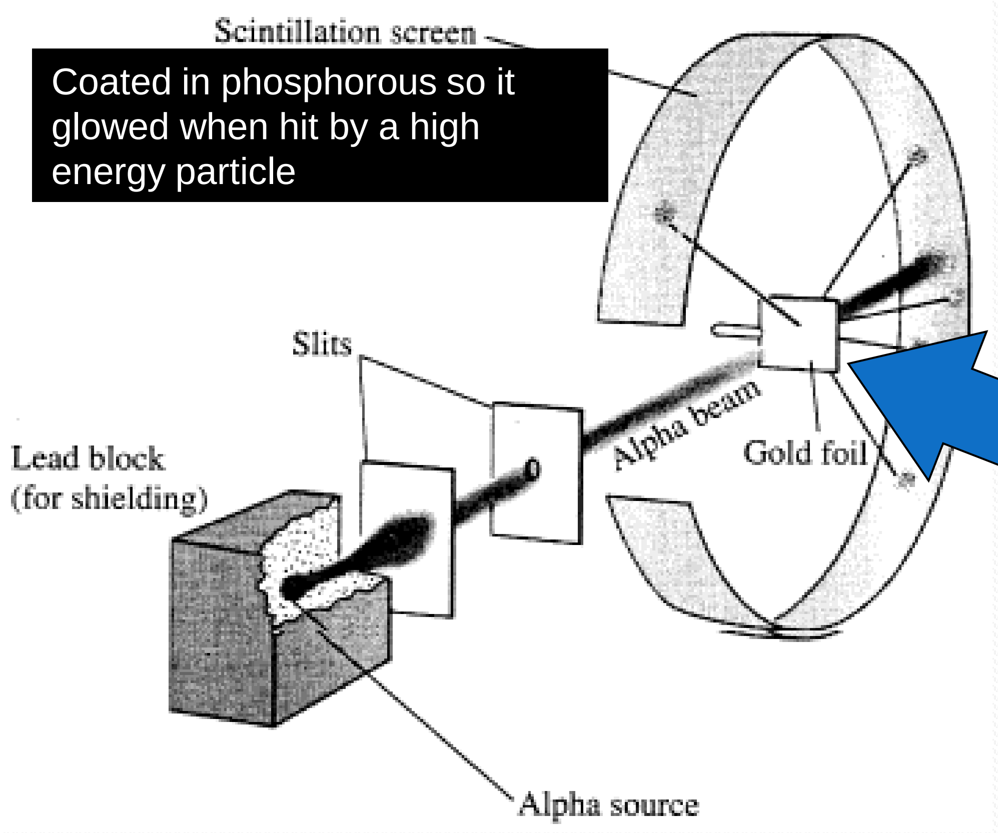
Alpha (α) Particles

To Rutherford, α particles were relatively large and positively charged bits that resulted from some forms of nuclear decay.

We know now that they are Helium nuclei, 2 protons and 2 neutrons

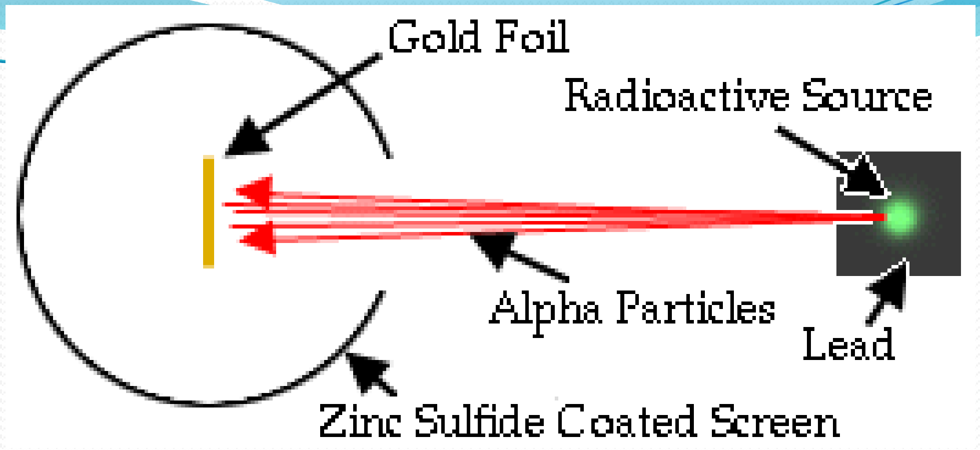


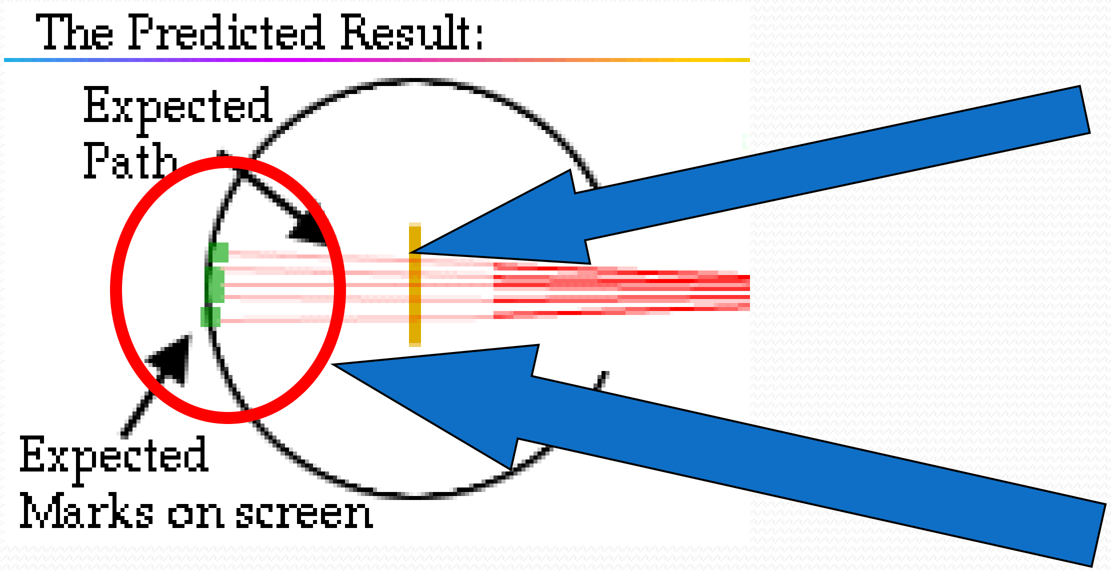
Rutherford has his 2 graduate students, Geiger & Marsden, run a series of experiments ~



(Gold foil just worked the best. They actually used all kinds of metal foils)

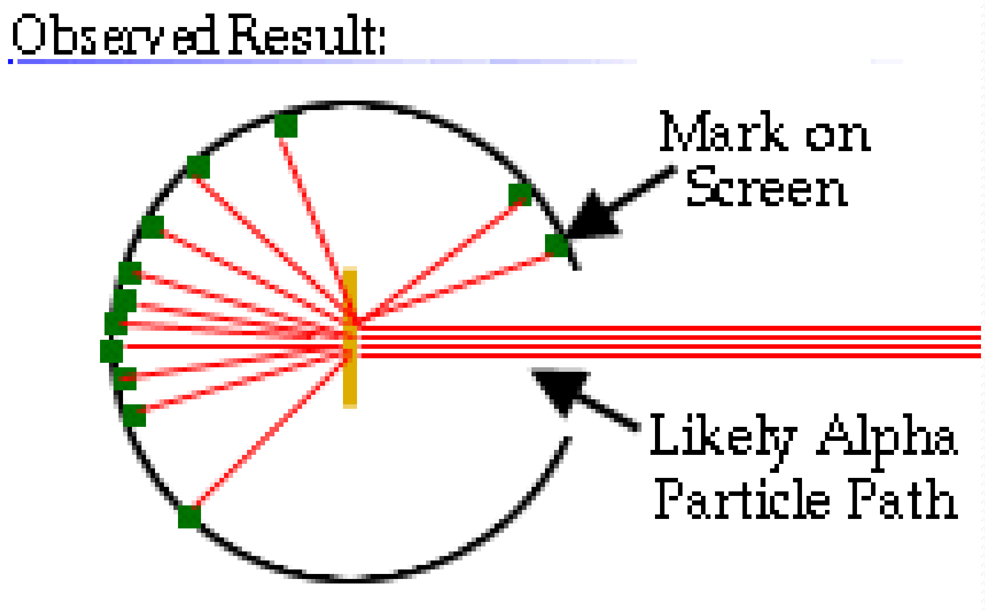
Schematic of Experimental Set-up





If Thomson was right, and the atom was like "plum pudding" then the heavier alpha particles should shoot right through.

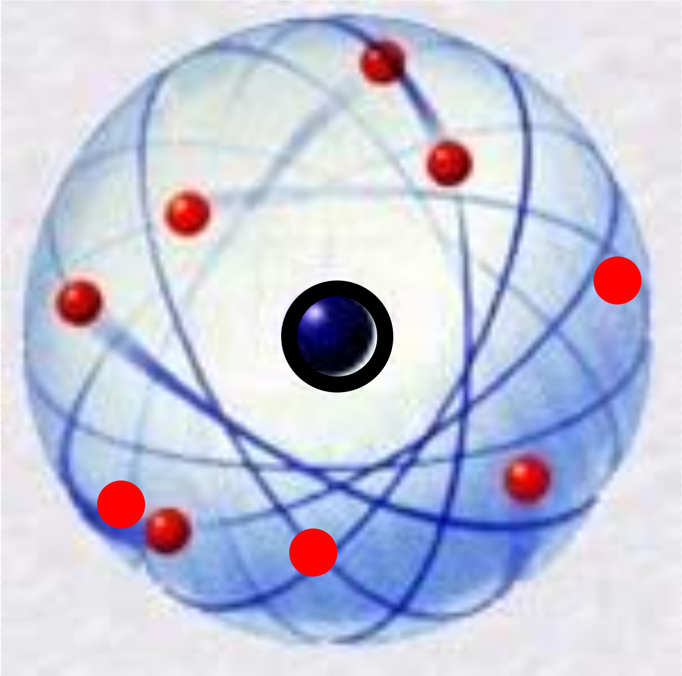
Surprise! A statistically large number of alpha particles get deflected.



"It's as if you had fired a 15 – inch artillery shell at a piece of tissue paper and it came back and hit you."

- E. Rutherford

In a brilliant bit of insight, Rutherford comes up with an explanation for the particle behavior and gives us a new atom around 1911:



The atom is mostly space with a small, dense nucleus.

The electrons are in orbit around this nucleus.

Size comparison:

If a period at the end of a sentence in your chem. book is the nucleus, your classroom would be the atom!

The rest of the atomic cast is assembled:

Goldstein: Finds positively charged particles coming out of the CRT opposite the direction of the electrons. **PROTONS** are found.

Mosley: Figures out that elements have different numbers of protons. **THE NUMBER OF PROTONS DETERMINES THE IDENTITY OF THE ELEMENT.**

Chadwick: Finds neutrons. Mass of atom is now accounted for.

A neutron goes into coffee house and orders a drink. “How much do I owe you?”, he asks the barista. “For you,” says the barista, “no charge.”

A. Tom on a Band

Two atoms were walking down the road. One turns to the other and says, “I think I’ve lost an electron.” “Are you sure?” asks his companion. “I’m positive”, he replied.

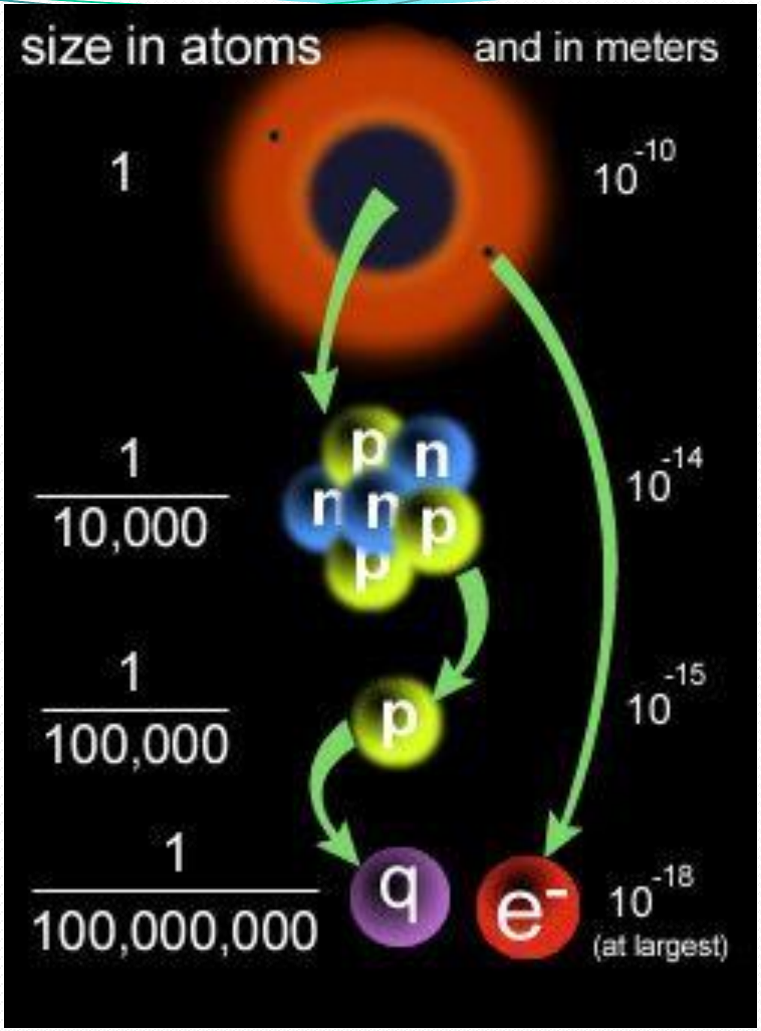
Name	Symbol	Mass (amu)
Protons	p	1
Neutrons	n	1
Electrons	e^{--}	1/2000
		(actually 1/1840)

Atomic Particles

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

The Atomic Scale

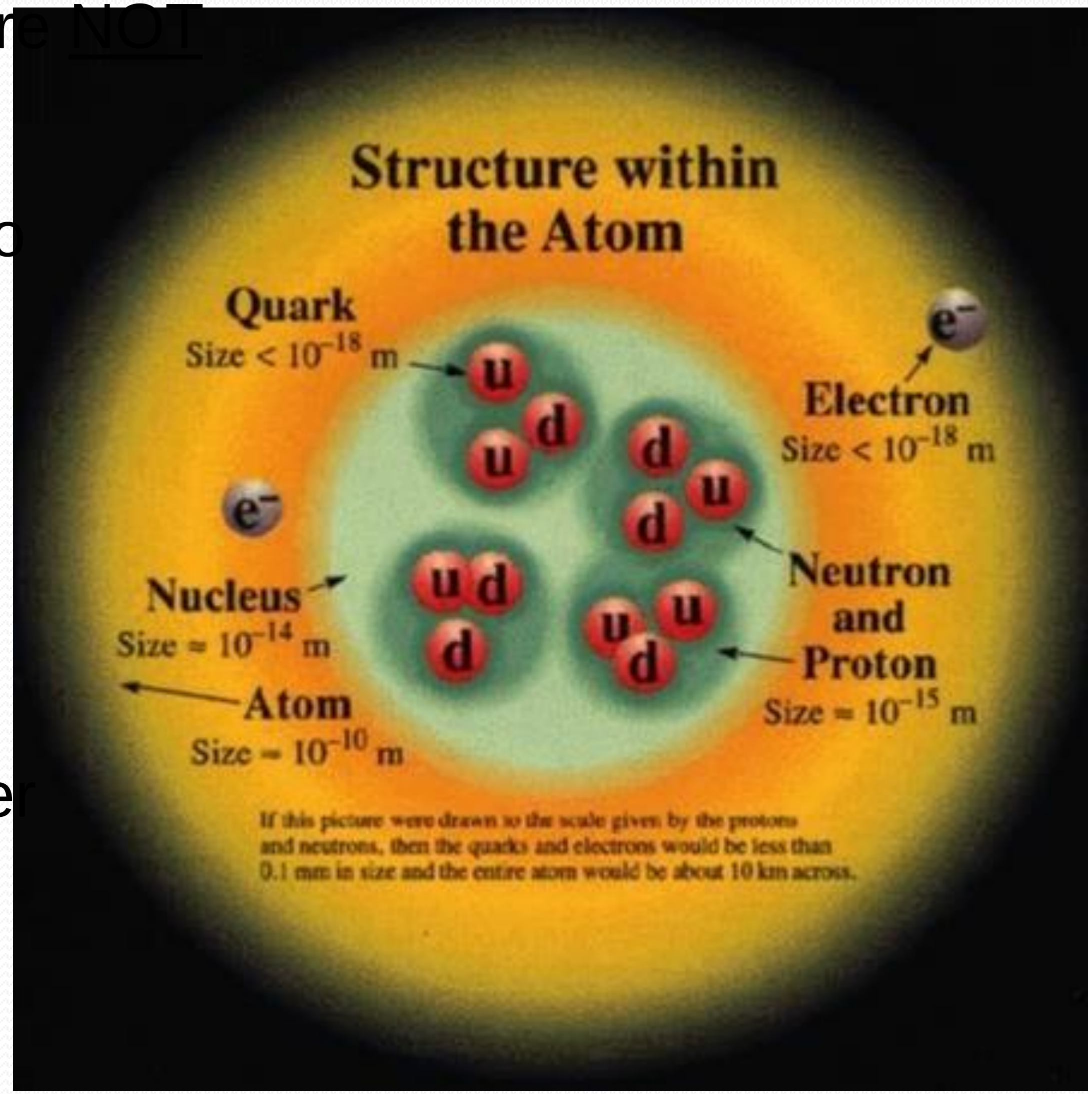
- Most of the mass of the atom is in the nucleus (protons and neutrons)
- Electrons are found outside of the nucleus (the electron cloud)
- Most of the volume of the atom is empty space



"q" is a particle called a "quark"

About Quarks…

Protons and neutrons are NOT 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

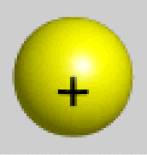
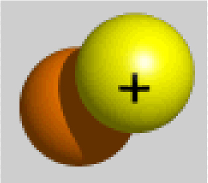
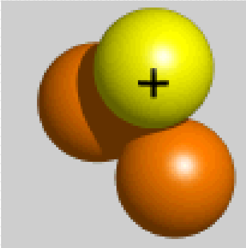
Mass number is the number of protons and neutrons in the nucleus of an isotope.

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

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%

But now w . .

1. Matter is made of very sm ms"

2. Atoms cannot be divided, created, or destroyed.

3. Atoms of one kind of element are identical to other atoms of that same element. Atoms different elements are unlike.

nall, whole-number ratios

ns are somehow combined,

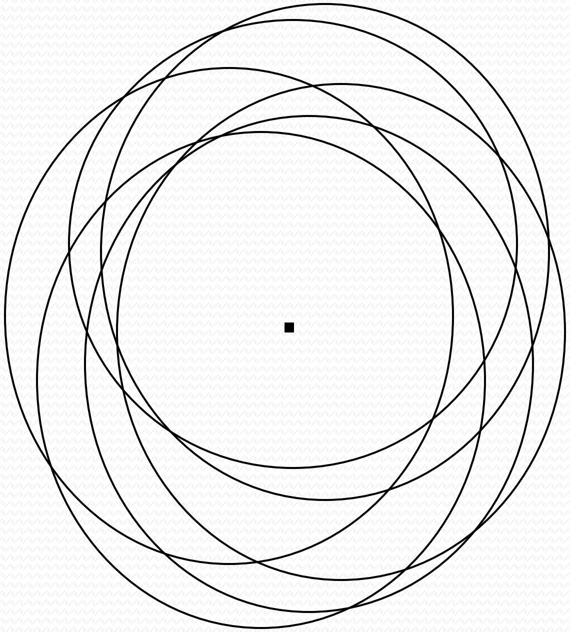
Can you say:

PROTON?
NEUTRON?
ELECTRON?
QUARK?

Can you say:

ISOTOPES!

Problems with Rutherford's Model



If the atom is mostly space, does it contain a vacuum?

If the electron orbits the nucleus, does the orbit eventually decay?

Wouldn't a negatively charged electron be attracted to a positively charge nucleus?

WHY DOESN'T THIS THING COLLAPSE IN ON ITSELF?!!!!

The answer starts with:

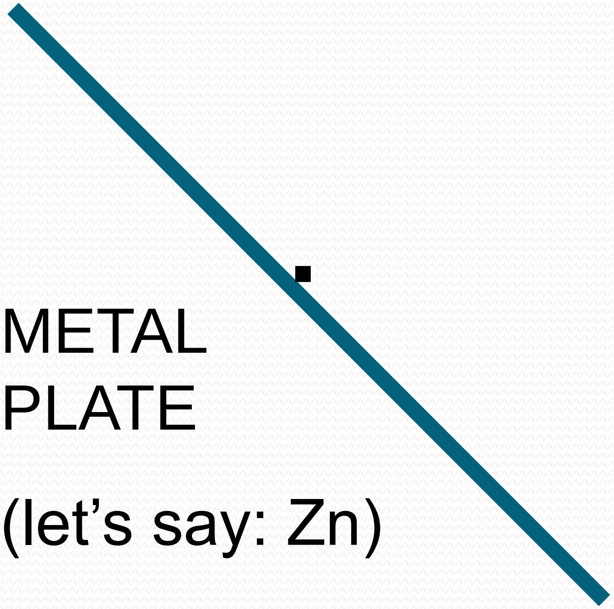
Flame Tests

Einstein’s Nobel Prize

Photo – Electric Effect

- Photon (light)

Ejected electron

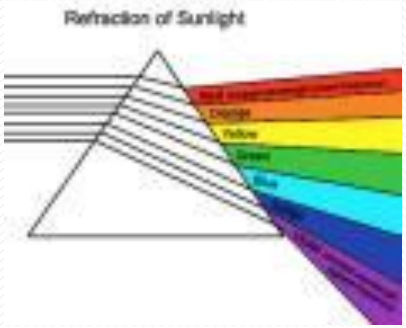


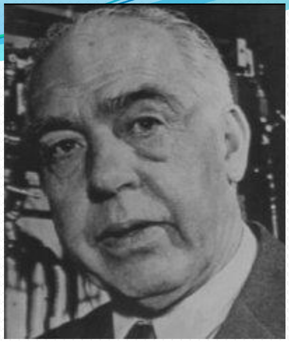
METAL PLATE

(let’s say: Zn)

Niels Bohr to the rescue!

Bohr was a physicist with an interest in *Spectroscopy*.

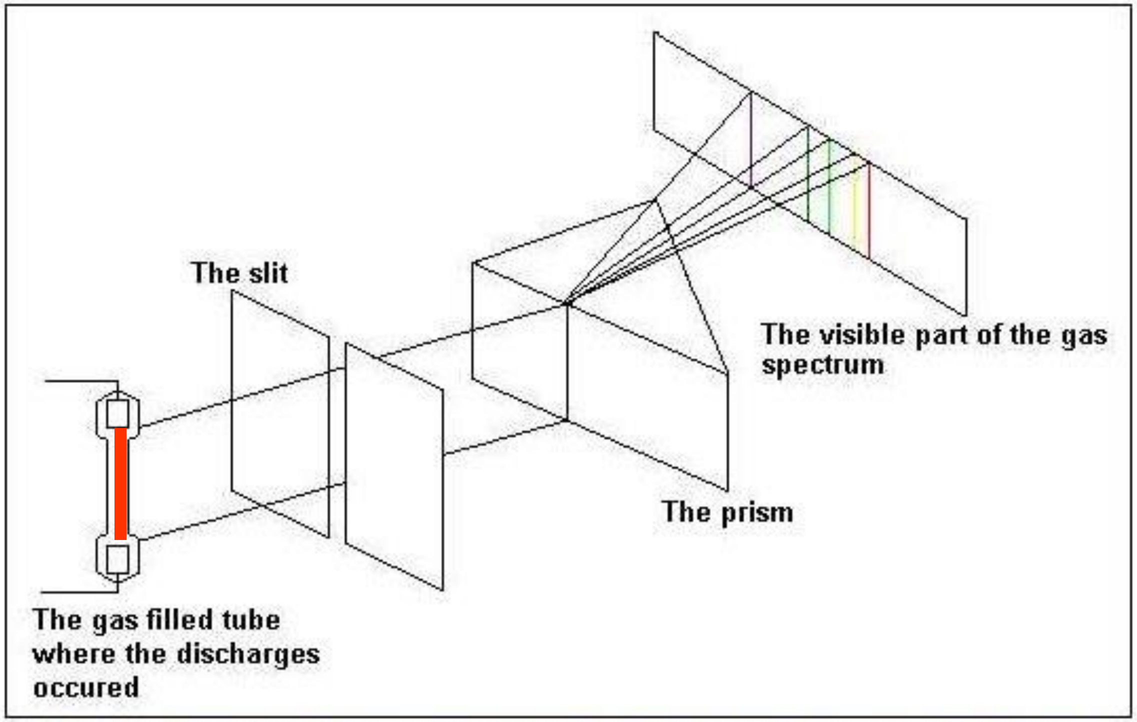




Spectroscopy is the study of light splitting into its different wavelengths. The most common example is sunlight being separated into the colors of the rainbow.

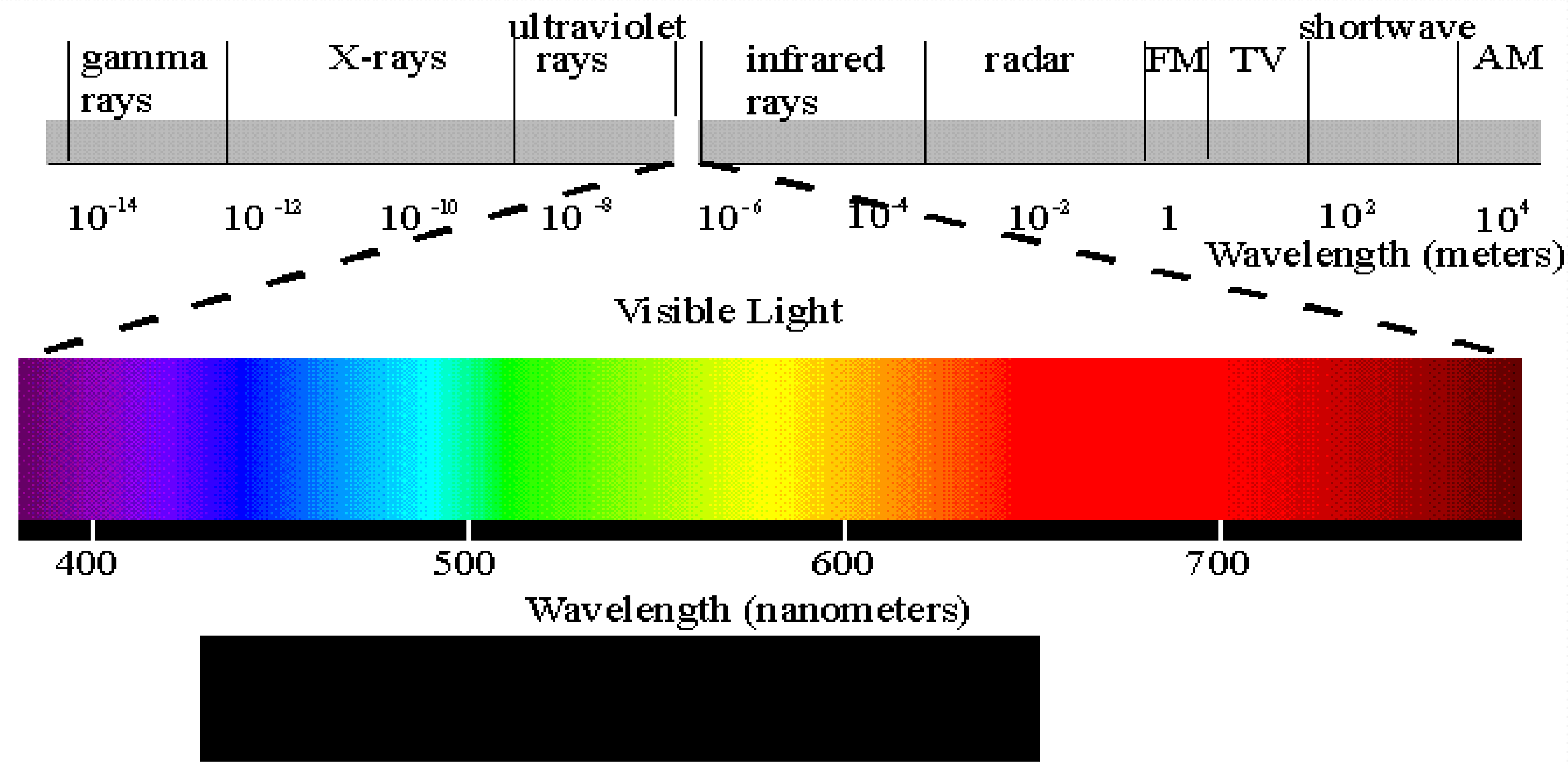
Bright Line Spectra

The series of light bars seen for a particular element. Bright line spectra are considered “Finger Prints” of elements because they are unique to that element.



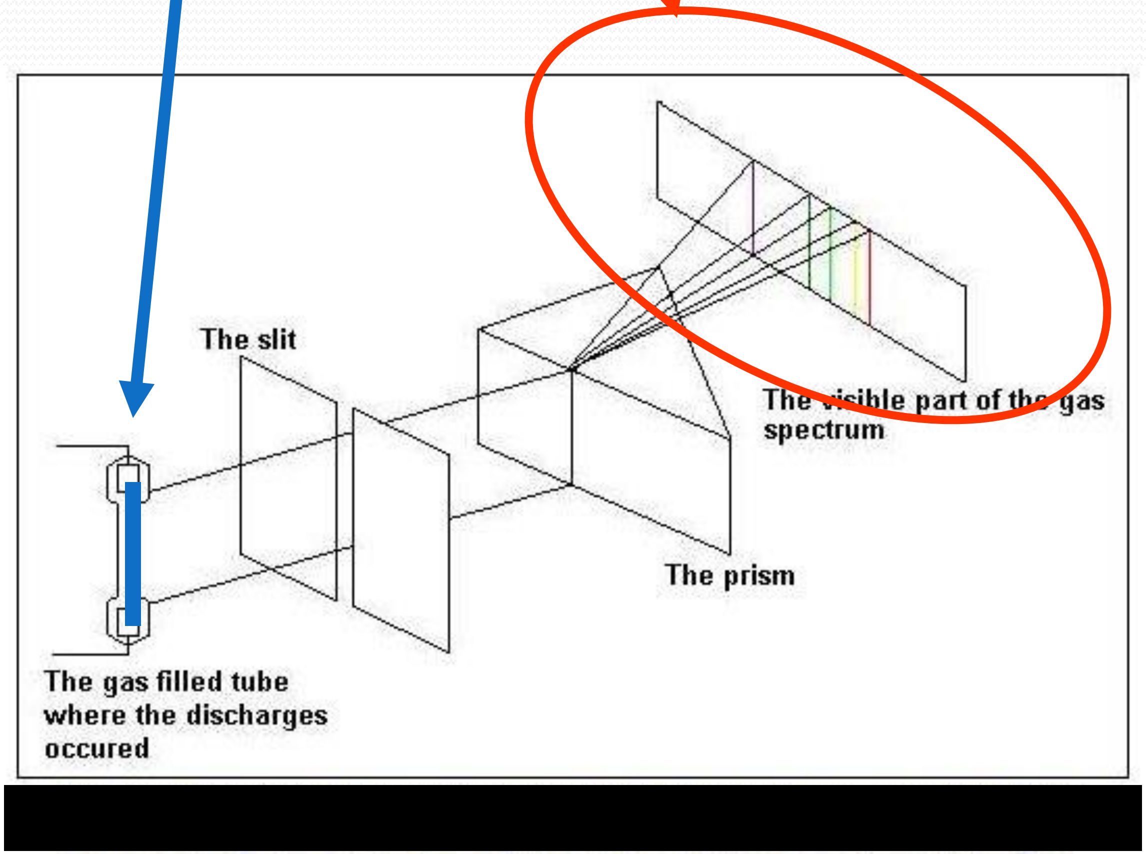
The discharges in the low pressure gas filled tube are the sources of the light which undergo refraction on the prism. We see the line spectrum of the gas.

Remember that each color represents a different ***wavelength*** *or* ***energy***.



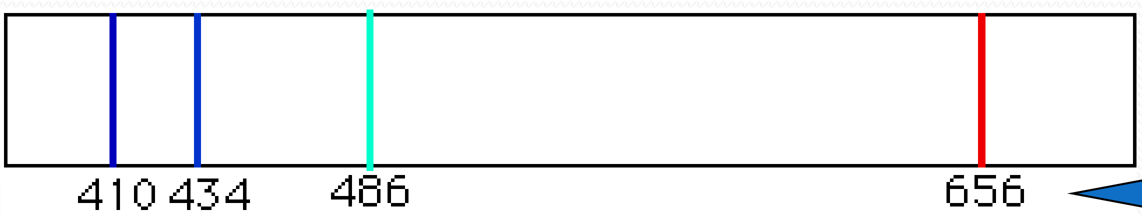
Remember, too, that we only see a very small part of the Electro-Magnetic Spectrum

So these color bars in the bright line spectra show the only wavelengths of energy that make up the original color of light *before* it gets split.

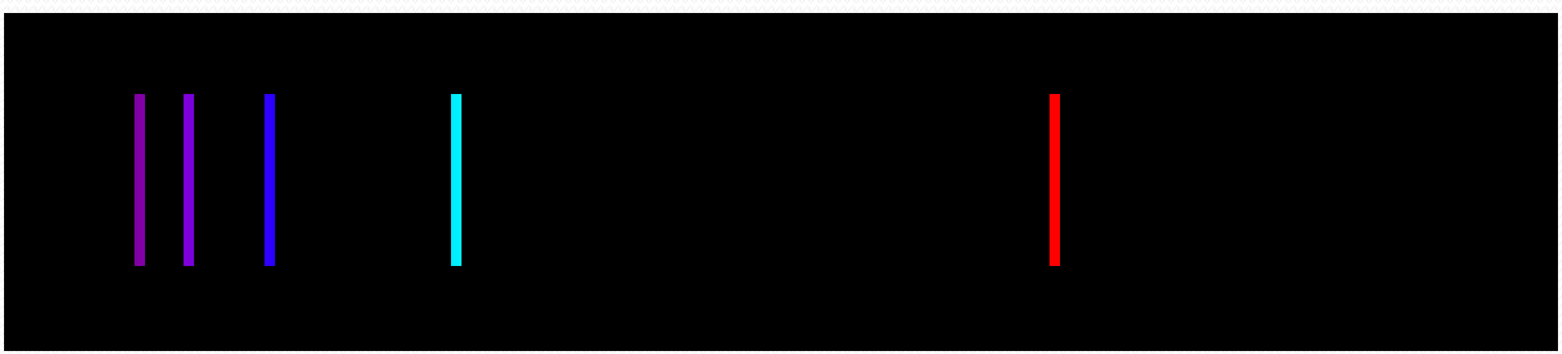


The blank spots in between the bars means that wavelength of energy does not exist in that original color.

Bohr worked with the spectra of the simplest atom, Hydrogen. With just one electron orbiting one proton, the Bright Line Spectra for H looked like these:



WAVE LENGTHS in nanometers



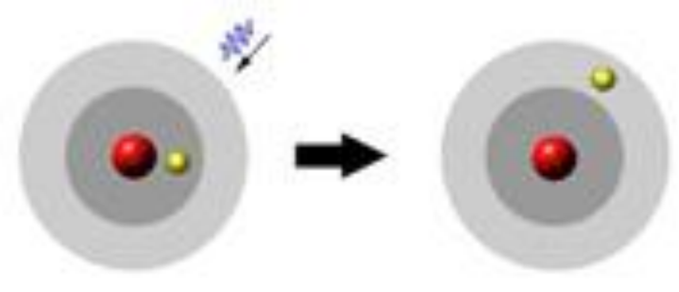
Bohr used all that he knew (which is way more than we've talked about)* to explain those individual lines of energy.

A new atomic model is born.

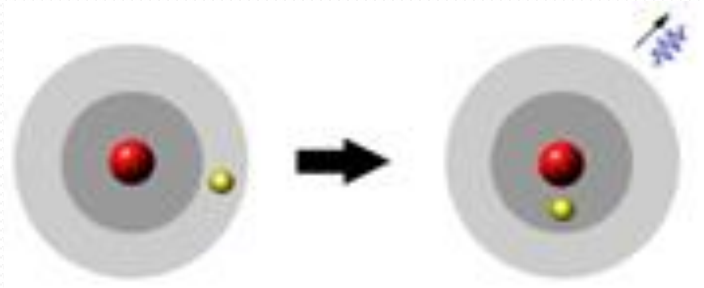
Let's See Bohr's Atom!

Commonly known as the "Solar System" model. It's what you learned in Middle School!

Bohr reasoned that when electricity goes through the hydrogen gas, it causes the electron to gain energy and move to a higher energy level.



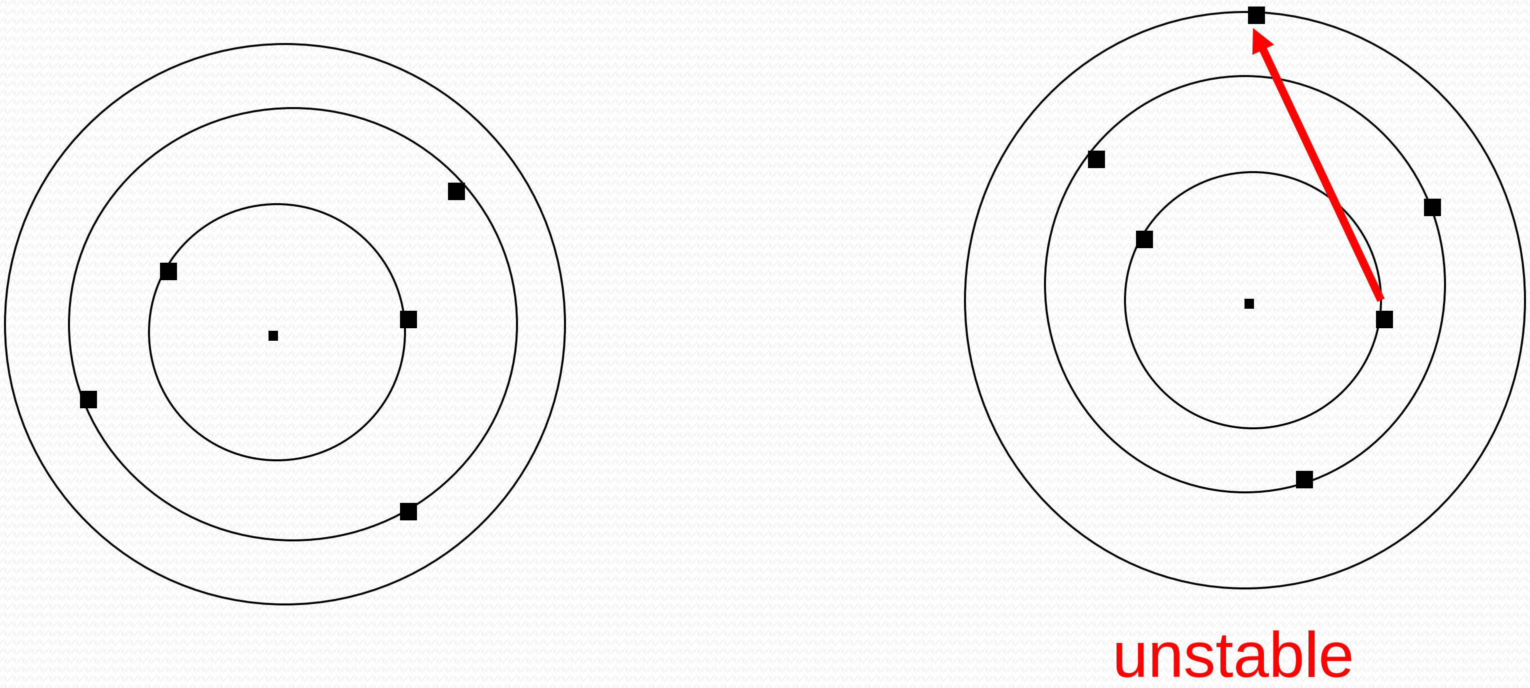
He thought that this higher level was probably unstable for the atom and the "excited" electron eventually goes back to its lower energy level. The energy it had doesn't disappear, it is given off as the bar of light – ***the spectral lines.***



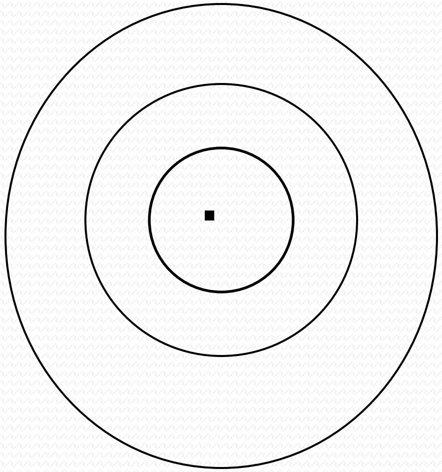
Take another look at Bohr's explanation . . .

Ground State: all e⁻ are in the lowest energy levels (states) possible (most stable)

Excited State: e⁻ absorb energy and are in higher energy levels (states)

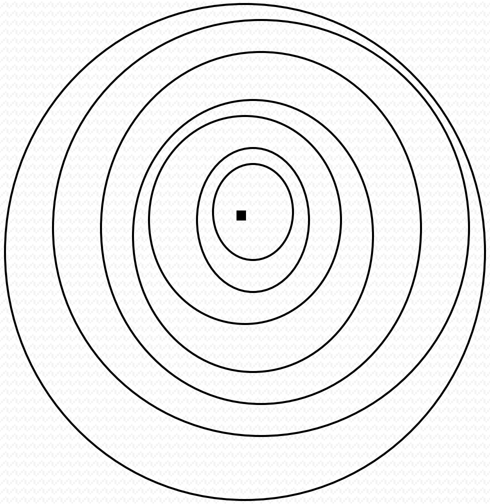


Naturally, questions arise. . .



Why this?

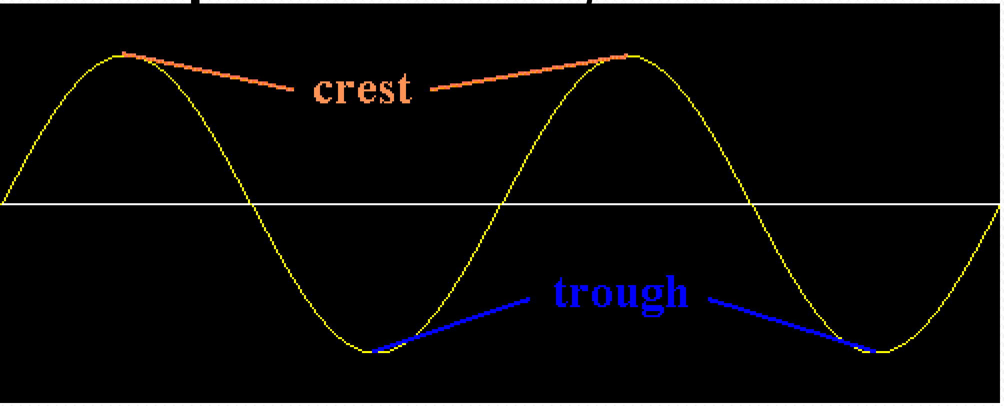
(only certain energy levels exist)

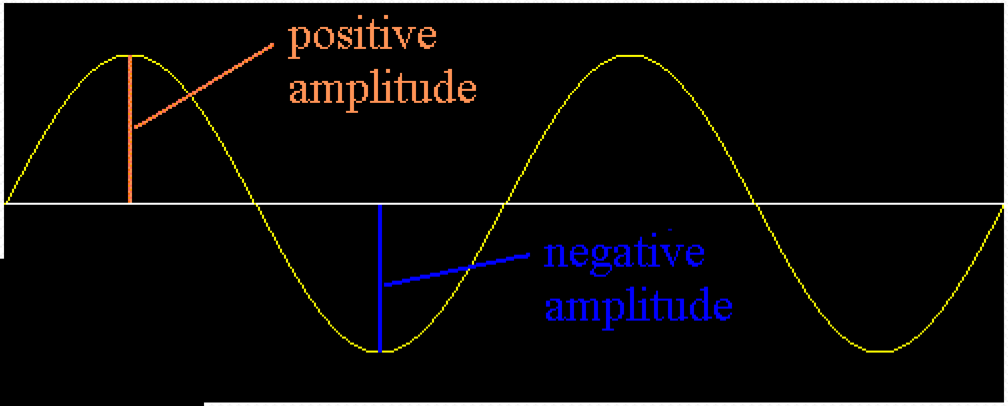


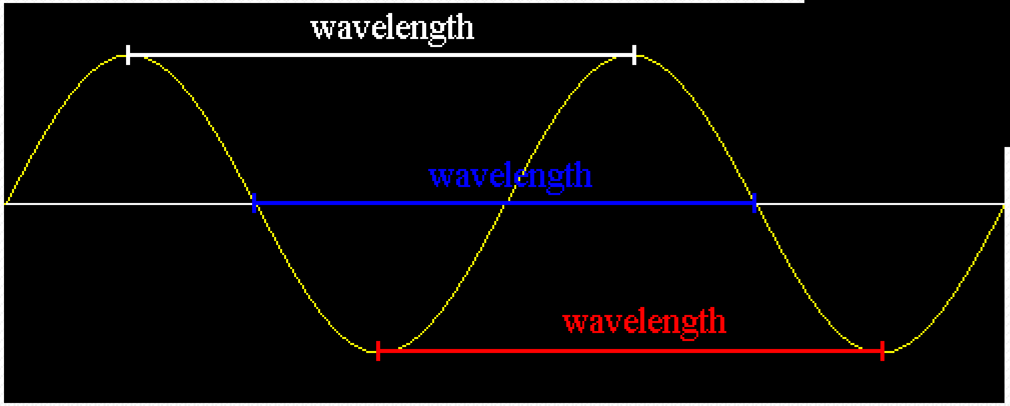
Instead of this?

(infinite energy levels)

To understand Louis de Broglie's explanation, we must review WAVES







FREQUENCY

WAVES

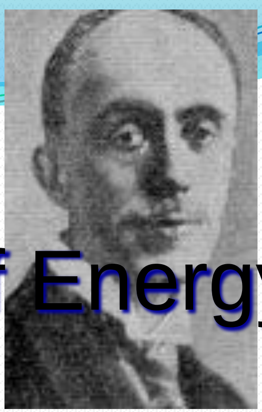
Here's the most important part:

Constructive and Destructive Interference

Let's Play!

Louis de Broglie:

Electron as both Particle and WAVE of Energy?



WAVES in a confined space (like around a nucleus) must meet up correctly or there will be destructive interference destroying the WAVE

de Broglie Waves in the Bohr Atom

Only certain wavelengths will not destroy themselves so only certain energy levels are allowed!

A New Atomic Theory. . . again . . .

Erwin Shrödinger created the mathematic formula that treats electrons as waves.

(relax, you can do this)

If I say, “y = mx + b”,

what shape pops into your mind?

That’s right, a line!

Schrödinger's Equation is big and scary but it does have parts you know:

$$\hat{H}\psi = -\frac{\hbar^2}{2m}\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)\psi = E\psi.$$

x, y, & z refer to what? (directionality on a Cartesian Coordinate graph)

What shape for the "square"? (parabolas)

So, x^2, y^2 & z^2 refer to what? (3-d spheres in space)

The Bohr electron “orbits” are now areas in space described by mathematical formulas. They surround the nucleus, but are not “rings”.

No, you do not need to learn the formulas.

Yes, you will need to learn (some of) the shapes

Currently known as:

Quantum Atom

Electron Cloud Model

There are four shapes or **sublevels**:

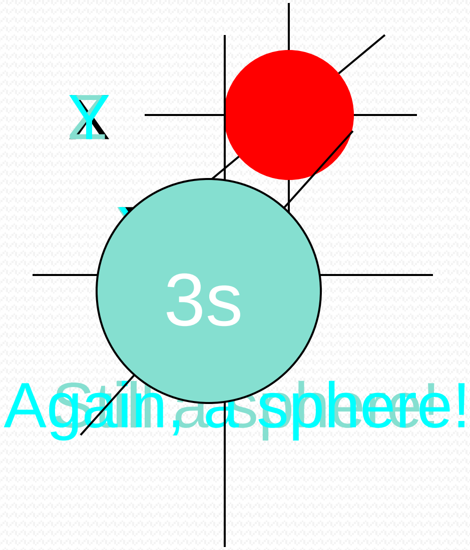
s p d f

Each sublevel has "orientations" or orbitals around the origin of the x-y-z axis.

Take a look!

The 2 that you need to remember are:

S = Shaped like a sphere



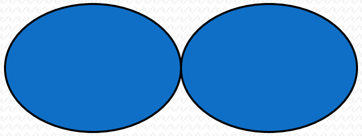
1) No matter which way you turn it in space, it will always be a sphere so there are no separate orbitals (orientations in space).

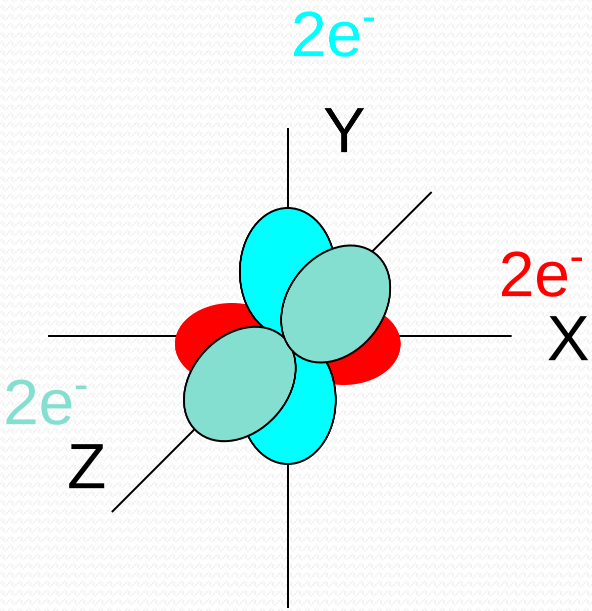
2) It exists on every energy level. Level 2’s S sublevel is big enough to encompass Level 1’s and Level 3’s encompasses them both, like nesting dolls.

3) No matter how big ‘s’ is, it only can hold 2 electrons, max!

And

P = Dumb Bell shape





1) The ‘p’ sublevel is made up of 3 orbitals or ‘orientations’ in space.

p_x When it lies along the x-axis

p_y When it lies along the y-axis

p_z When it lies along the z-axis

2) Each orientation or orbital can hold 2 electrons max for a total of 6 electrons.

3) The ‘p’ sublevel is first found on Principle Energy Level 2. Like ‘s’, it increases in size with each increase in energy level.

sublevel	first appears on level	# of orbitals	2 per orbital total # electrons	level configuration
s	1	1	2	1s
p	2	3	6	1s2s2p
d	3	5	10	1s2s2p3s3p3d
f	4	7	14	1s2s2p3s3p 3d4s4p4d4f

How does this work, anyway?

Each element can be represented by its

Electron Configuration

for example:

The superscript tells how many electrons are in that sublevel.

Carbon (C) is $1s^2\ 2s^2\ 2p^2$

The coefficient shows what level from the nucleus. This is known as the Principle Quantum Number.

The letter s,p,d or f, represents the shape of the sublevel. This is known as the Orbital Quantum Number.

So

$1s^2 2s^2 2p^2$

tells us that Carbon has:

There are 4 electrons total in the valence shell. These are the ***valence electrons.***

2 electrons in the 's' sublevel (the sphere) on principle energy level '1'

The outermost energy level is '2' for Carbon. This is its ***valence shell.***

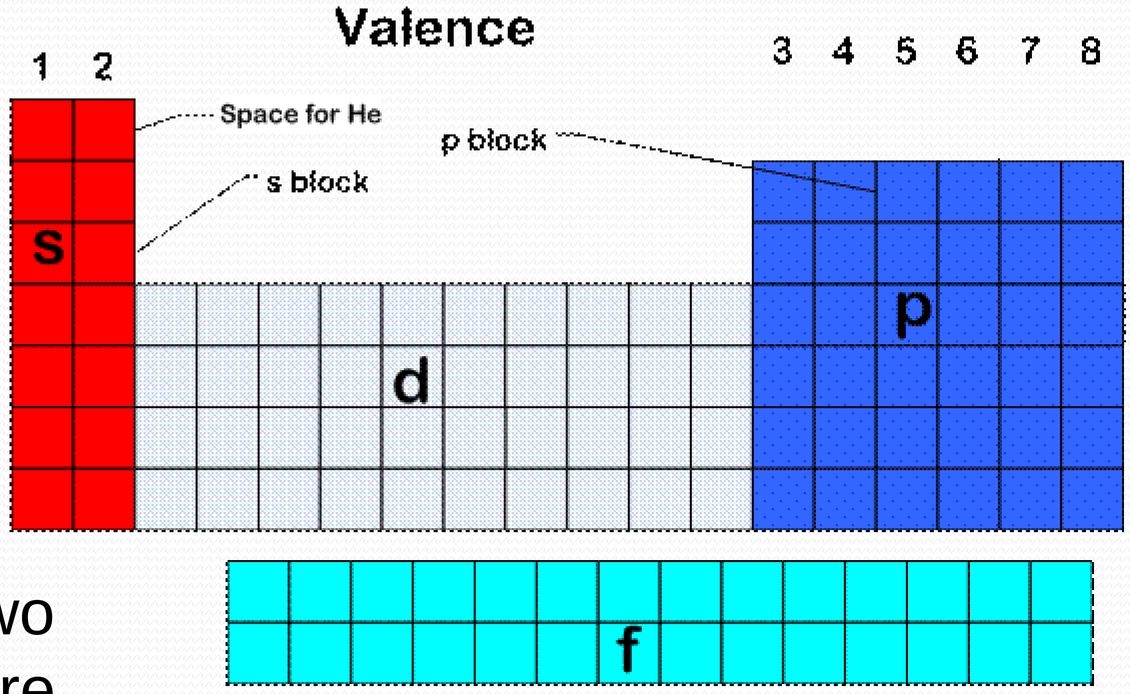
2 electrons in the 's' sublevel (the sphere) on principle energy level '2'

2 electrons in the 'p' sublevel (the dumb bell) on principle energy level '2'

Creating Electron Configurations

It starts with the periodic table:

The transition metals are known as the “d” block



The first two columns are called the “s” bock.

The right side is known as the “p” block

CREATING ELECTRON CONFIGURATIONS

*Hint #1: The “Z” number refers to the Atomic Number which is the number of protons AS WELL AS electrons.

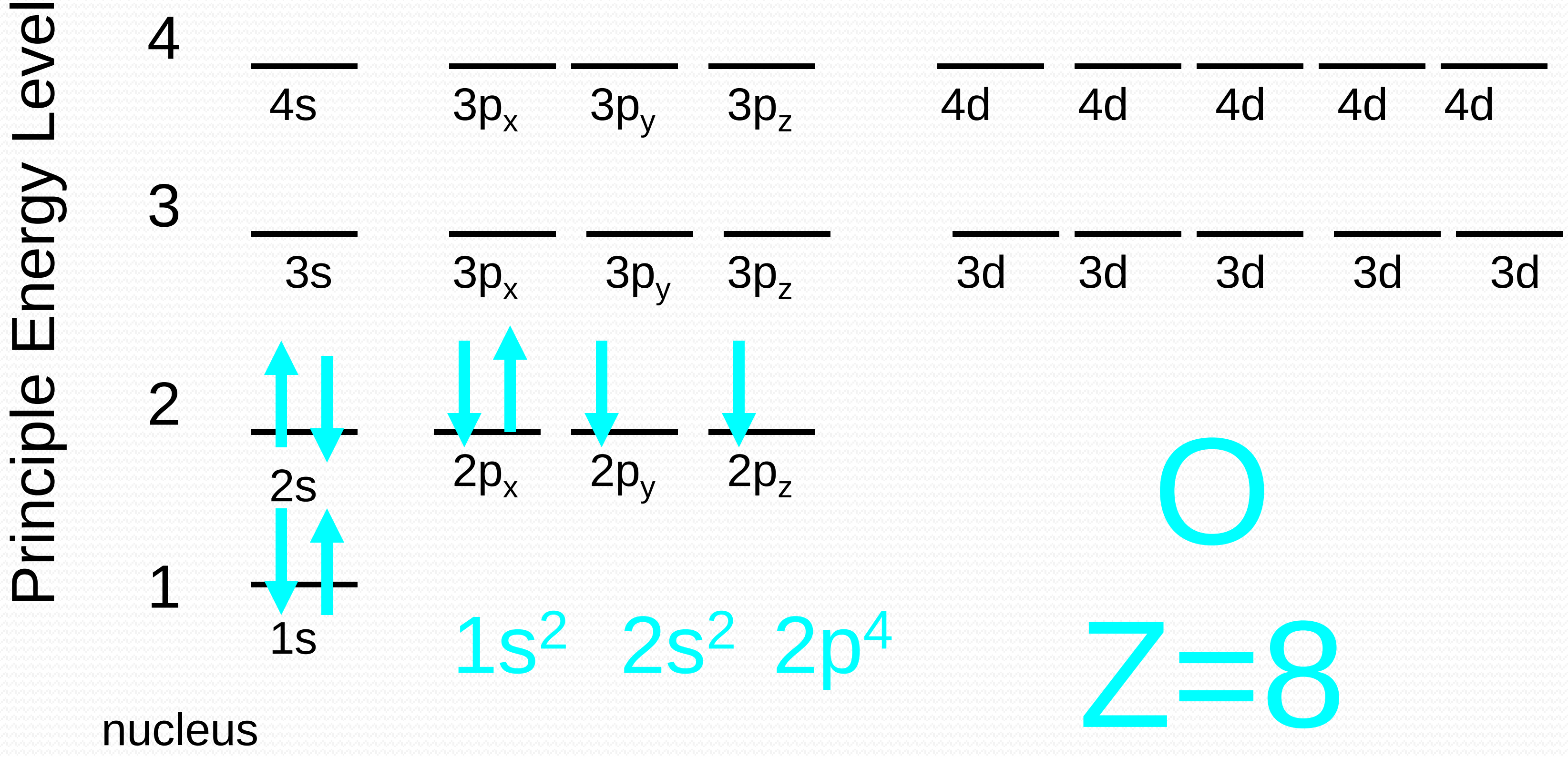
* Hint #2: The arrows in the animation represent electrons being placed in the energy sublevels and orbitals.

TRY CARBON (Z=6) TO SEE WHERE ITS ELECTRONS ARE AND IF IT MATCHES THE ELECTRON CONFIGURATION THAT YOU’VE ALREDY LOOKED AT.

BUILDING AN ELECTRON CONFIGURATION

(click the mouse to start an example)

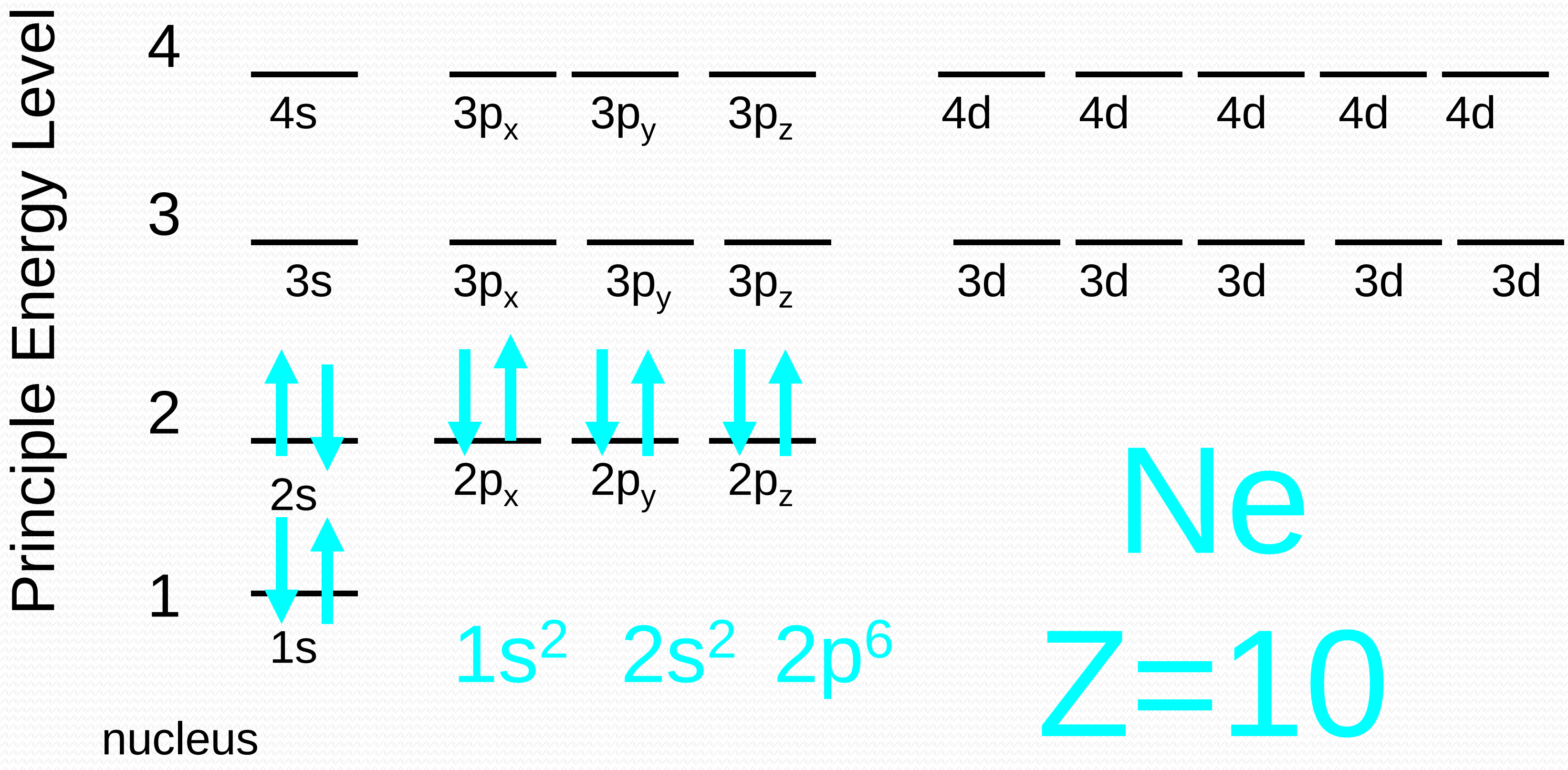
(there are 4 more examples – click again!)



BUILDING AN ELECTRON CONFIGURATION

(click the mouse to start an example)

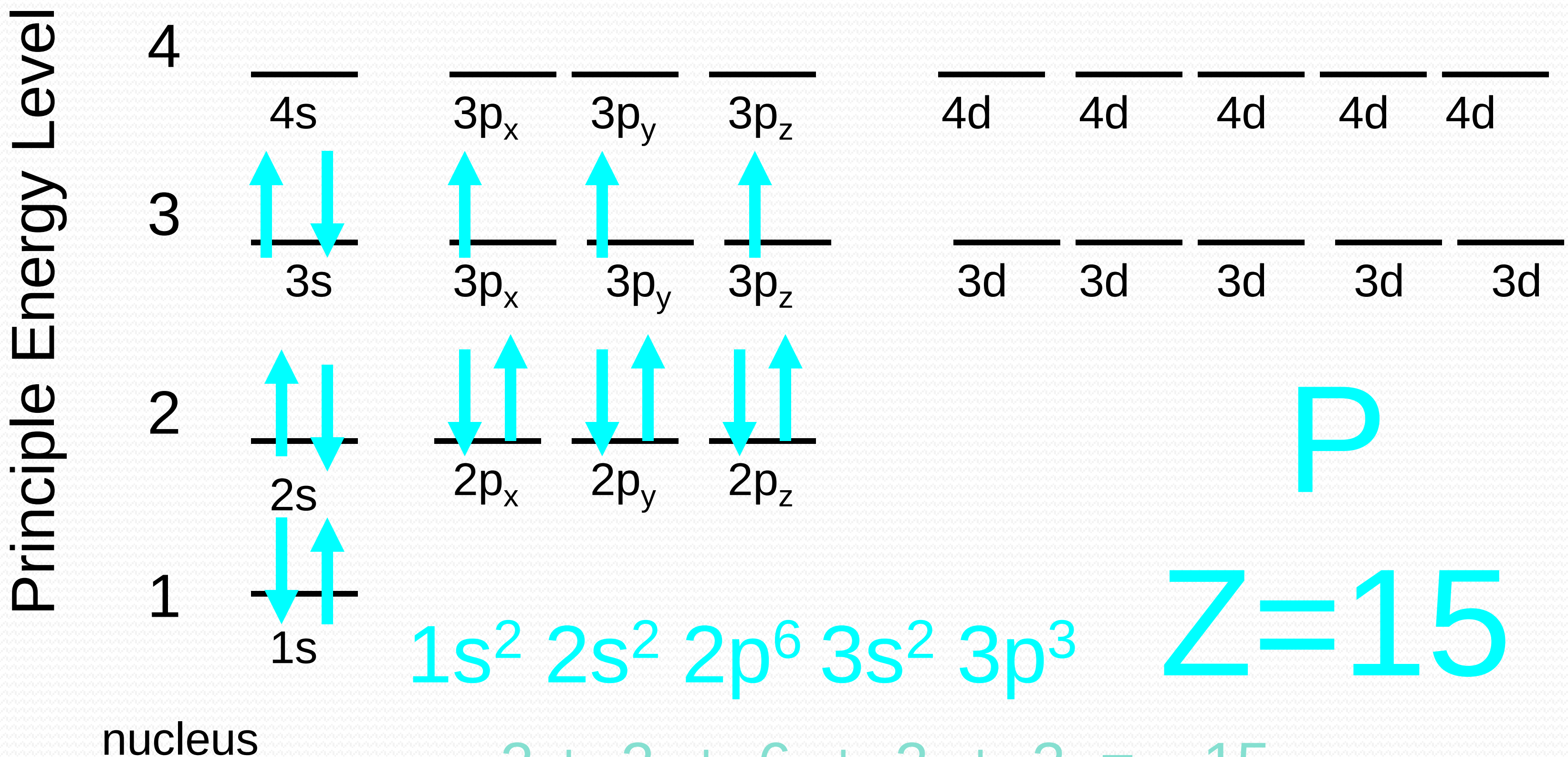
(there are 3 more examples – click again!)



BUILDING AN ELECTRON CONFIGURATION

(click the mouse to start an example)

(there are 2 more examples – click again!)

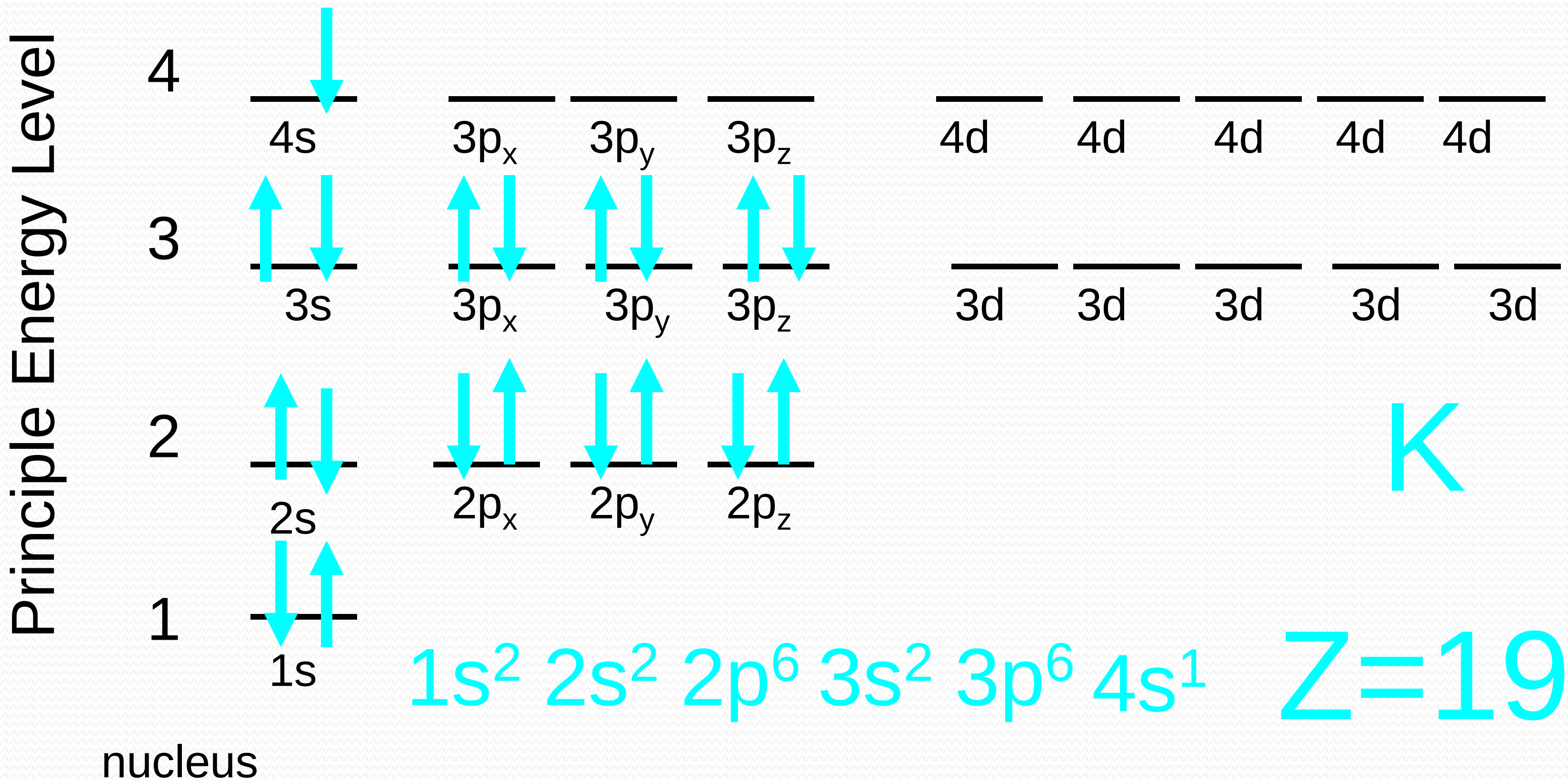


$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$

2 + 2 + 6 + 2 + 3 = 15

BUILDING AN ELECTRON CONFIGURATION

(click the mouse to start an example)



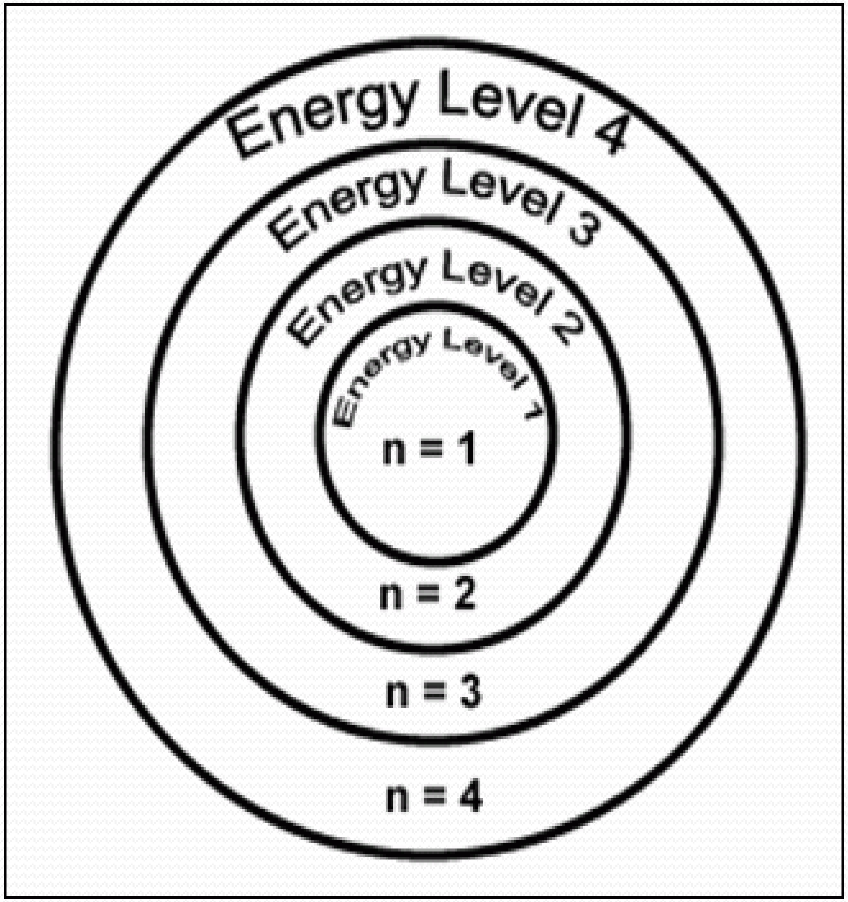
2 + 2 + 6 + 2 + 6 +1 = 19

Element	Configuration notation	Orbital notation	Noble gas notation
Lithium	$1s^2 2s^1$	1s: ↑↓ 2s: ↑ 2p: _ _ _	$[He]2s^1$
Beryllium	$1s^2 2s^2$	1s: ↑↓ 2s: ↑↓ 2p: _ _ _	$[He]2s^2$
Boron	$1s^2 2s^2 2p^1$	1s: ↑↓ 2s: ↑↓ 2p: ↑ _ _	$[He]2s^2 p^1$
Carbon	$1s^2 2s^2 2p^2$	1s: ↑↓ 2s: ↑↓ 2p: ↑ ↑ _	$[He]2s^2 p^2$
Nitrogen	$1s^2 2s^2 2p^3$	1s: ↑↓ 2s: ↑↓ 2p: ↑ ↑ ↑	$[He]2s^2 p^3$
Oxygen	$1s^2 2s^2 2p^4$	1s: ↑↓ 2s: ↑↓ 2p: ↑↓ ↑ ↑	$[He]2s^2 p^4$
Fluorine	$1s^2 2s^2 2p^5$	1s: ↑↓ 2s: ↑↓ 2p: ↑↓ ↑↓ ↑	$[He]2s^2 p^5$
Neon	$1s^2 2s^2 2p^6$	1s: ↑↓ 2s: ↑↓ 2p: ↑↓ ↑↓ ↑↓	$[He]2s^2 p^6$

Electron Energy Level (Shell)

Generally symbolized by n, it denotes the probable distance of the electron from the nucleus. “n” is also known as the **Principle Quantum number.**

As “n” increases the radius increases.



Orbital qunatum number (Subshell or Sublevel)

- Generally symbolized by ℓ, it is a measure of orbital angular momentum, which indicates the shape of the orbital.
- Values up to n-1
  - 0=s
  - 1=p
  - 2=d
  - 3=f

Magnetic quantum number

- Generally symbolized by m_ℓ, in indicates the orbital around the 3 axes in space (orientation in space)
  - s = 1 orientation
  - p = 3 orientations
  - d = 5 orientations
  - f = 7 orientations
- Identifies the specific orbital.

Spin Quantum number

- Generally symbolized by m_s, it tells the electrons spin on its axis.
- + or -
- Whether bound or free all electrons spin.

Electron Spin

<u>**Electron spin**</u> describes the behavior (direction of spin) of an electron within a magnetic field.

Possibilities for electron spin:

$$+\frac{1}{2} \qquad -\frac{1}{2}$$

Clockwise Counterclockwise

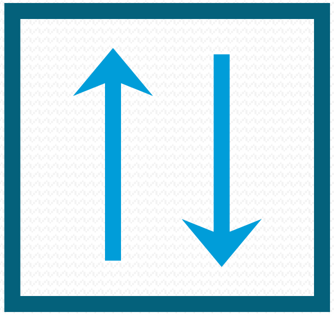
Pauli Exclusion Principle

Wolfgang Pauli

Two electrons occupying the same orbital must have *opposite* spins

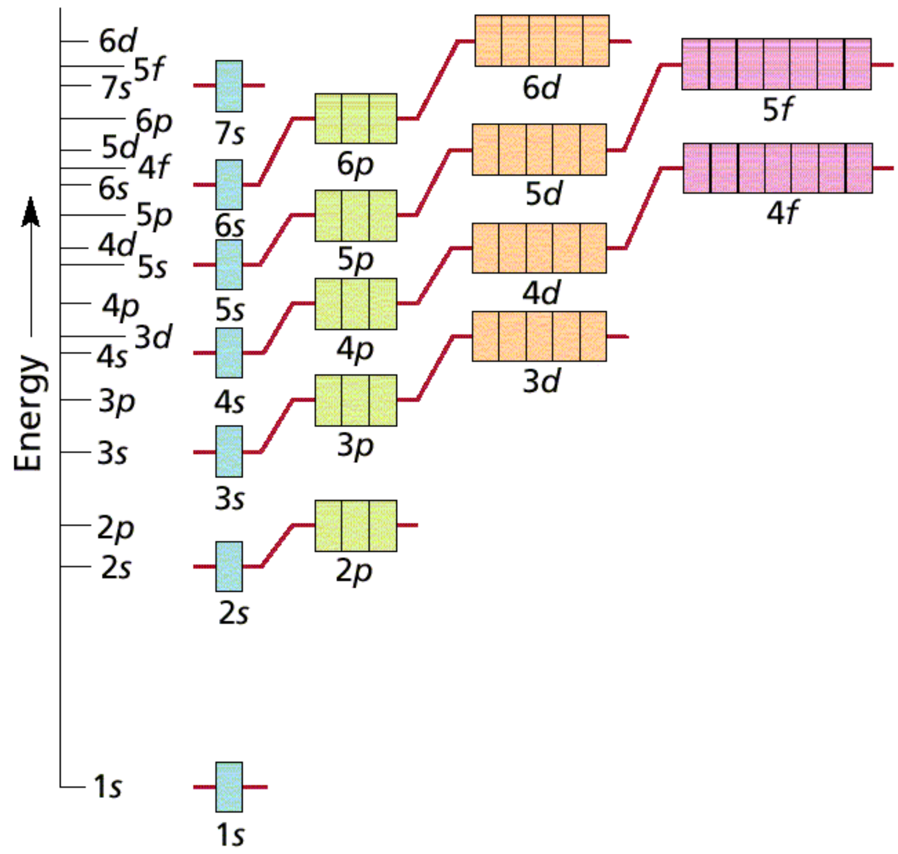
A. General Rules

- **Pauli Exclusion Principle**
  - Each orbital can hold TWO electrons with opposite spins.
  - 2 P's in a Pod



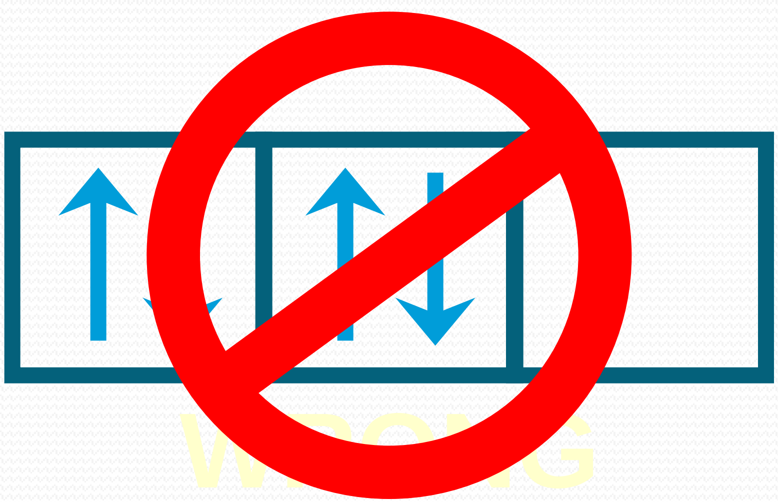
A. General Rules

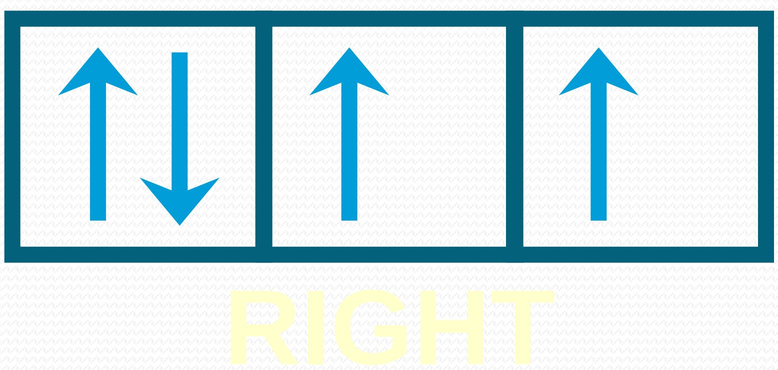
- **Aufbau Principle**
  - Electrons fill the lowest energy orbitals first.
  - "Lazy Tenant Rule"
  - aufBAU



A. General Rules

- **Hund's Rule**
  - Within a sublevel, place one e$^-$ per orbital before pairing them.
  - "Empty Bus Seat Rule" or Hund's Rule





Analogy

Electron Cloud = dorm

- Energy level (shell) = floor
- Subshell = room
- Orbital = love seat
- Spin = each person

Nuclear Symbols

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

Element symbol

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

Atomic number
(number of p^+)

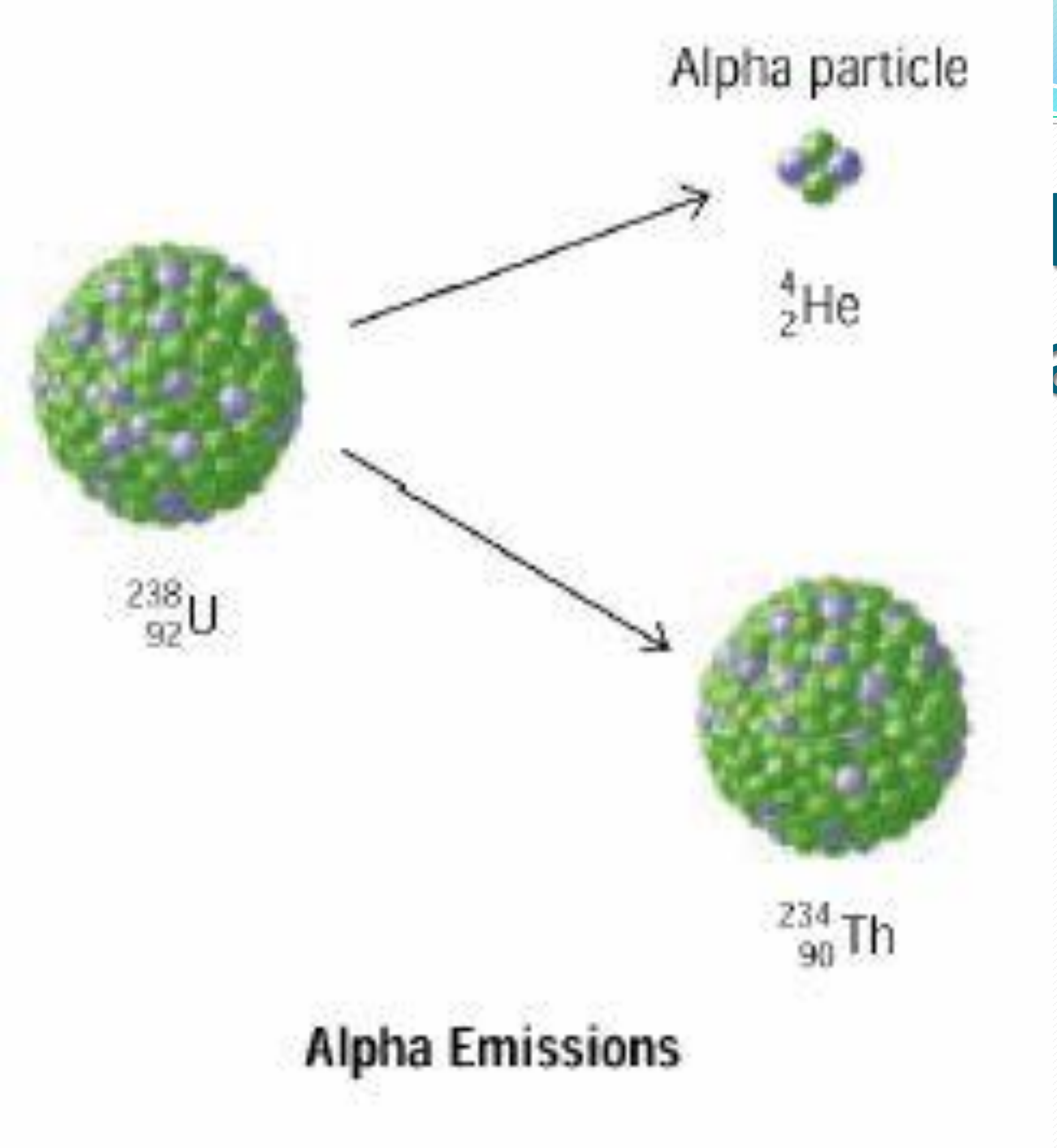
Types of Radioactive Decay

- alpha production (α): helium nucleus He^{2+}

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

- beta production (β): electron

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

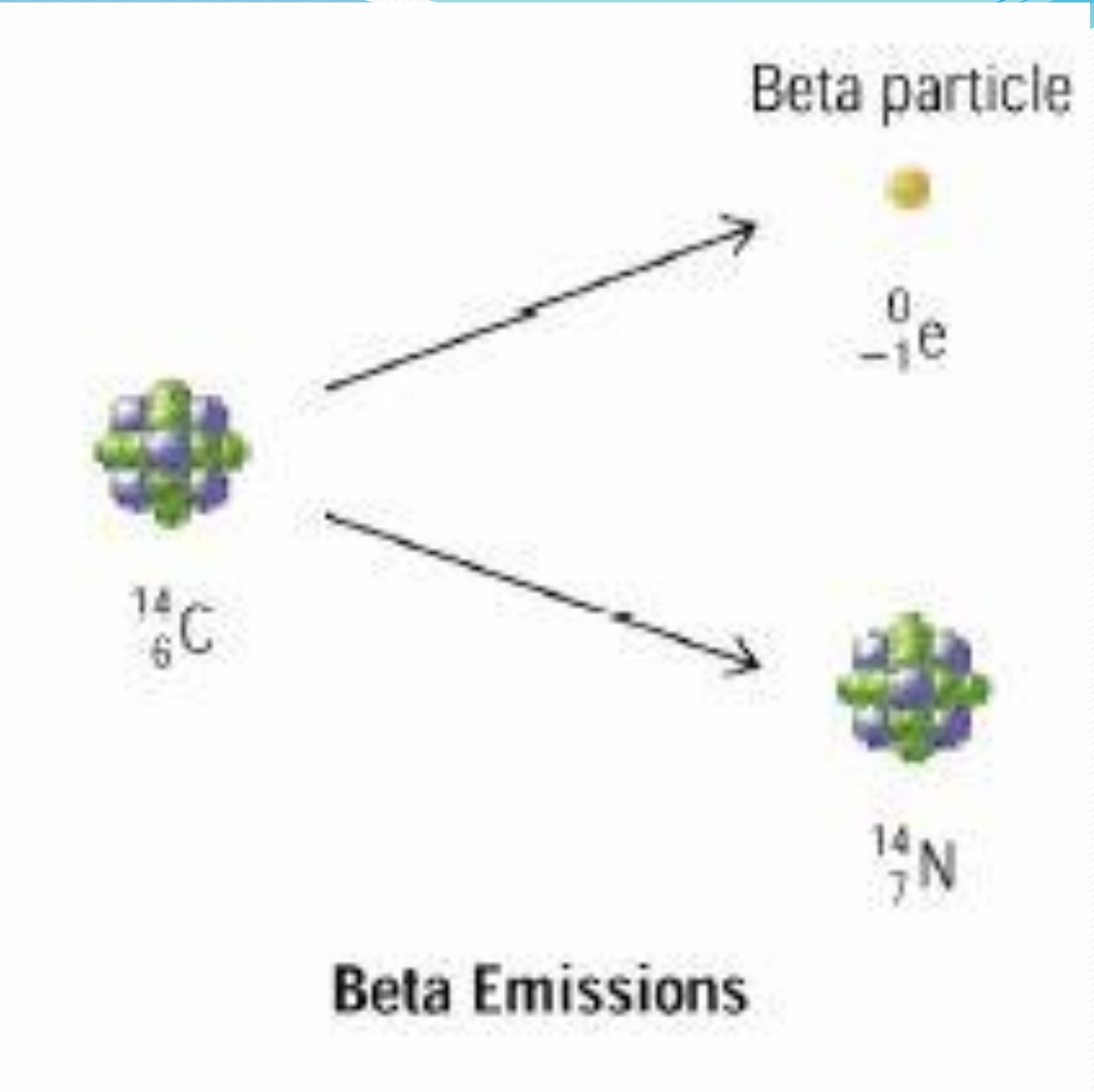


lpha adiation

Limited to VERY large nucleii.

Beta Radiation

Converts a neutron into a proton.



Types of Radioactive Decay

- gamma ray production (γ):

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

- positron production :

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

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

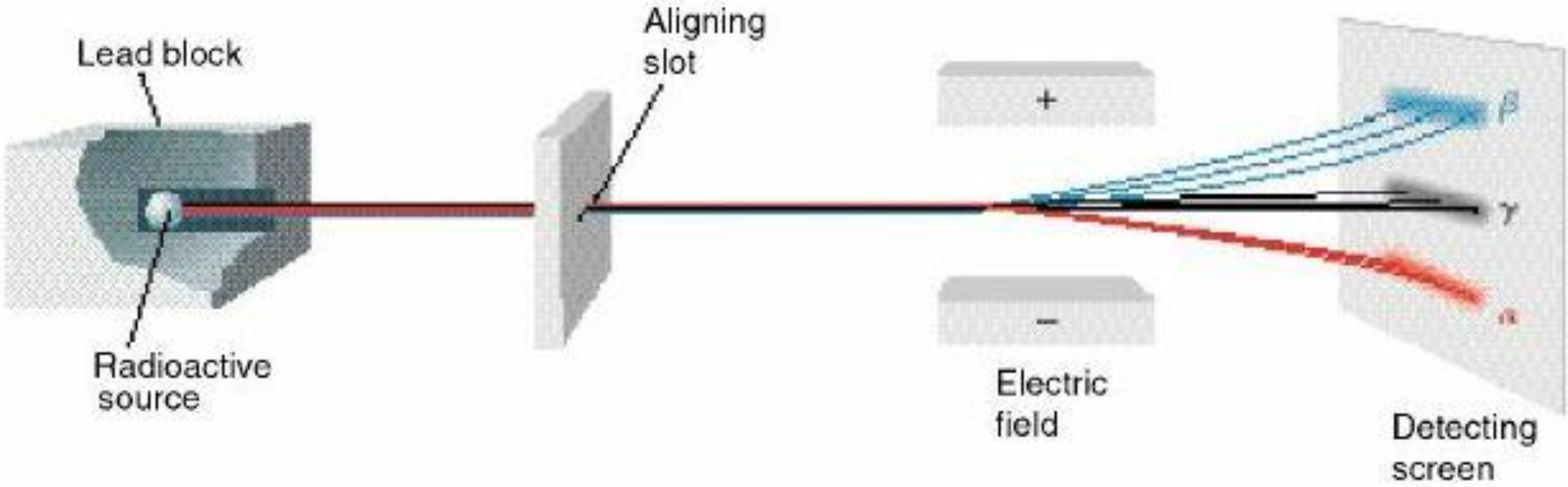
$$^{201}_{80}Hg + \ ^{0}_{-1}e \rightarrow \ ^{201}_{79}Au + \ ^{0}_{0}\gamma$$

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)

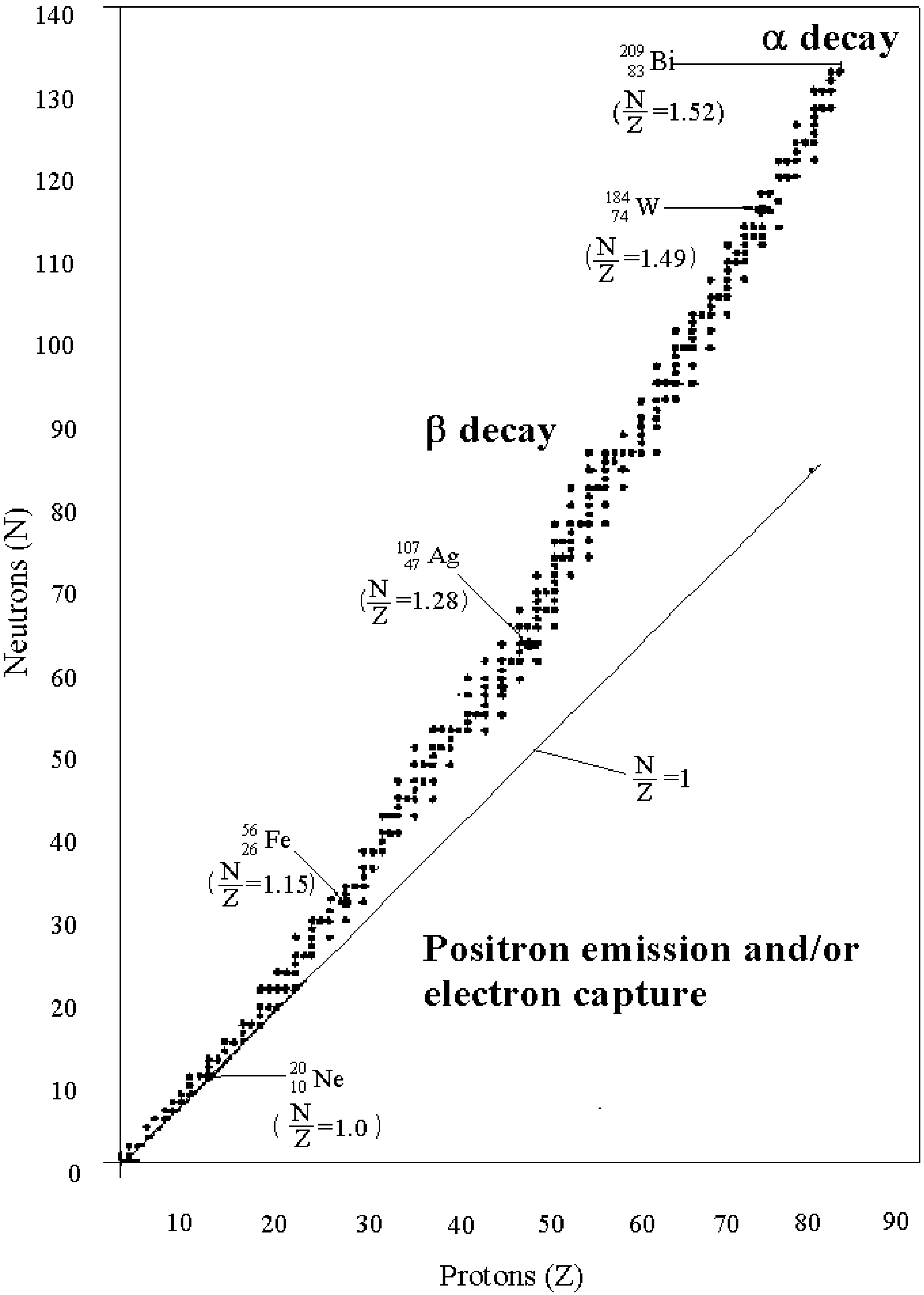
*(1 MeV = 1.60×10^{-13} J)

Deflection of Decay Particles



Opposite charges___attract___ each other.

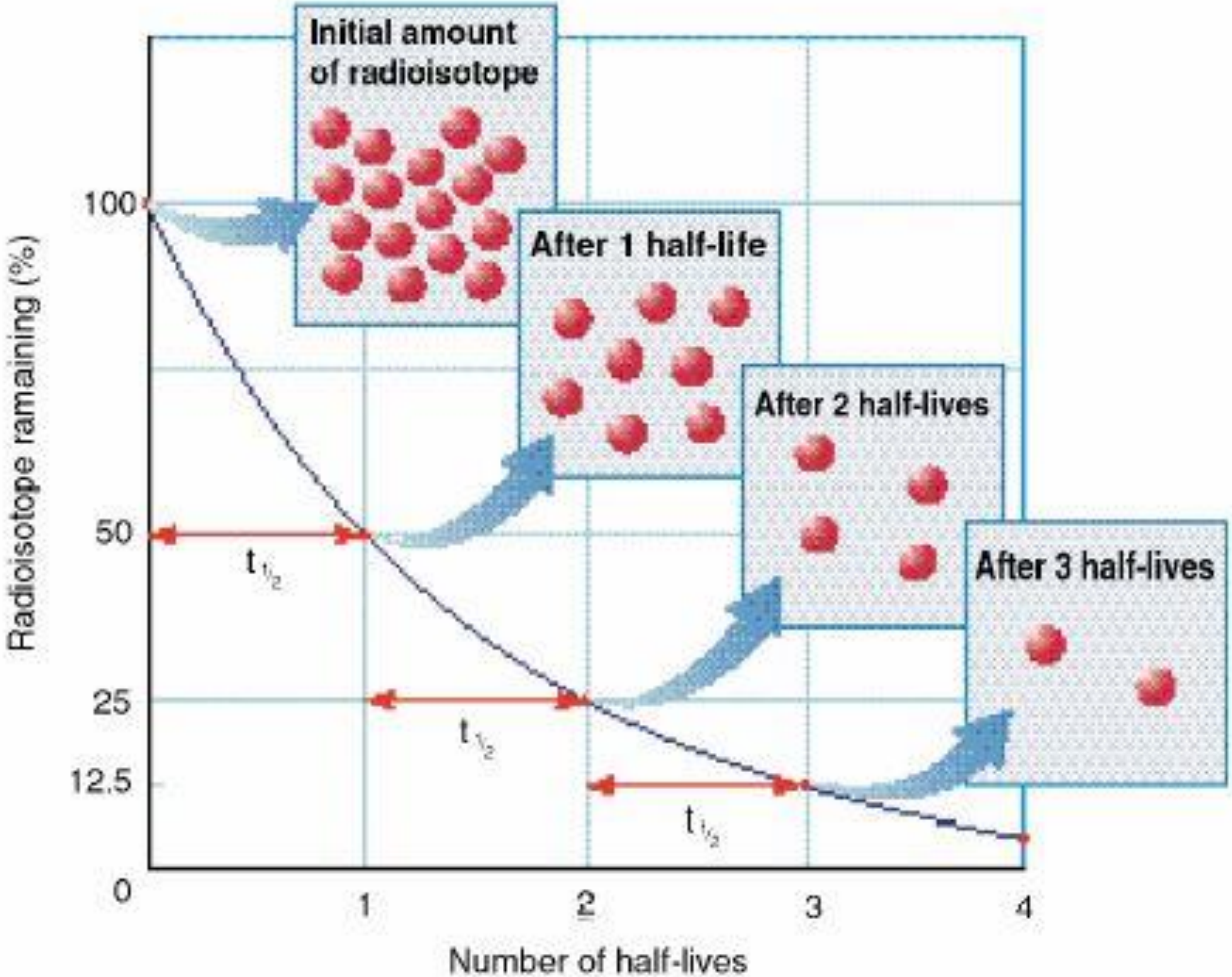
Like charges___repel___ each other.



Nuclear Stability

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

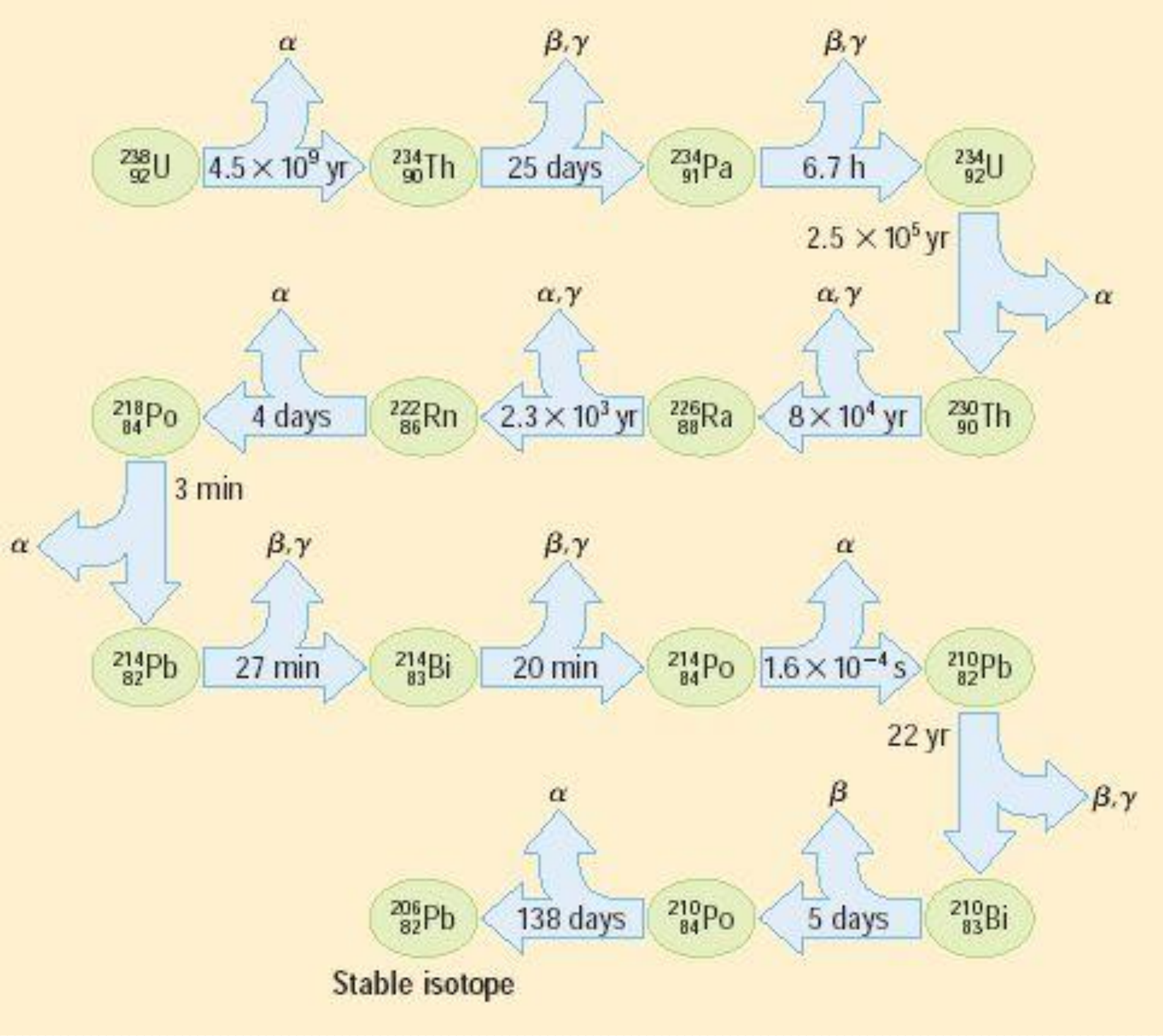
Half-life Concept



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

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.*

Nuclear Fission and Fusion

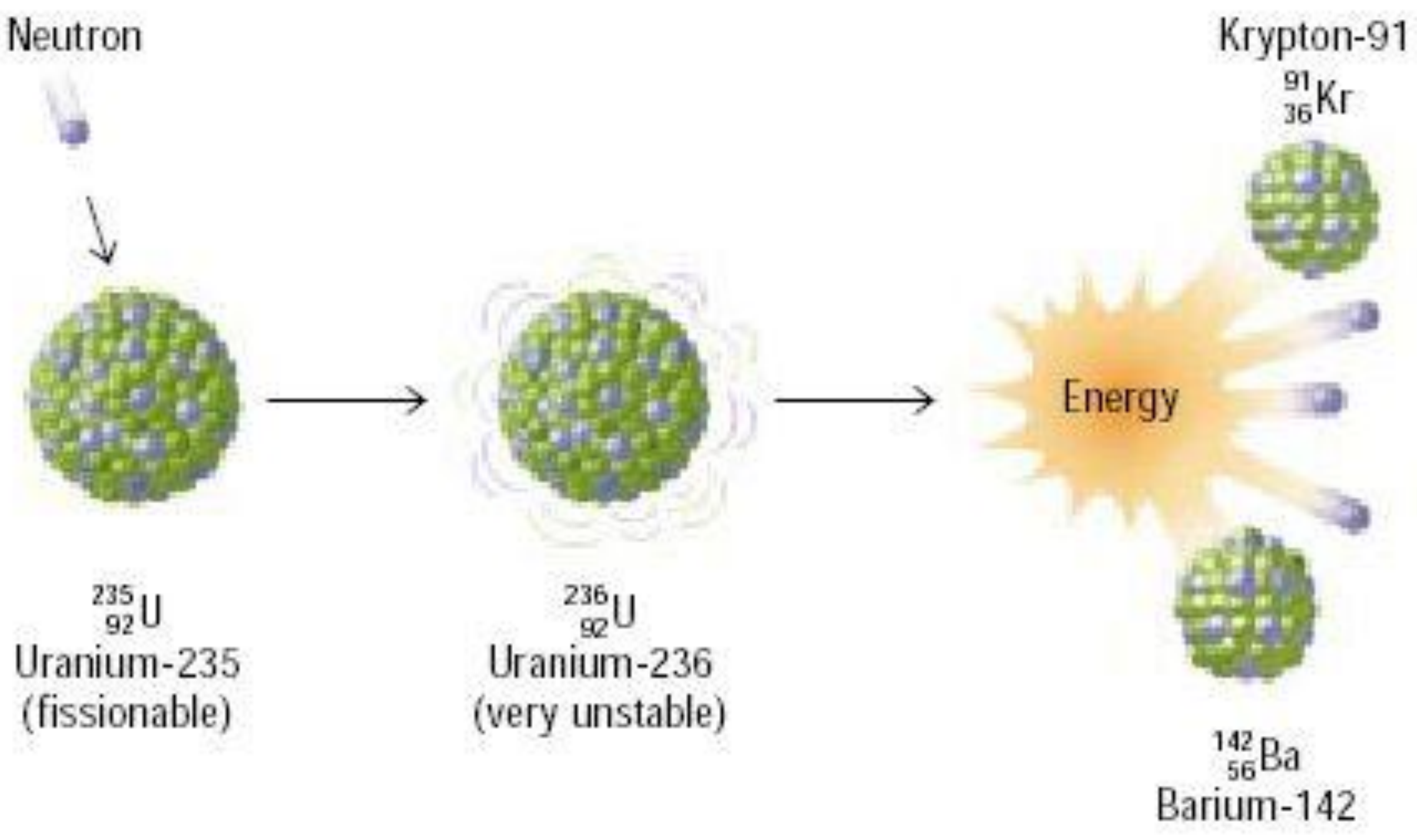
- Fusion: Combining two light nuclei to form a heavier nucleus.

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

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

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

Fission



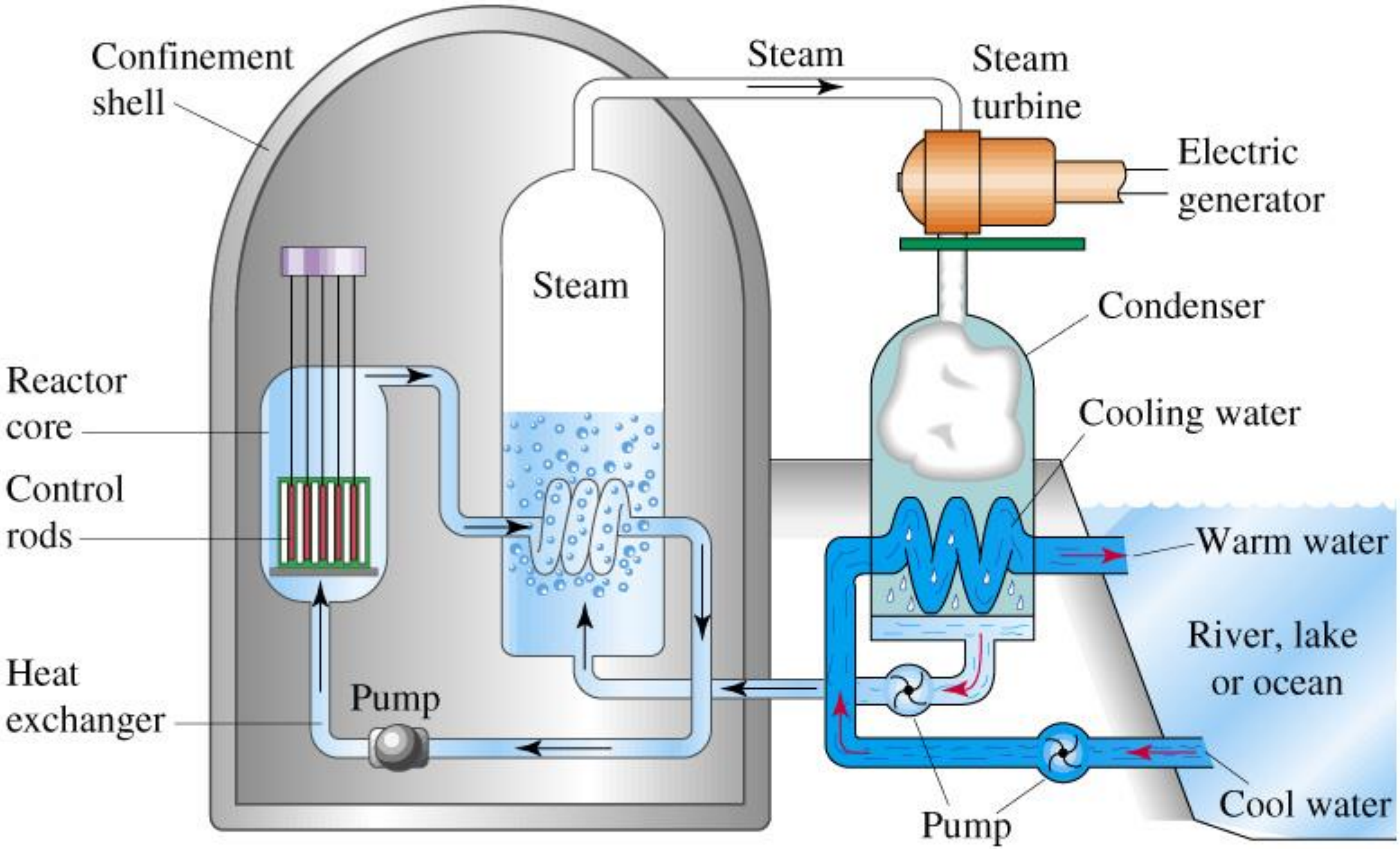
Neutron
Krypton-91
$^{91}_{36}Kr$
Energy
$^{235}_{92}U$
Uranium-235
(fissionable)
$^{236}_{92}U$
Uranium-236
(very unstable)
$^{142}_{56}Ba$
Barium-142

Fission Processes

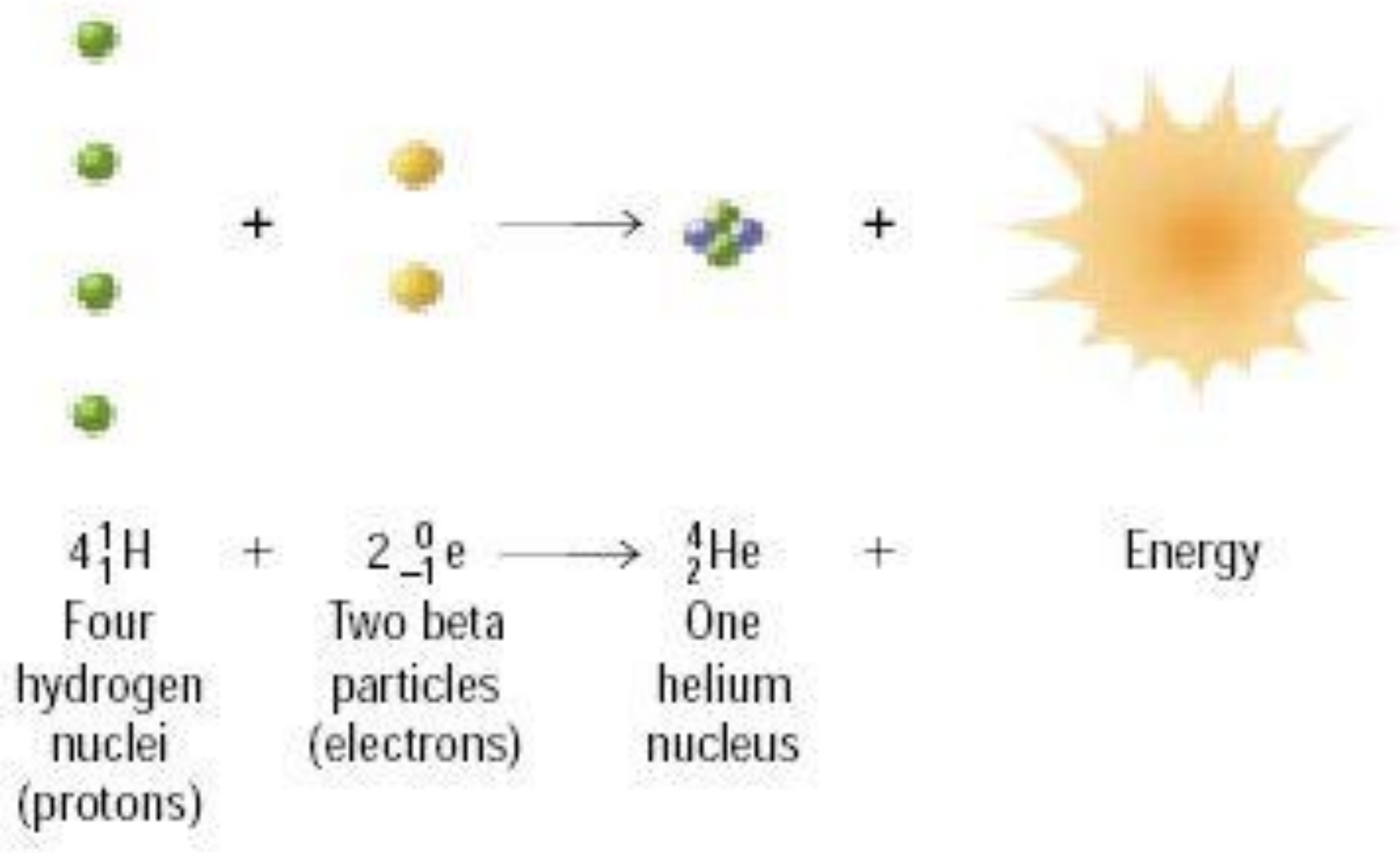
A self-sustaining fission process is called a chain reaction.

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

A Fission Reactor



Fusion



$4\,^{1}_{1}H$
+
$2\,^{0}_{-1}e$
→
$^{4}_{2}He$
+
Energy
Four hydrogen nuclei (protons)
Two beta particles (electrons)
One helium nucleus