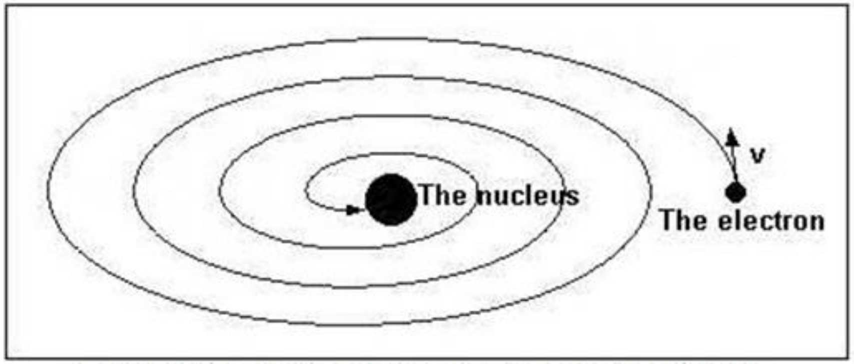
WARM-UP

"Models of the Hydrogen Atom" showing the History of Atomic Theory.

https://screencast-omatic.com/watch/cD6ZXZj5Ma

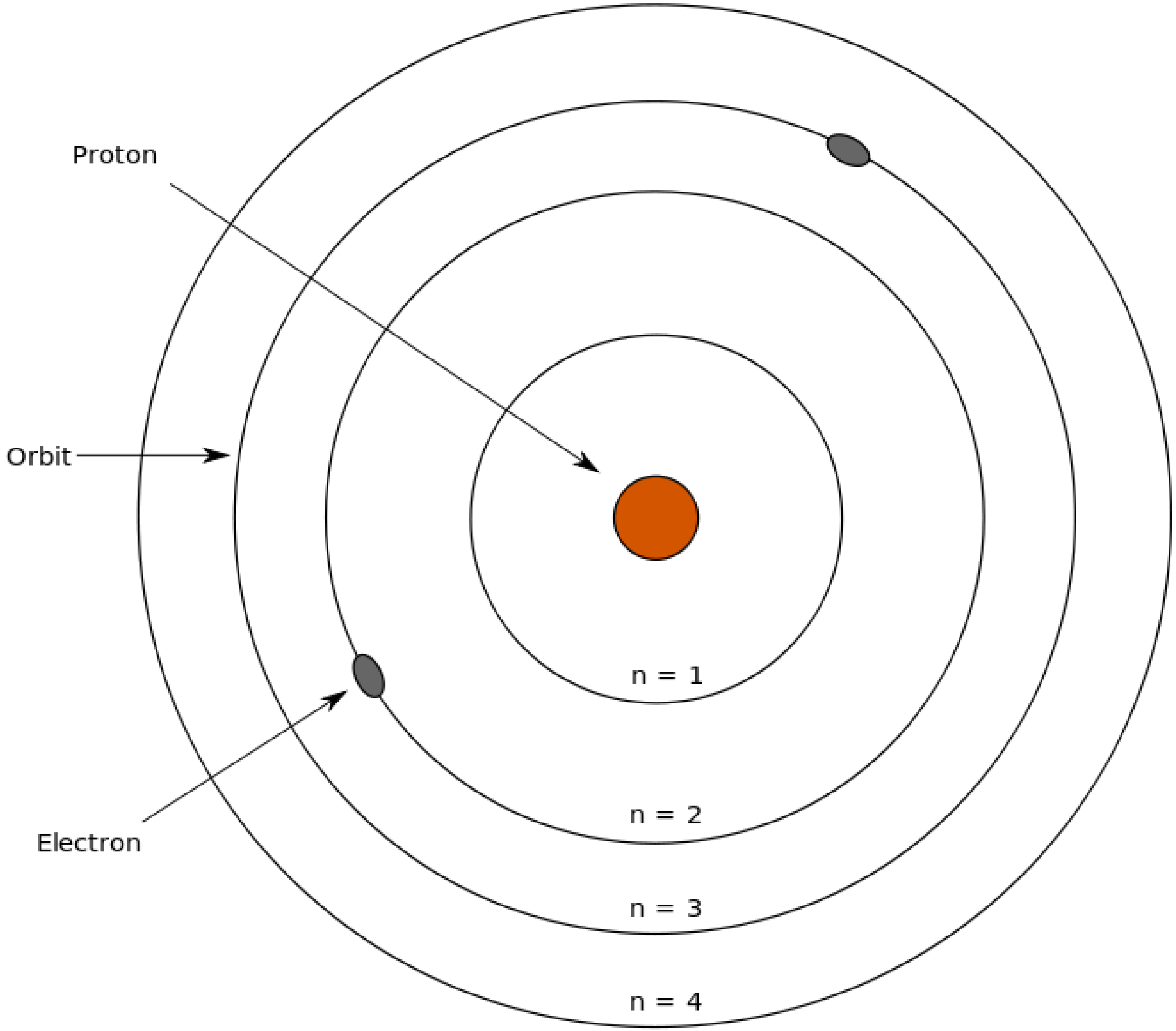
Limitations of Rutherford's Atomic Model

- Electrons are charged particles (unlike planets).
- An accelerating electric charge would steadily lose energy and spiral in, toward the positively charged nucleus, colliding with it in a fraction of a second.



- *Rutherford's model could not explain the highly peaked emission and absorption spectra of atoms that were observed.*

How was the modern understanding of the atom developed?



THINK ABOUT IT

Determine and explain the commonality of the following and how each may relate to Atomic Structure:

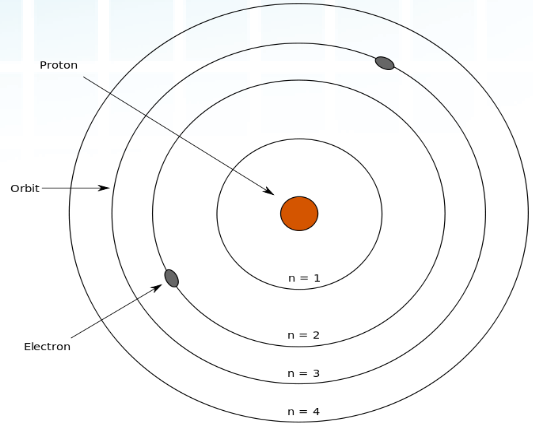
Staircase or ladder or bleacher

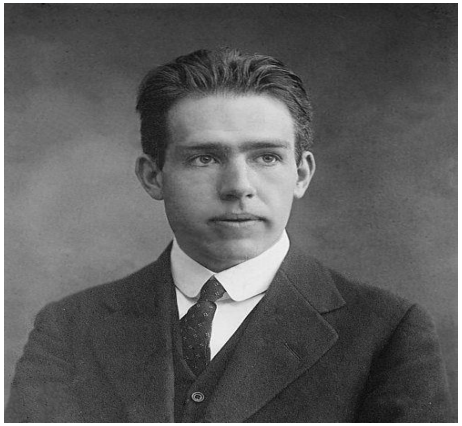
Pitches in a major scale

Radio stations on the AM or FM scale

You come up with your own example that fits

The Bohr Model





In 1913, Niels Bohr (1885–1962), a young Danish physicist and a student of Rutherford, developed a new atomic model.

Bohr proposed that an electron is found only in specific circular paths, or **orbits**, around the nucleus.

Bohr's model only worked for the simple Hydrogen atom and his perspective was still "Newtonian" based (electrons are particles).

The Bohr Model

shows that atoms and molecules can only exist in certain energy states so he designated the electron orbitals as **energy levels** or **quantum levels**.

A change in the energy level of such a system involves the absorption or emission of a definite amount (QUANTA) of energy.

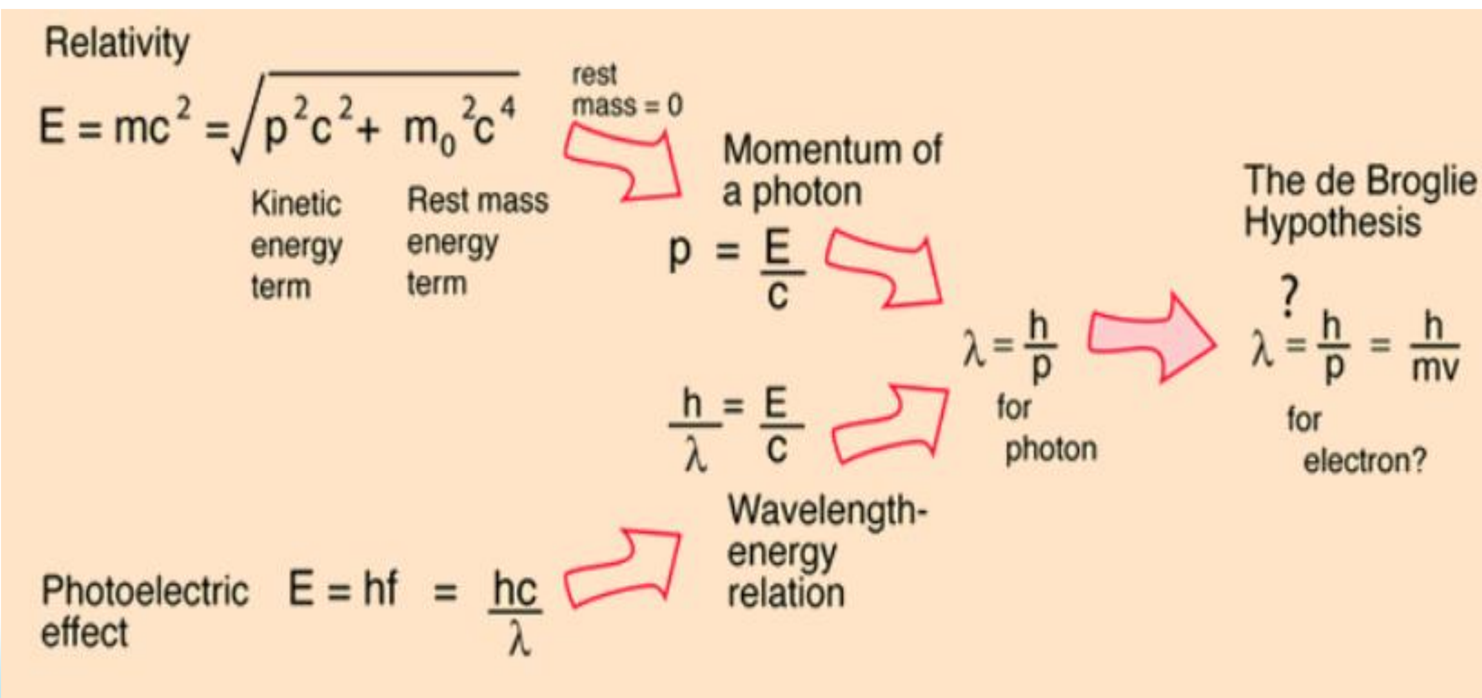
The rungs on this unusual ladder are somewhat like the energy levels in Bohr's model of the atom.

One can only stand ON the rungs of a ladder.
Similarly, the electrons in an atom cannot exist between energy levels.

Louis DeBroglie

Proposed that all matter and slow moving particles (e.g. electrons) have a dual nature.

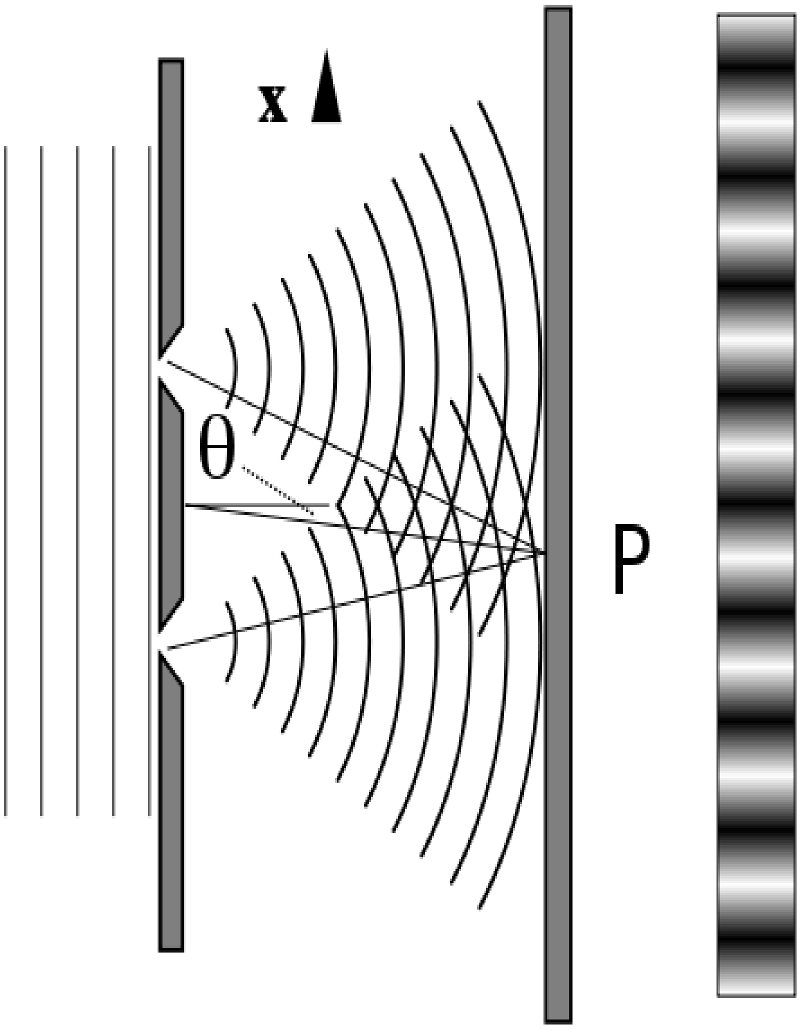
Electrons can behave as **waves (wavelength, reflection, refraction, diffraction**) or **particles (momentum)**.



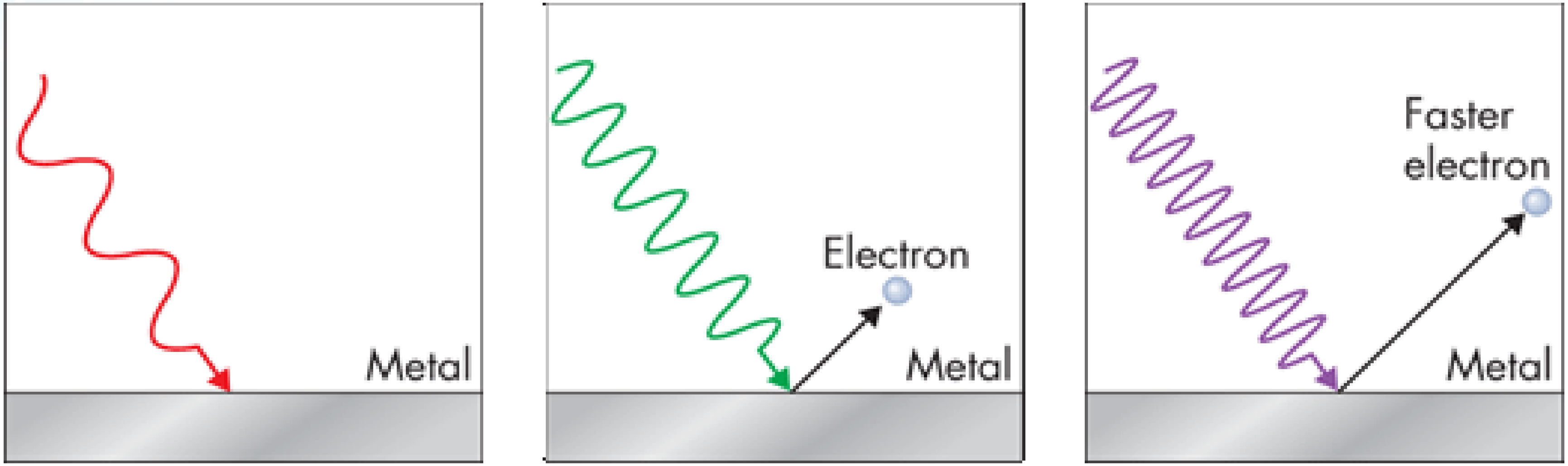
Modification: Wave-Particle Duality of Light

Major Theories of Light:

- Newton (1704): Light behaves as a <u>particle</u>.
  - *With mass, acceleration, action/reaction.*
- Young (*early 1800s*): Light behaves as a <u>wave</u>.
  - *Reflection, refraction,* ***diffraction in double-slit experiment*** →



The Photoelectric Effect → Shows "Quanta"



No electrons are ejected because the frequency of the light is below the threshold frequency.

If the light is at or above the threshold frequency, electrons are ejected.

If the frequency is increased, the ejected electrons will travel faster.

e.g. garage door opener; remote controls

Photoelectric Effect: Discrete Particle & Wavelength

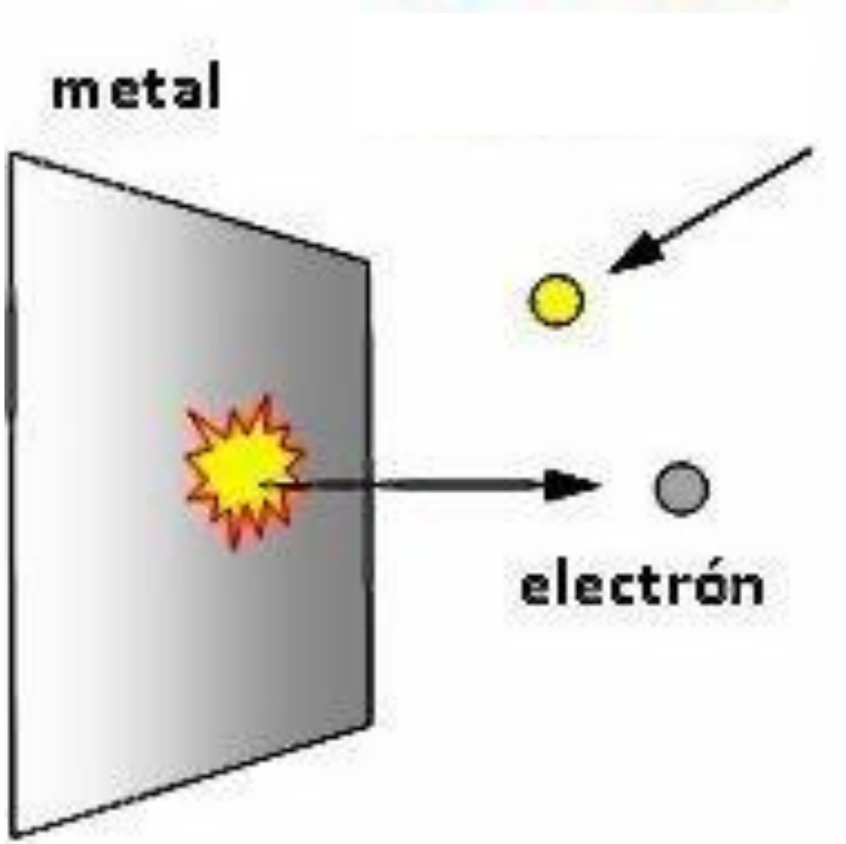
Einstein explained the photoelectric effect incorporating Planck's particle view (quantum) while proposing that light being a wave behaves as "Photons" or bundle of energy.

Every Photon has a quantized amount of energy as described by $\boldsymbol{E = hv}$.

E = energy of photon

h = Planck's constant

v = frequency



THINK ABOUT IT

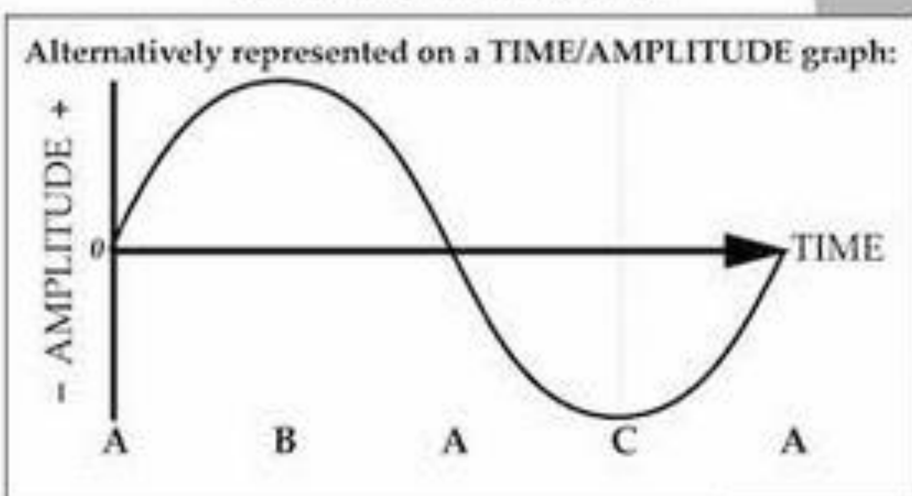
Consider a Guitar

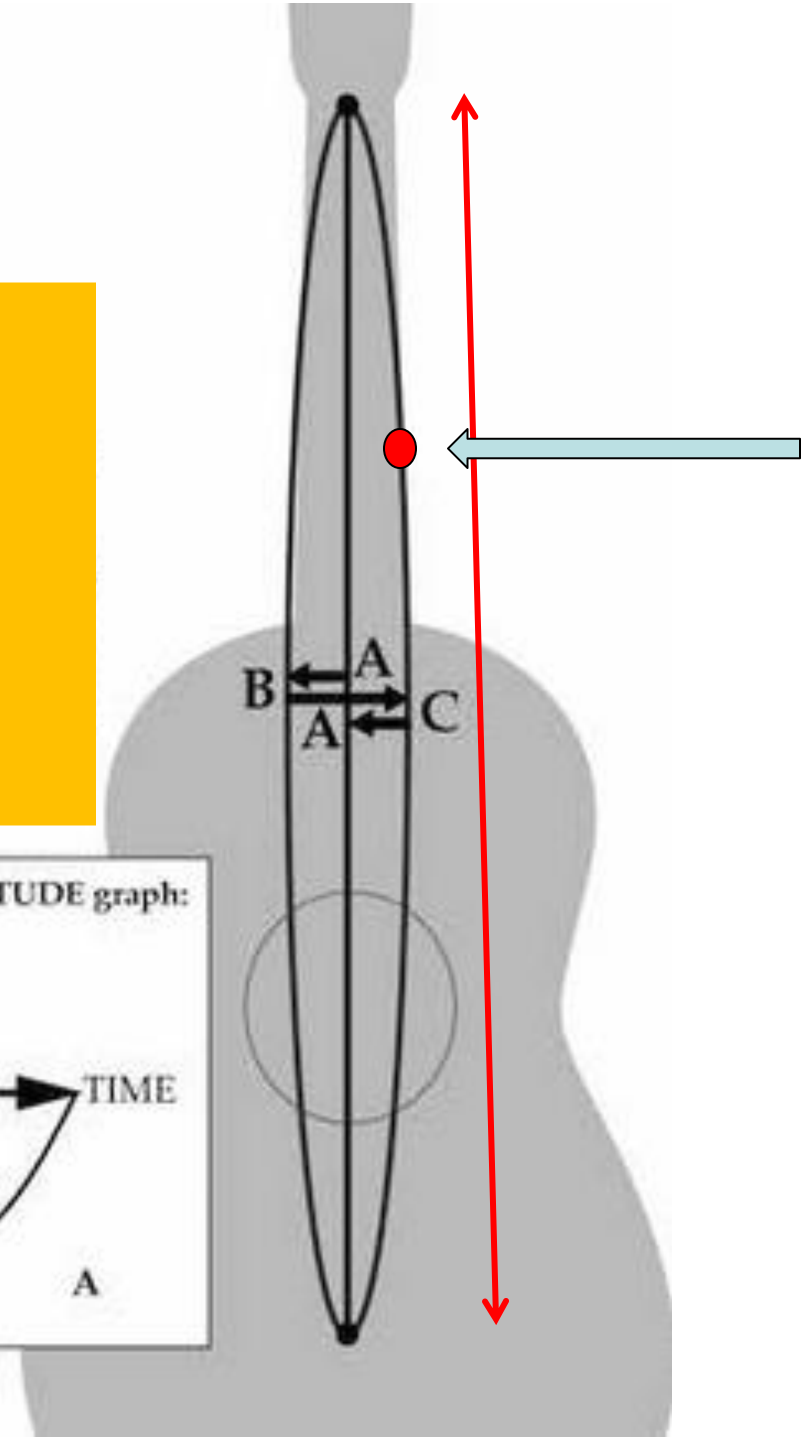
Wavelength → each string represents ½ wavelength from the bridge

Particle → the pulse sent on the string represents the particle nature of sound which travels back and forth on the string (*longitudinal wave*)

Guitar: Wave – Particle Duality

- One string represent λ/2 (wave)
- The sound travels as a pulse back & forth on the string (particle)



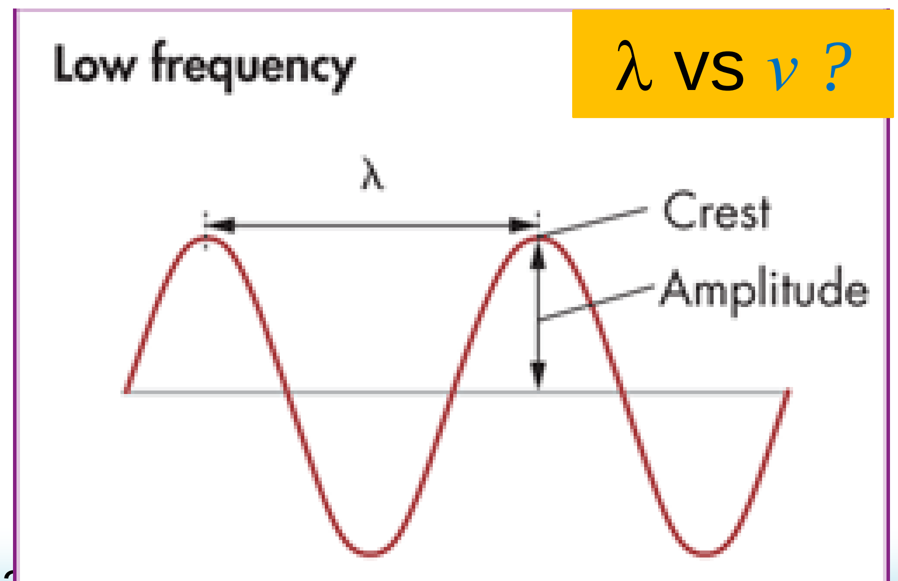


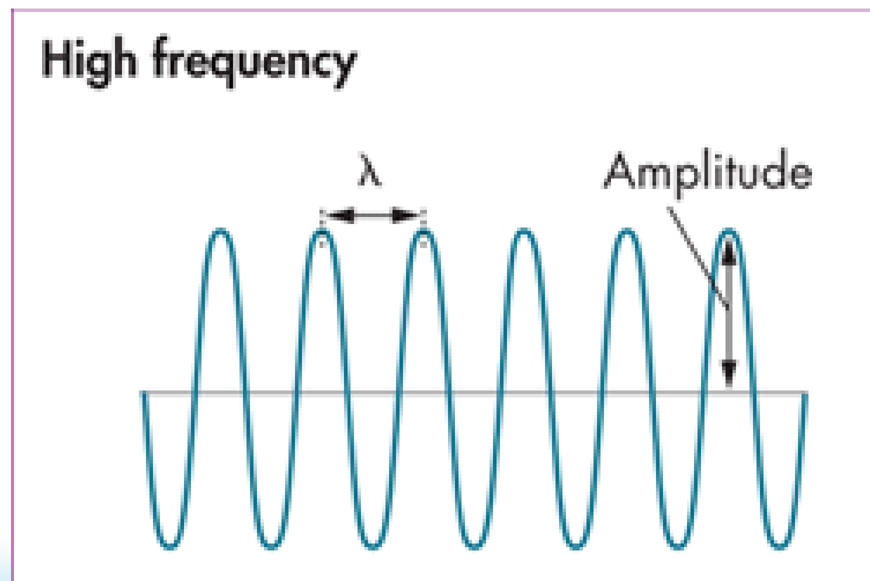
Wavelength (λ) of light corresponds to its color; red light has the longest λ, 700 nm, & lowest frequency; violet, at 380 nm, has the shortest λ & highest frequency. units: meters

Frequency (*ν*) corresponds to energy; wave cycles to pass a given point per unit of time; units: hertz (hz, sec^{-1})

Amplitude corresponds to brightness of the light.

λ vs *ν* ?





Wavelength, λ, and **frequency, ν**, are ***inversely*** proportional.

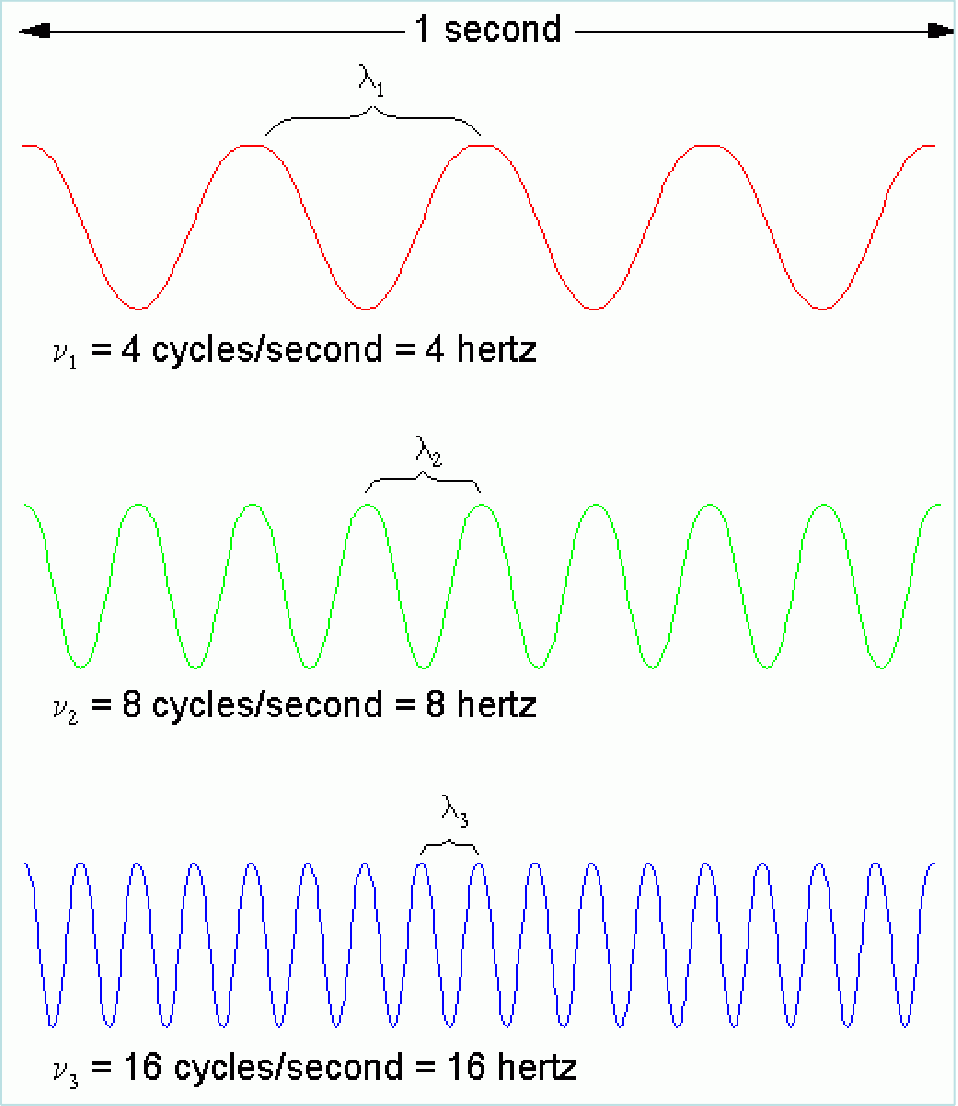
$$c = f\,\lambda$$

Speed of light

Frequency, ν, and **energy** are ***directly*** proportional. The higher the frequency, the higher the energy.

$$E = h\nu$$

$h = 6.626 \times 10^{-34}$ J·s
Planck's constant.



TRY IT

How does the energy of the higher energy levels of an atom compare with the energy of the lower energy levels of the atom?

A. They are greater in magnitude than those of lower energy levels.

B. They are lesser in magnitude than those of lower energy levels.

C. There is no significant difference in the magnitudes.

Which variable is directly proportional to frequency in relation to the speed of light?

wavelength position velocity energy

What are quanta of light called?

quarks excitons muons photons

Who predicted that all matter can behave as waves as well as particles?

Einstein Schrodinger Planck Louis de Broglie

How does the energy of the higher energy levels of an atom compare with the energy of the lower energy levels of the atom?

TRY IT

A. They are greater in magnitude than those of lower energy levels.

~~**B. They are lesser in magnitude than those of lower energy levels.**~~

~~**C. There is no significant difference in the magnitudes.**~~

Which variable is directly proportional to frequency in relation to the speed of light?

wavelength ~~**position**~~ ~~**velocity**~~ ~~**energy**~~

What are quanta of light called?

~~**quarks**~~ ~~**excitons**~~ ~~**muons**~~ **photons**

Who predicted that all matter can behave as waves as well as particles?

~~**Einstein**~~ ~~**Schrodinger**~~ ~~**Planck**~~ **Louis de Broglie**

Calculating the Energy of a Photon

TRY IT

Calculate the energy of a photon of red light with a wavelength of 5.77×10^{-5} cm. $h = 6.626 \times 10^{-34}$ Js $c = 2.998 \times 10^{8}$ m/s

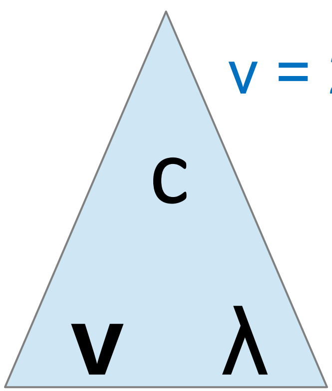
Calculating the Energy of a Photon

TRY IT

Calculate the energy of a photon of red light with a wavelength of 5.77×10^{-5} cm. $h = 6.626 \times 10^{-34}$ Js $c = 2.998 \times 10^{8}$ m/s

NOTICE: there are two unknown variables (E, frequency). Therefore, we need to do a step in-between … $c = v\lambda$ … $v = c/\lambda$

Change to common units: $\lambda = 5.77 \times 10^{-5}\ \text{cm} \times 1\ \text{m}/100\text{cm} = 5.77 \times 10^{-7}\ \text{m}$



$v = 2.998 \times 10^{8}\text{m/s} / 5.77 \times 10^{-7}\ \text{m} = 5.20 \times 10^{14}\ 1/\text{s}$

Calculating the Energy of a Photon

TRY IT

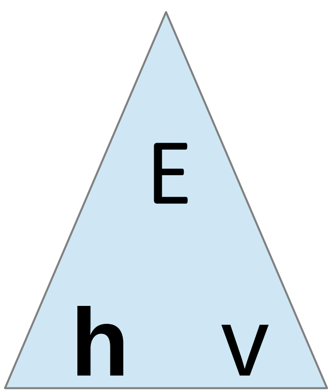
Calculate the energy of a photon of red light with a wavelength of 5.77×10^{-5} cm. $h = 6.626 \times 10^{-34}$ Js $c = 2.998 \times 10^{8}$ m/s

SUBSTITUTE frequency into the Energy equation:

$$E = hv$$

$$E = 6.626 \times 10^{-34} \text{ Js} \times 5.20 \times 10^{14} \text{ 1/s}$$

$$E = 3.44 \times 10^{-19} \text{ J}$$



You may use $c = 3.000 \times 10^{8}$ m/s

Calculating the Energy of a Photon

Calculate the energy of a photon of red light with a wavelength of 5.77×10^{-5} cm. $h = 6.626 \times 10^{-34}$ Js $c = 2.998 \times 10^{8}$ m/s

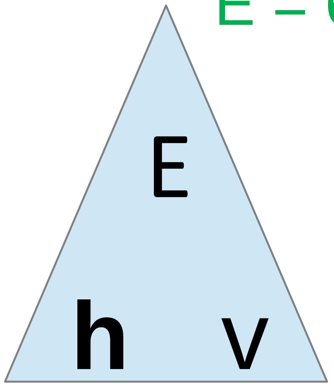
Change to common units: $\lambda = 5.77 \times 10^{-5}$ cm x 1 m/100cm = 5.77×10^{-7} m

The easier way to do this: since $\nu = c/\lambda$, replace "ν" with "c/λ"

$$E = h\nu = hc/\lambda$$

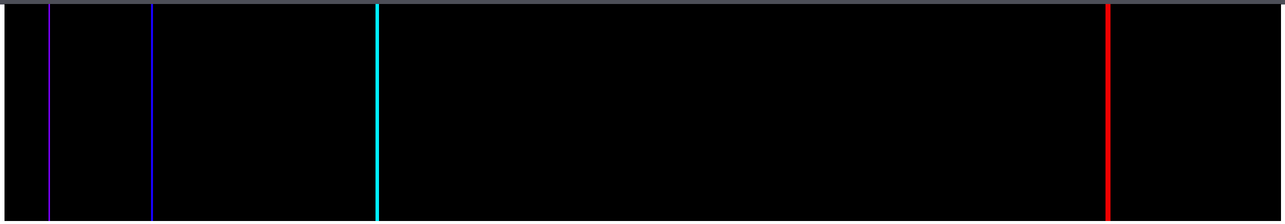
$$E = 6.626 \times 10^{-34}\ \text{Js} \times 2.998 \times 10^{8}\ \text{m/s} / 5.77 \times 10^{-7}\ \text{m}$$

$$E = 3.44 \times 10^{-19}\ \text{J}$$



Evidence of “Quanta” of Energy

Hydrogen (g)



Helium (g)

Johannes Rydberg studied **emission spectra**.

- **Emission spectrum**: a visible light spectrum in which wavelengths of light emitted by a substance show up as bright, colored lines
- Emission spectra for some metals produced discrete lines (e.g. quanta), not continuous or gradual.
- *Determined a **DIRECT relationship** between frequency and energy.*

Flame Tests

Elements give off characteristic Emission Spectra (colors of light), as electrons transition between energy levels.


strontium

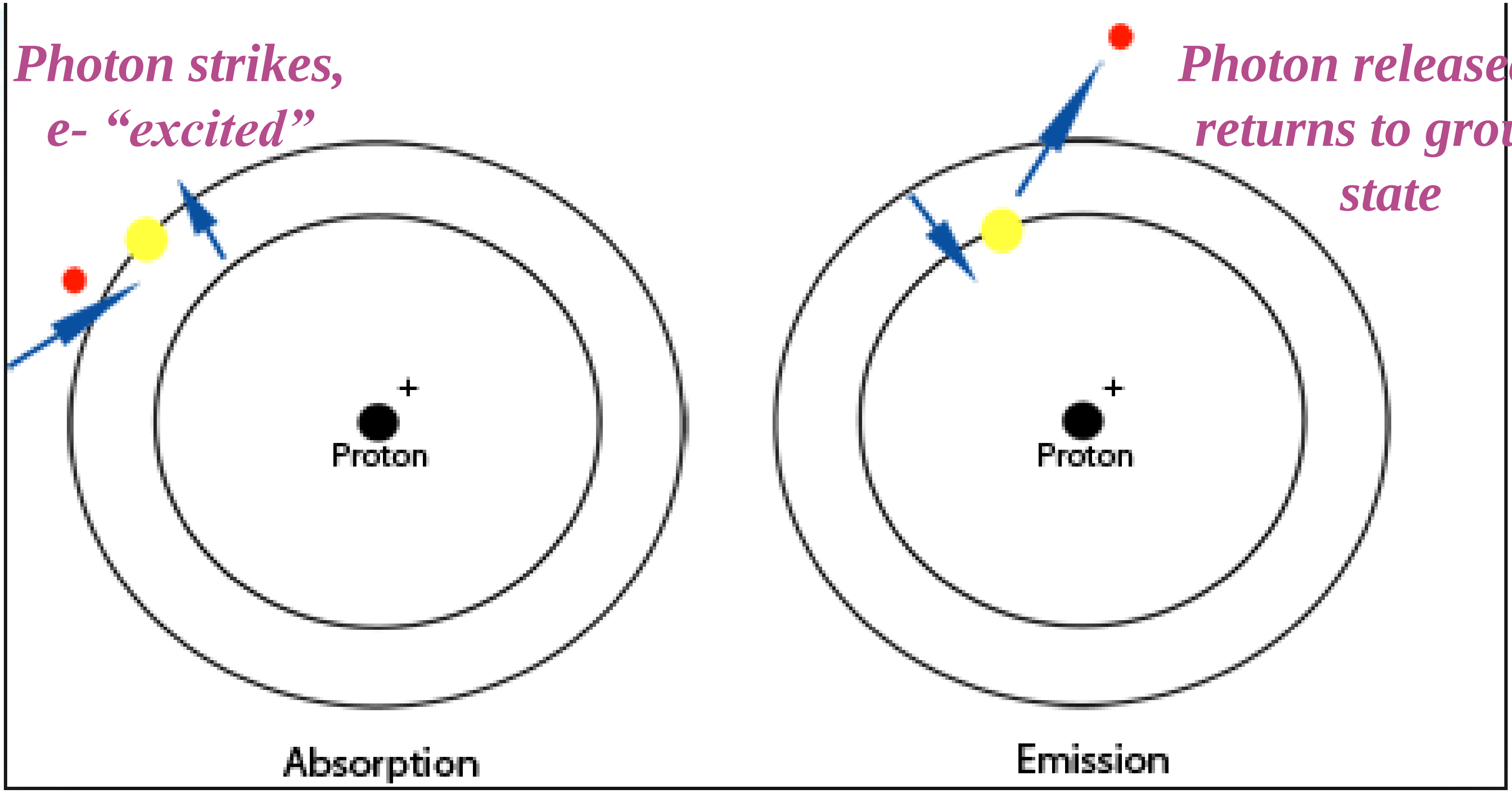

sodium


lithium


potassium


copper

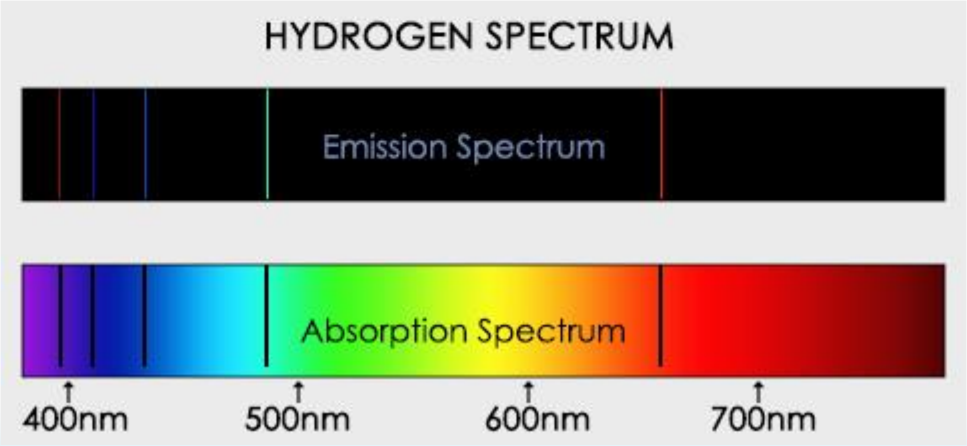
Absorption & Emission Spectra



Notice the movement of electrons based on the photon.

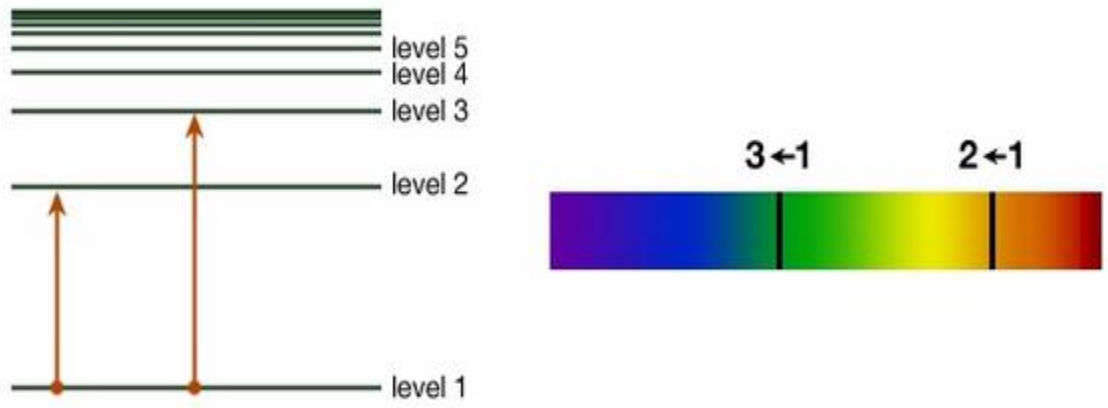
Absorption & Emission Spectra

- The energy **absorbed** by an electron to move from its current energy level to a higher energy level.
    - is identical to the energy of the light emitted by the electron as it **drops back to its original energy level (Emission)**.
- Emission Spectra are like "**fingerprints**" … no two elements have the same spectra.

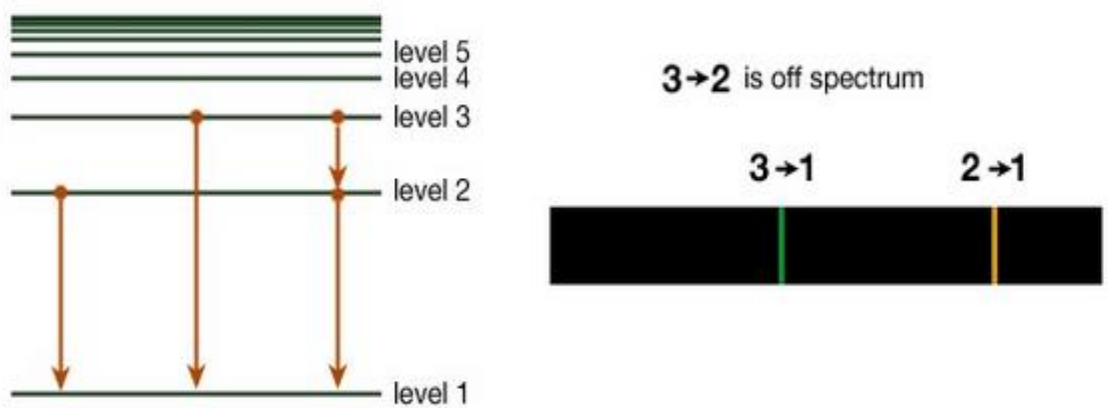


5.3 Atomic Emission Spectra and the Quantum Mechanical Model >

Electrons absorb heat or electrical energy to reach the EXCITED STATE → Absorption, dark line spectra

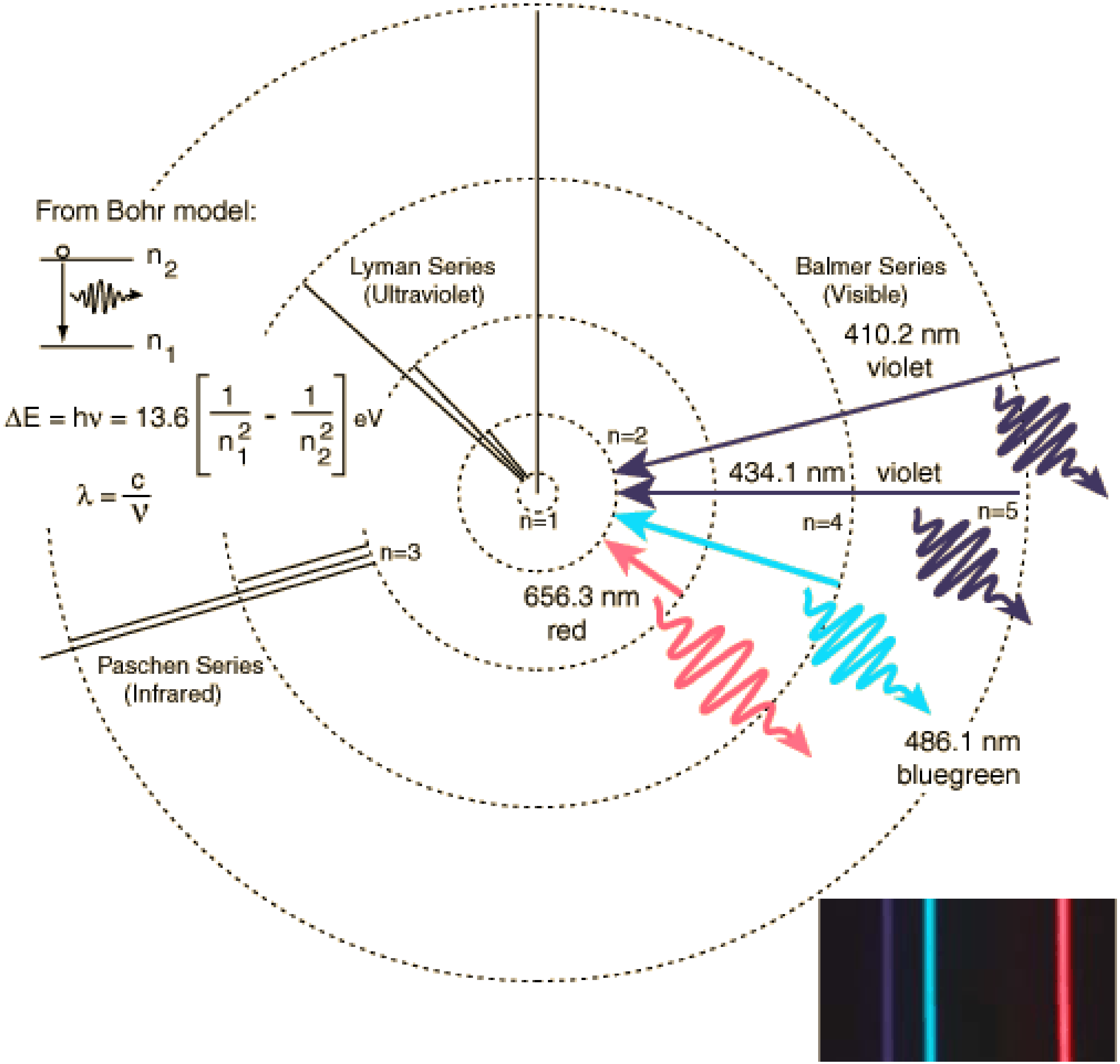


Electrons return to the GROUND STATE (*most stable energy state*) → Bright-Line Spectra



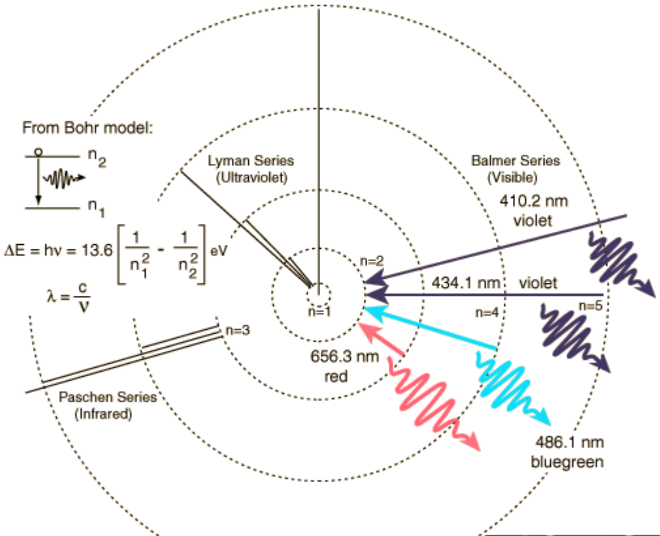
Energy is DISCRETE or QUANTIZED (*like stairs*)

QUICK CHECK



Explain this diagram in terms of energy, electrons & spectra

QUICK CHECK



Electrons begin in the ground state (lowest energy level).

Energy is "absorbed" so electrons get "excited" to a higher energy level → (Absorption Spectra)

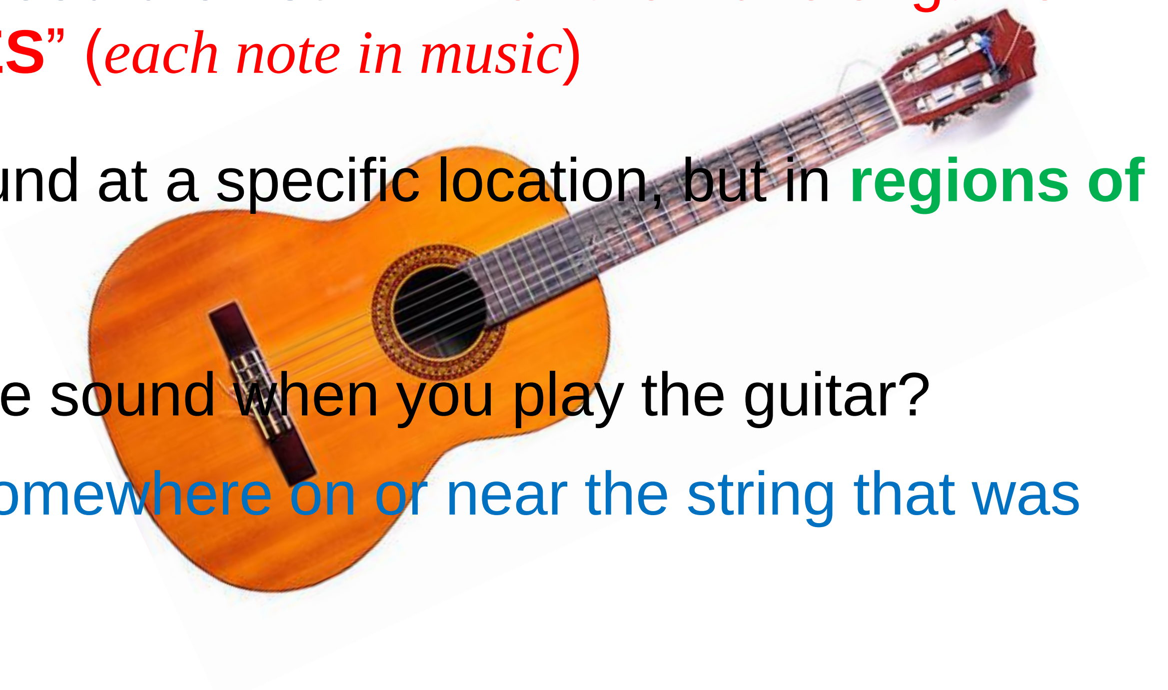
The "excited" state is UNSTABLE so the electrons will return to the ground state by giving off energy in the form of light (color) → Emission Spectra.

Energy absorbed" or "emitted" is in discrete bundles (quanta), not gradual.

"O, where oh where has my Electron gone?"

Erwin Schrödinger (1887–1961) worked from the premise that the electron was a <u>wave</u> and a <u>particle</u>. Therefore, its **location** could be statistically determined using previous diffraction techniques [*Thomson Double Slit Diffraction pattern*]

- **Only certain energies could exist** in which the wavelength form → "**STANDING WAVES**" (*each note in music*)
- Electrons cannot be found at a specific location, but in **regions of high probability**.
- E.g. where exactly is the sound when you play the guitar?
- ~90% of the time it is somewhere on or near the string that was plucked.

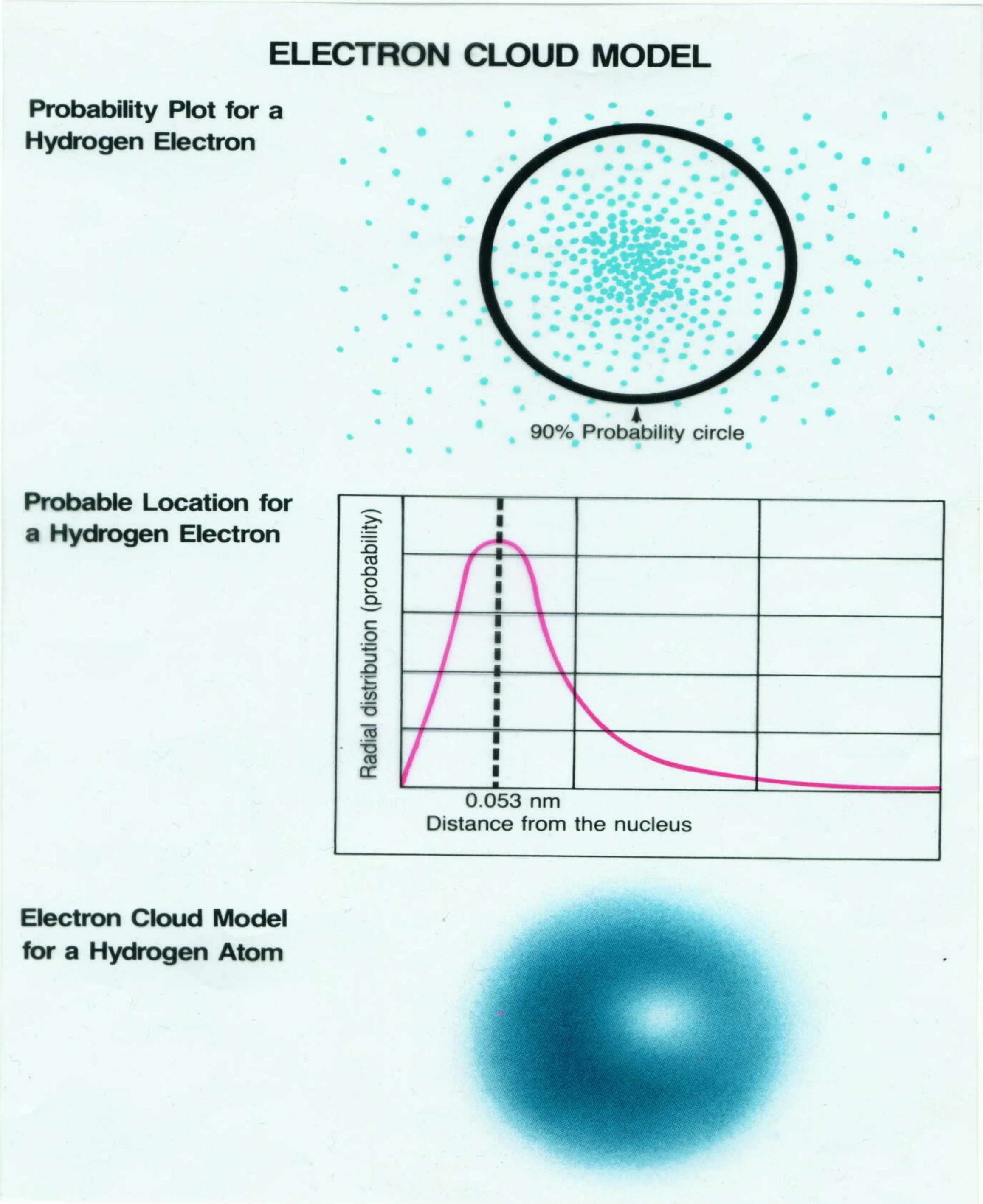


Electron Cloud

Schrödinger

Region of **high probability** (90%) for finding an electron

Developed the **quantum numbers** to describe the location of the electrons in the atom.



Alice in Wonderland

Electron Configuration Song (3:24)

https://screencast-o-matic.com/watch/cq6nYuuIbb

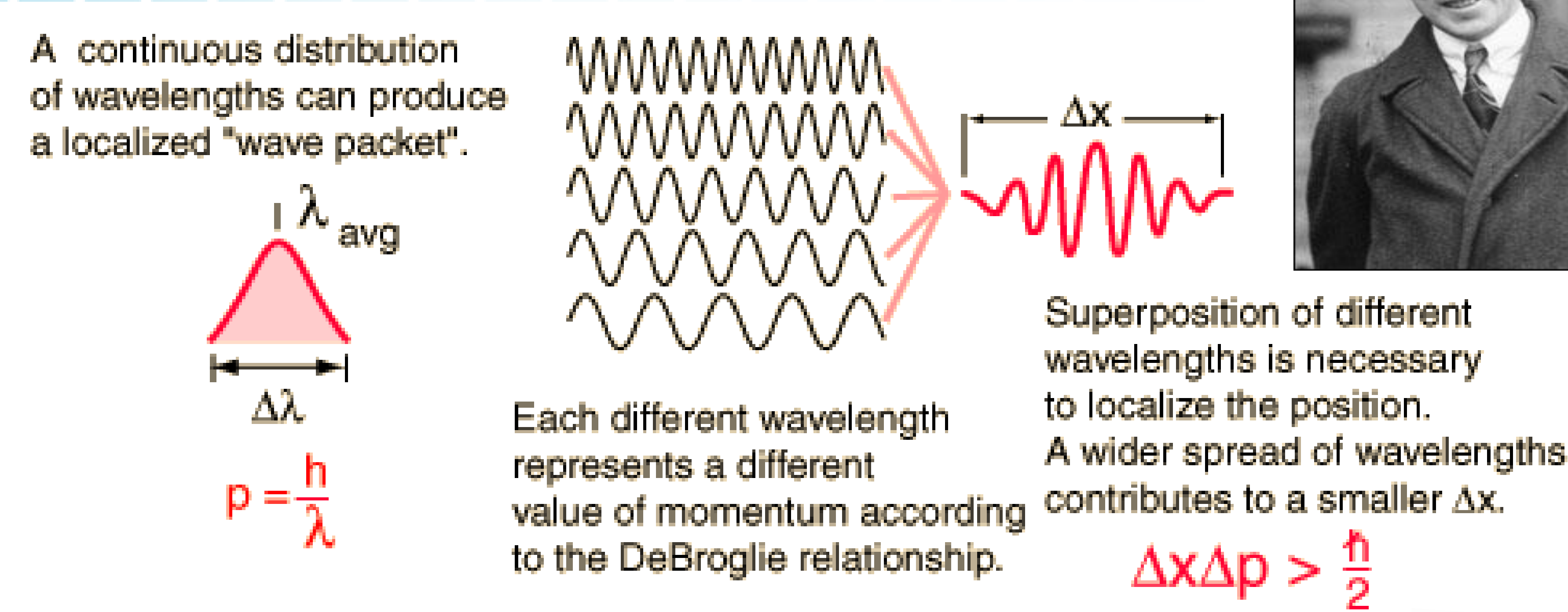
The Heisenberg Uncertainty Principle

- Heisenburg noted and worked with the uncertainties in the **position (ΔX)** and **momentum ($\Delta \rho$)** of small particles
- He used the **PROBABILITY** of finding an electron between two points of a **monochromatic wave** (*integrals of calculus*)
- He needed to use a "Pulse Wave" → constructive addition of many waves of various wavelength (*antinodes*) and destructive interference at the nodes

$$\Delta X \times \Delta \rho = \sim h/2$$

h → Planck's constant → 6.6 x 10^{-34} js

5.3 Atomic Emission Spectra and the Quantum Mechanical Model



The Heisenberg Uncertainty Principle

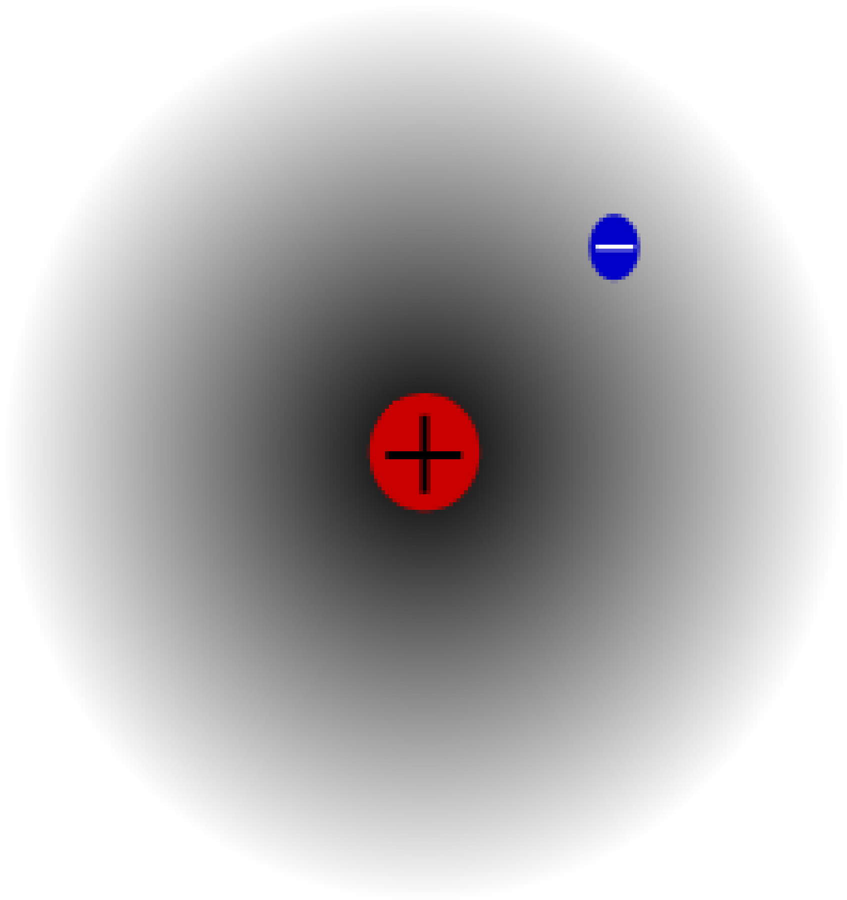
- *The length of the guitar string ~* **ΔX**
- *The momentum of the sound "pulse" ~***Δρ**

"You observed me speeding? Are you familiar with the Heisenberg uncertainty principle?"

Quantum Mechanics: Electron Cloud Model

$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2 \Psi}{\partial x^2} + V(x)\Psi.$$

The modern description of the electrons in atoms, the **quantum mechanics model**, came from the mathematical solutions (the Schrödinger equation).



Electron Cloud model:

- *Electrons in a cloud have regions of high probability (uncertain location).*
- *Electron clouds have different energy levels that are discrete.*
- *Cannot know the exact position of the electron.*

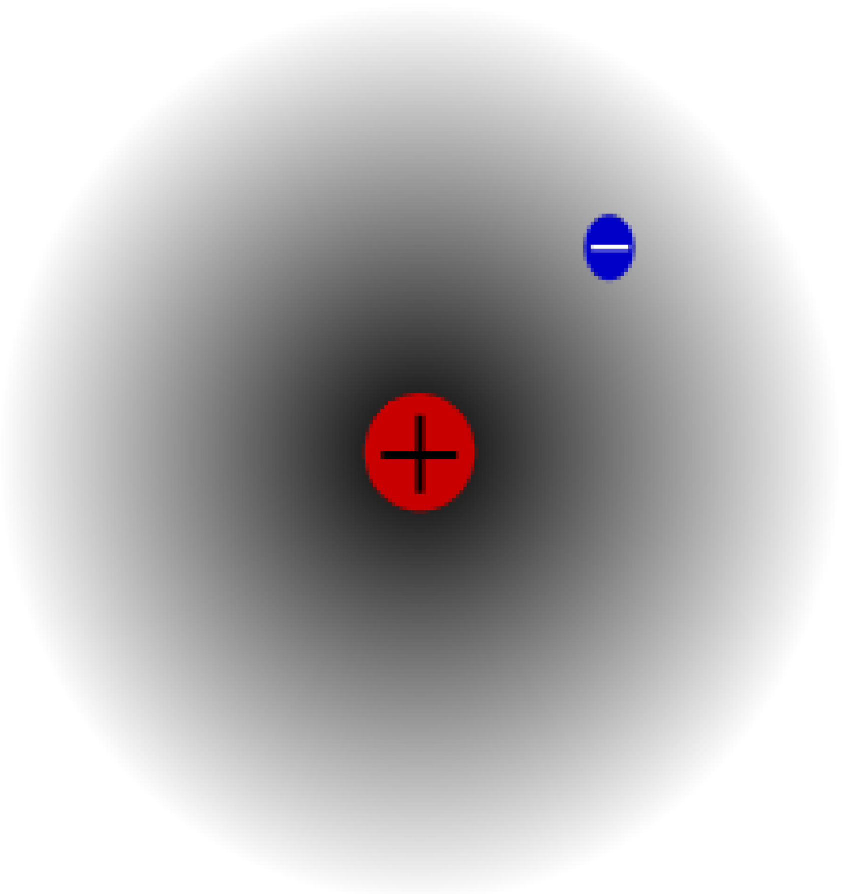
Quantum Mechanics: Electron Cloud Model

Demonstration:

$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2 \Psi}{\partial x^2} + V(x)\Psi.$$

http://somup.com/crjT2YriIi

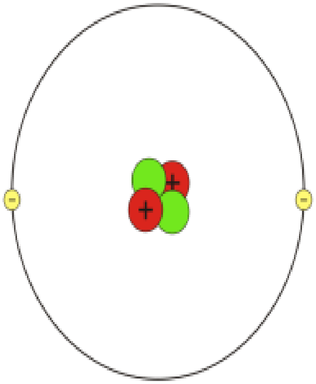
Uncertainty Principle with Pennies (1:28)



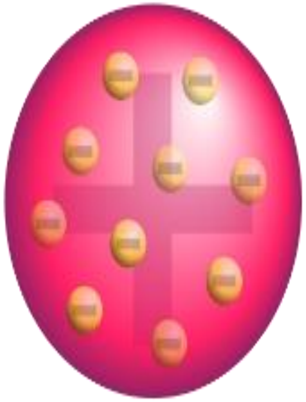
Understanding Atomic Structure

QUICK CHECK

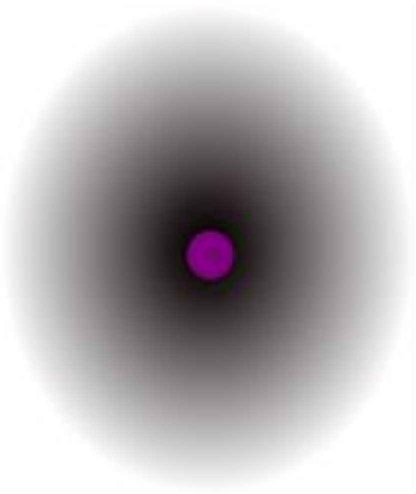
What scientist suggested each of the models shown below? Which best represents the modern understanding of the structure of the atom?



Model A



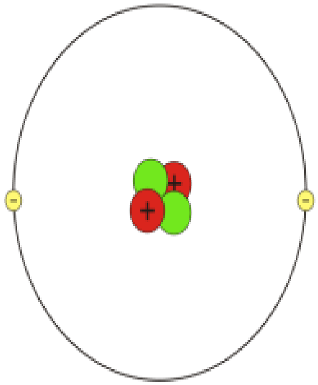
Model B



Model C

Understanding Atomic Structure

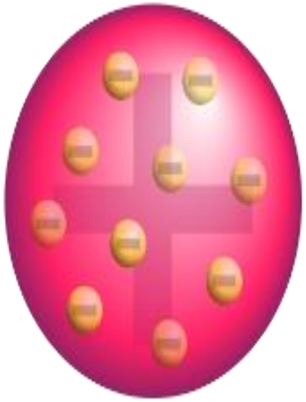
What scientist suggested each of the models shown below? Which best represents the modern understanding of the structure of the atom?



Model A

Rutherford & Bohr

Nucleus with orbiting electrons



Model B

Thomson

Plum Pudding

Model C

Electron Cloud

Schroedinger

Subshell	n	l	Maximum No. of Electrons
1s	1	0	2
2s	2	0	2
2p	2	1	6
3s	3	0	2
3p	3	1	6
3d	3	2	10
4s	4	0	2
4p	4	1	6
4d	4	2	10
4f	4	3	14

LESSON QUESTION

How can scientists describe the arrangement of electrons in an atom?

Atomic Orbitals

- An atomic orbital is represented pictorially as a region of space in which there is a high probability of finding an electron.
- **Every electron in an atom is assigned a QUANTUM NUMBER** described by the Schrödinger equation - a mathematical expression
- **Quantum numbers indicate different energy states of electrons in an atom**
- Every **electron** can be described by **FOUR quantum numbers** and NO two electrons have the same 4 numbers.

The quantum mechanical model of the atom

a. Defines the exact path of an electron around the nucleus.

b. Was proposed by Neils Bohr.

c. Involves the probability of finding an electron in a certain position.

d. No longer requires the use of energy levels.

The maximum number of electrons in any orbital: ____.

Give the maximum number of electrons in any single energy level for the s sublevel: ____; p sublevel _____; d sublevel _____; f sublevel _____.

The letters s, p, d, f in an electron configuration indicate the ____.

a. Spin of an electron

b. Orbital shape

c. Principle energy level

d. Speed of an electron

Emission of light from an atom occurs when an electron

a. Drops to a lower energy level

b. Jumps to a higher energy level

c. Moves within its atomic orbital

d. Falls into the nucleus

Heisenberg's principle dealt with the uncertainty of ____ and _____ of electrons.

The quantum mechanical model of the atom

~~a. Defines the exact path of an electron around the nucleus.~~

~~b. Was proposed by Neils Bohr.~~

c. Involves the probability of finding an electron in a certain position.

~~d. No longer requires the use of energy levels.~~

The maximum number of electrons in any orbital: 2.

Give the maximum number of electrons in any single energy level for the s sublevel: 2; p sublevel 6; d sublevel 10; f sublevel 14.

The letters s, p, d, f in an electron configuration indicate the ____.

~~a. Spin of an electron~~

b. Orbital shape

~~c. Principle energy level~~

~~d. Speed of an electron~~

Emission of light from an atom occurs when an electron

a. Drops to a lower energy level

~~b. Jumps to a higher energy level~~

~~c. Moves within its atomic orbital~~

~~d. Falls into the nucleus~~

Heisenberg's principle dealt with the uncertainty of position & momentum (speed) of electrons.

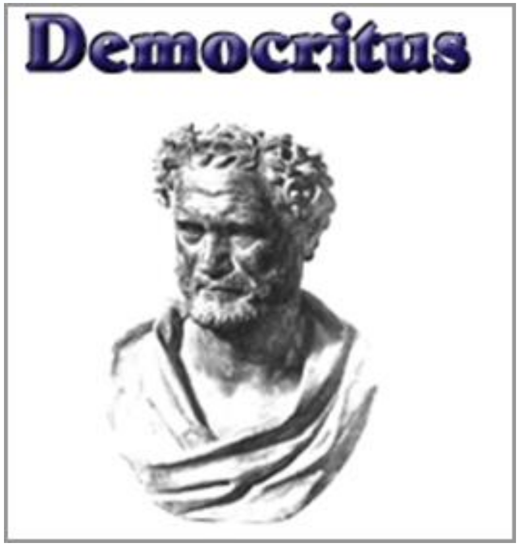
WARM-UP

Watch the video and consider what causes what you observe.

http://somup.com/cFQ22DVSKM

Light, sparks, pie tin, Styrofoam, toy (1:15)

Democritus



Greek philosopher (460 – 370 BC)

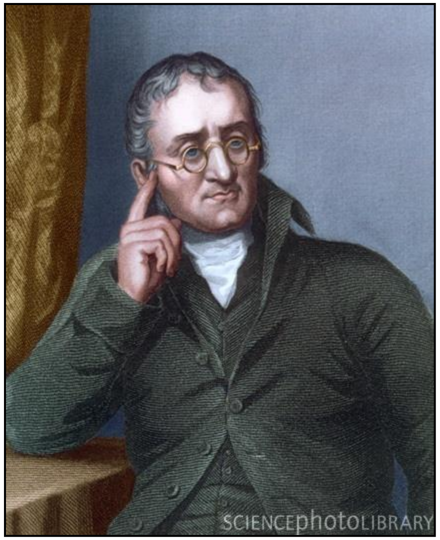
Coined the term "Atom"

"Matter consists of discrete, indivisible particles"

Democritus held a very general theory with <u>no experimental evidence</u>

Democritus' ideas were rejected by Plato & Aristotle (*fathers of <u>philosophy</u> and <u>ancient "scientific thinking</u>"*) … & therefore, set aside

John Dalton 1766-1844



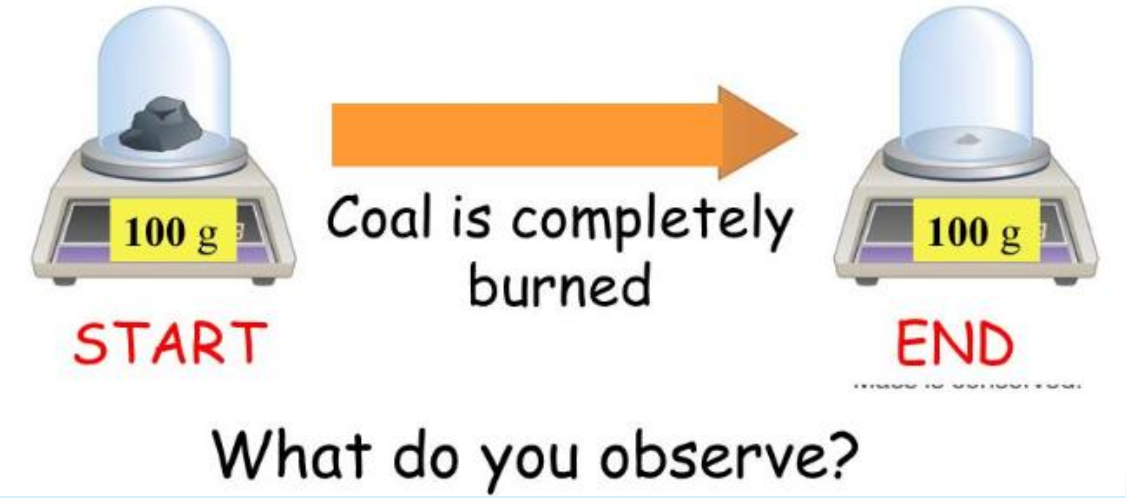
Dalton's Atomic Theory (1808)

1. All elements are composed of extremely small, indivisible particles called "atoms."
2. All atoms of the same element have the same chemical properties. Atoms of different elements have different properties.
3. **In the course of an ordinary chemical reaction, no atom of one element disappears or is changed into an atom of another element.**
4. Compounds are formed when atoms are joined together in simple, whole-number ratios (*Law of "Multiple Proportions")*.

Lavoisier, ~1770

The Law of Conservation Of Mass

- Matter cannot be created nor destroyed.
- There is no detectable change in mass in an ordinary chemical reaction.
  - All compounds/elements that react are just rearranging their atoms.



Acrylic Tape

Take TWO separate pieces of acrylic tape ~ 7.5 cm long (3 inches).

Hold them "back" to "back" so the NON sticky sides are facing each other.

Bring them together slowly and observe.

Watch the video "Electrostatic Force" on Study Place

http://somup.com/cF6elPnVza (2:59)

THINK ABOUT IT

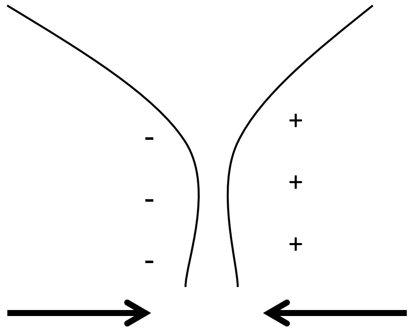
NOW, take TWO other separate pieces of acrylic tape ~ 7.5 cm long (3 inches).

Hold them by the ends and place one on top of the other on your table *so that one sticks to the table & the other sticks to the NON sticky side of the one on the table*.

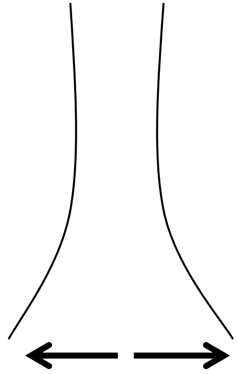
Pull the pieces off the table. Pull them apart and then bring them together slowly "back" to "back" & observe.

THINK ABOUT IT

In the first case you should have noticed "attraction"



In the second case, "Repulsion"



WHY?

Benjamin Franklin

Learned from experiments with thunderstorms, that lightning is a flow of electrical energy through the atmosphere.

He arbitrarily decided that there must be "charges" … and called them charge "A" and charge "B"

Electrons

A "cathode ray" can also be deflected by a magnet.

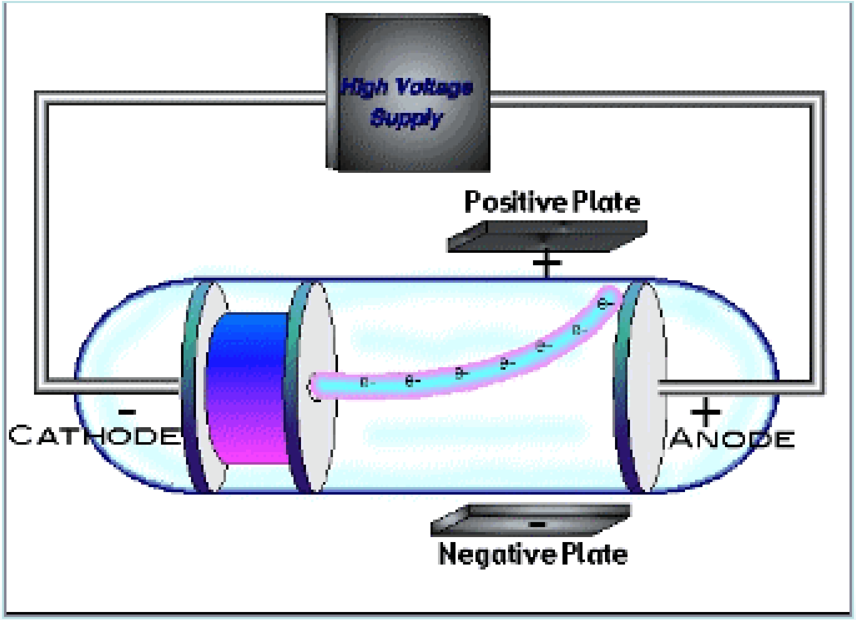
http://somup.com/cF6eVJnVy6 (1:07)

4. 2 Structure of the Atom

Electron: J.J. Thomson

In 1897, JJ Thomson got the same result as Crookes with any gas he used, which contradicted Dalton's assumption that all atoms are indivisible.

He theorized the existence of a particle common to all atoms → using the charged plates on either side of the tube, he showed the particle was negatively charged.

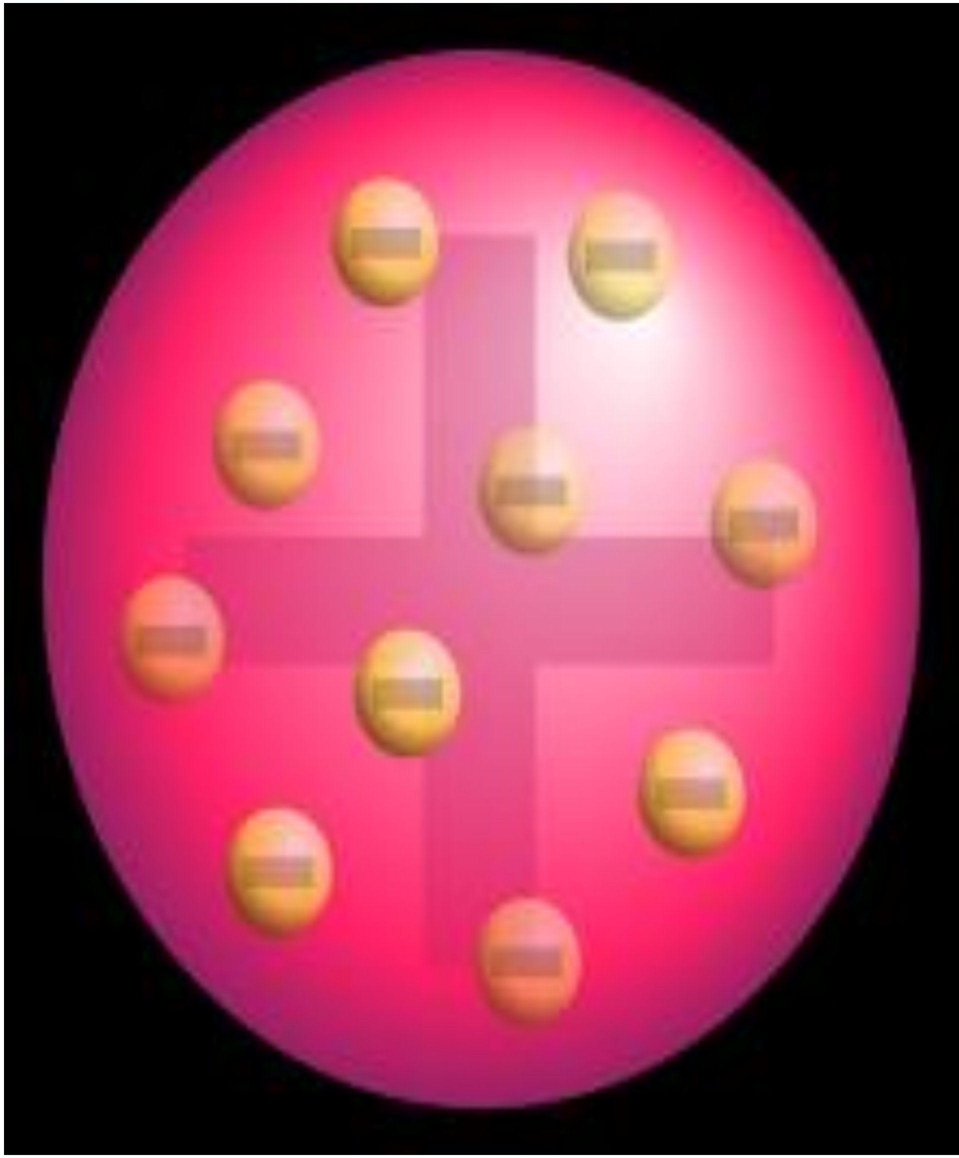


PEARSON

The Plum Pudding Model

Thomson's results led to the proposal of a new atomic model, **the plum pudding model**.

- Electrons floating in a sea of positive charges
- Modification of Dalton's model of a solid, indivisible sphere
- Recognition of the existence of electrons and the neutrality of the whole atom

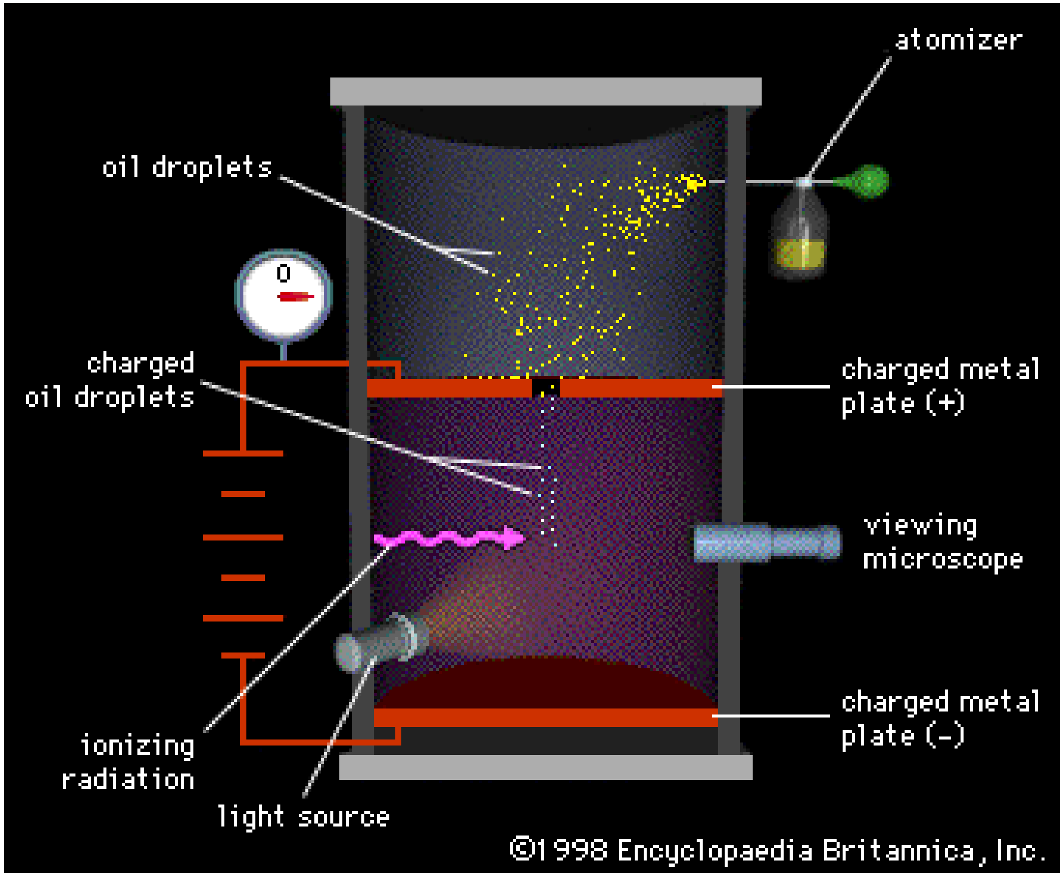


Millikan's Oil Drop Experiment

http://somup.com/cF6eVdnVyl (1:14)

Millikan repeatedly measured charges between the positive and negatively charged plates and found that they were always a multiple of 1.60×10^{-19} coulomb.

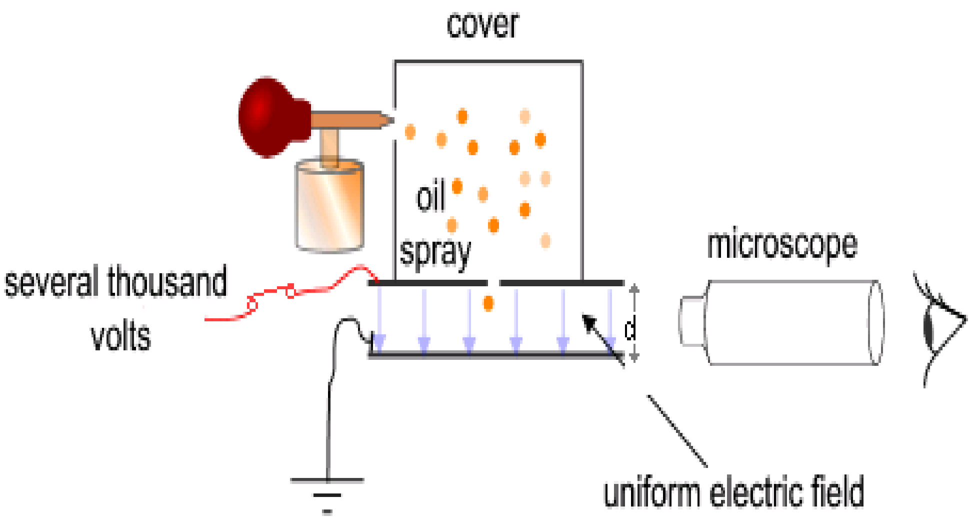
Millikan called this the **charge** on the **electron**.



Millikan’s Oil Drop Experiment

Oil drop experiment

- Measured rate of fall of charged oil droplets
- Determined the **charge** on an electron
- Thomson’s experiment: mass-to-charge ratio for an electron



Millikan's Oil Drop Experiment

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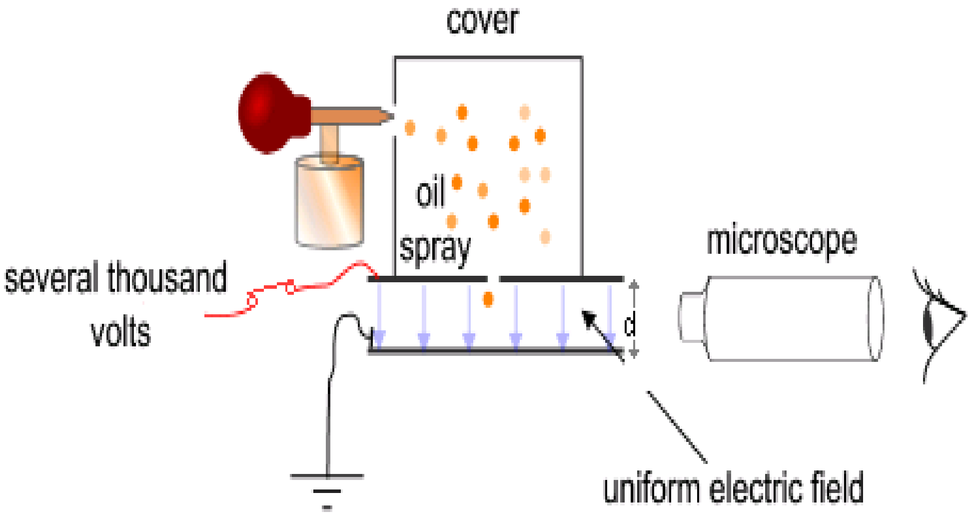


Together, Millikan's and Thomson's results allowed for the determination of the mass and charge of the electron.

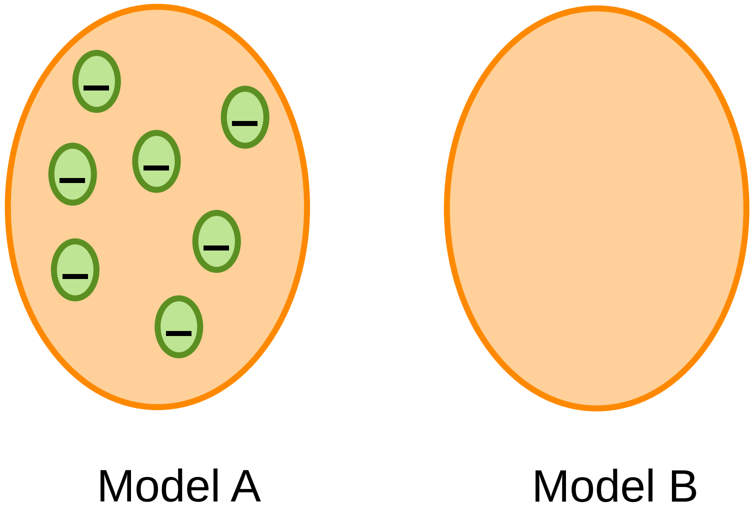
Modify the Theory

QUICK CHECK

The pictures show two different models of the atom.

Which model best represents Dalton’s atomic theory?

Which model best represents the modifications to the theory that Thomson’s results made necessary?



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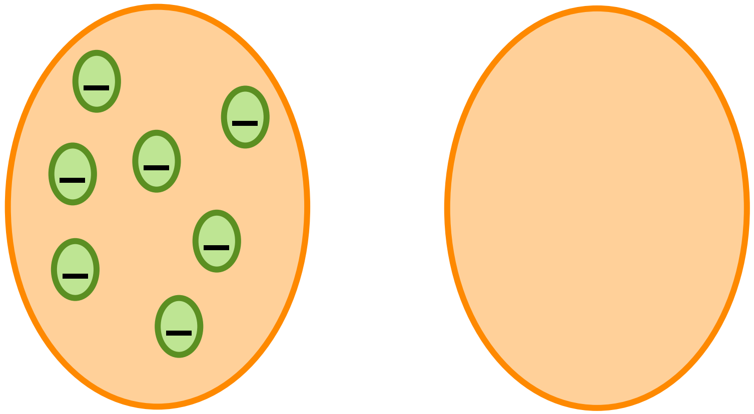


Model A

Model B

Thomson

"plum pudding"

Dalton

Indivisible particle

Testing the Plum Pudding Model

Ernest Rutherford (*right*) developed an experiment to test the plum pudding model of JJ Thomson (*left*).

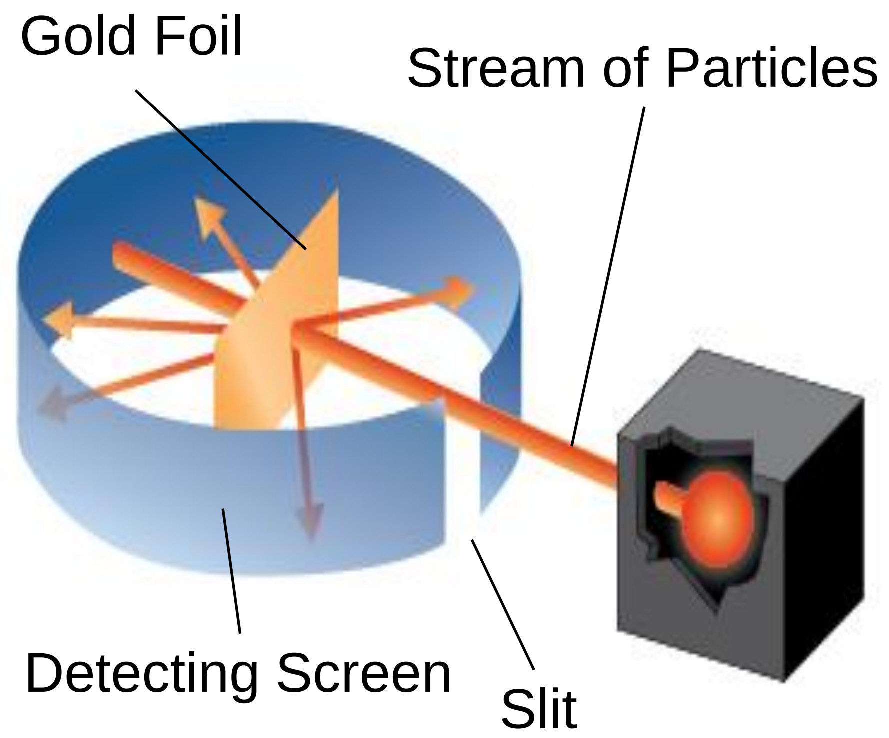
http://somup.com/cF6eVsnVyD
Empty space (0:48)

http://somup.com/cF6eVMnVyb
Rutherford (0:47)

Rutherford’s Experiment (1871–1937)

- He shot alpha particles (+) at a thin sheet of gold foil.

- Reflected particles are detected at various angles.



Rutherford's Results: Discovery of the Nucleus

- Most particles pass straight through gold foil (99%)
- **A few particles deflected at <u>very large angles</u> ???**

Conclusions:

- ?

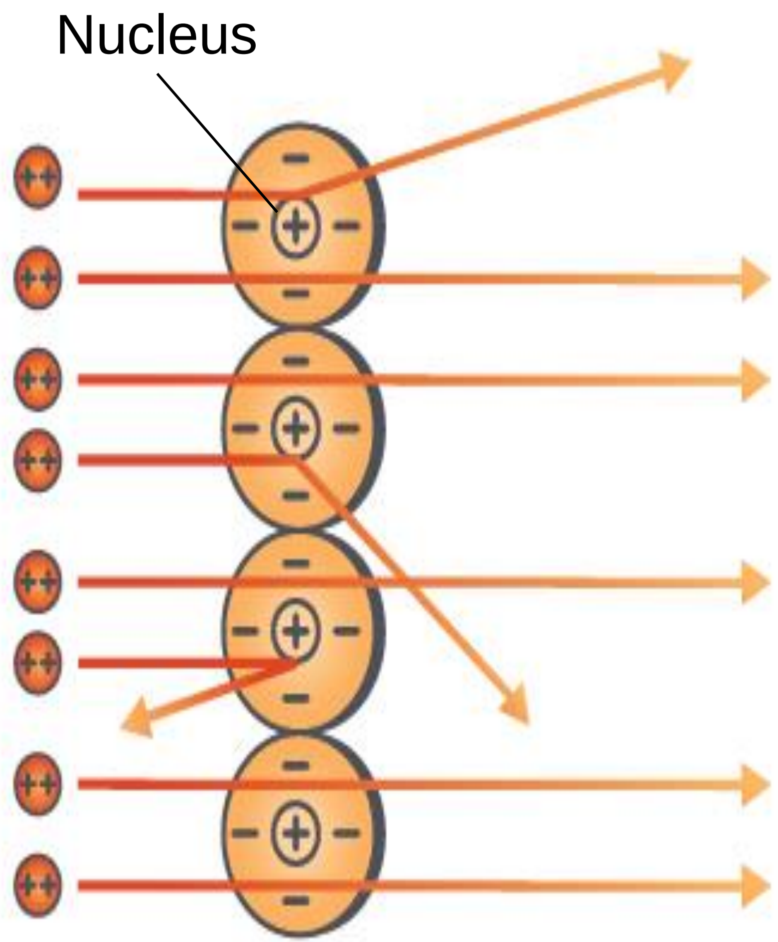


Diagram is not drawn to scale

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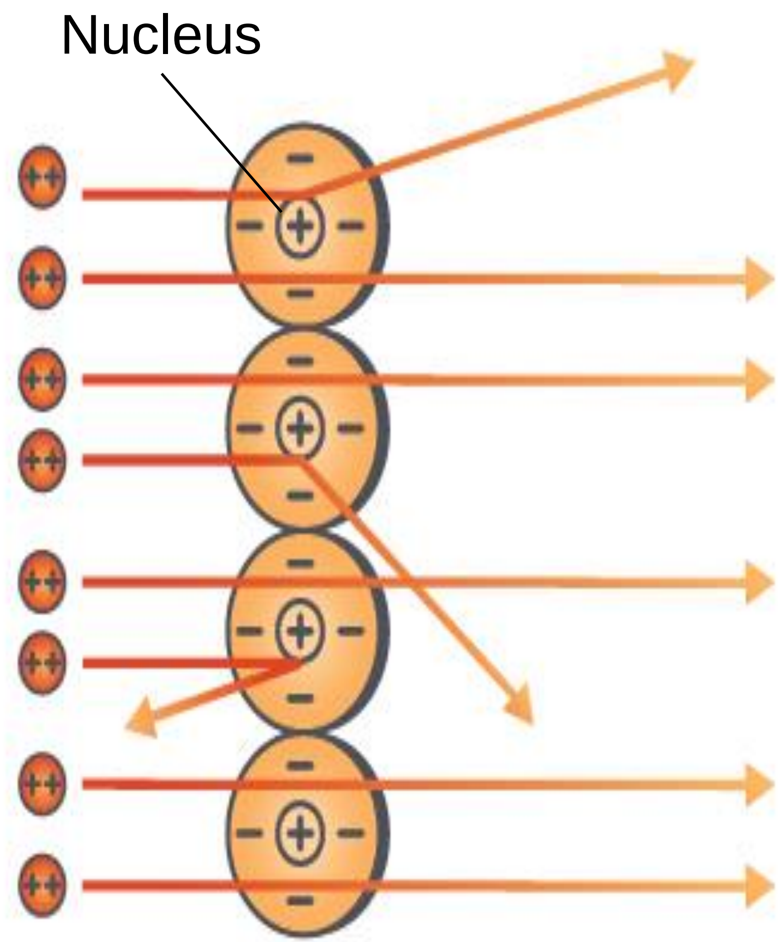
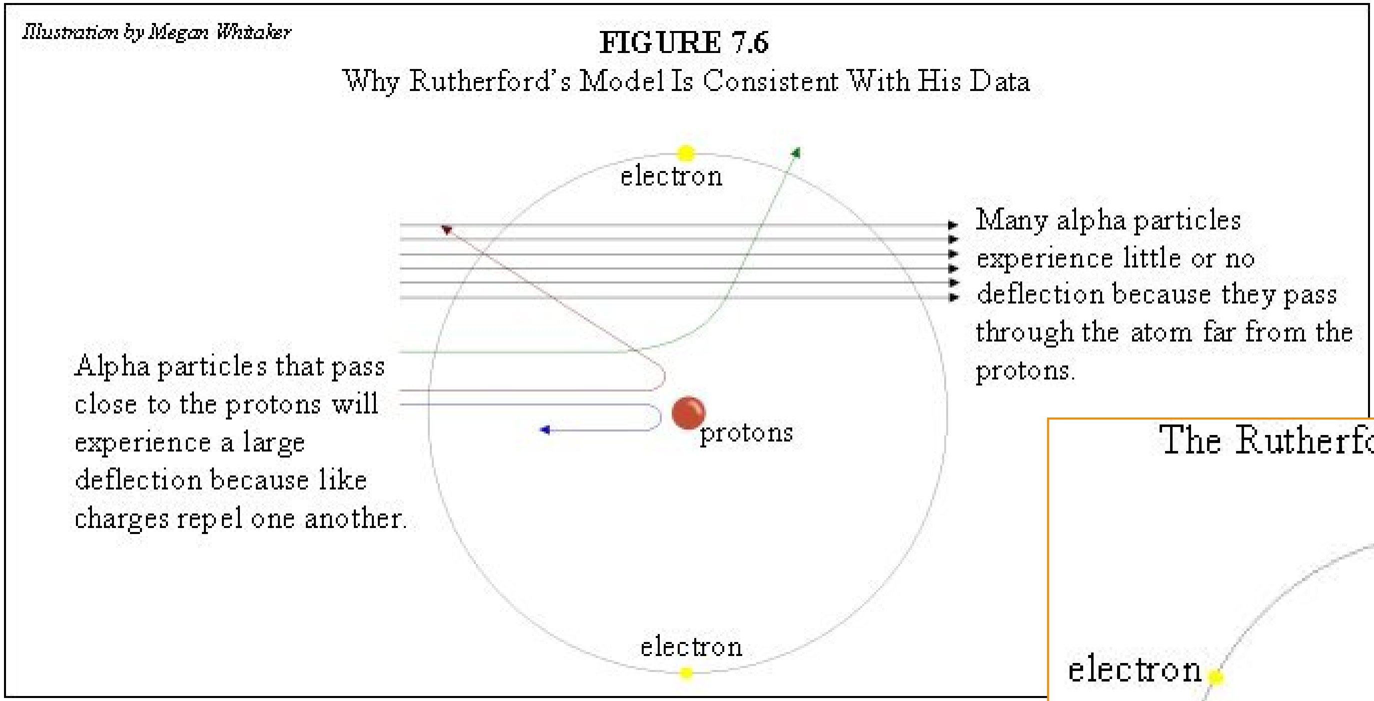


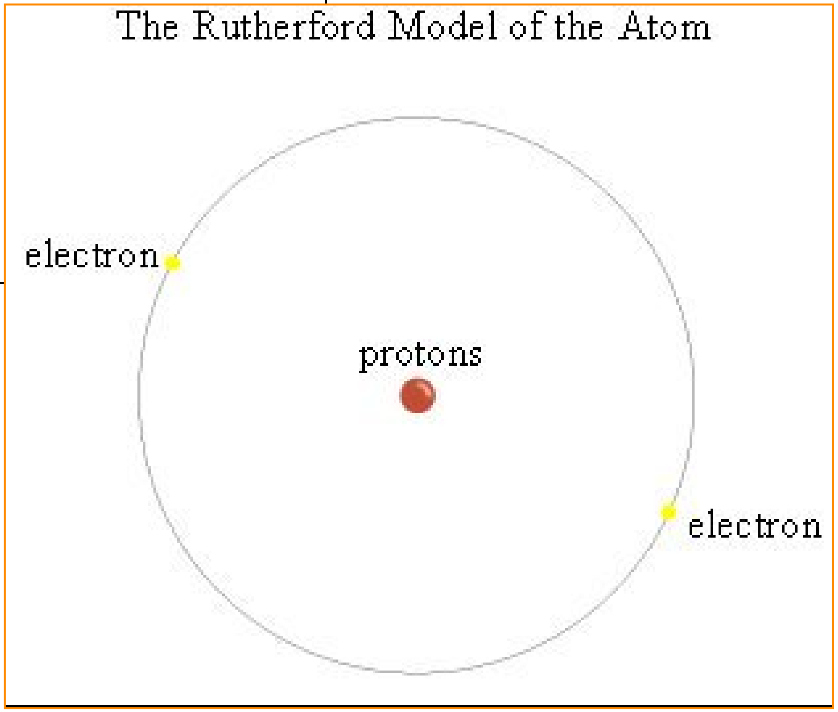
Diagram is not drawn to scale

Conclusions:

- Atom: mostly empty space
- Positive charge is concentrated in small, central region (nucleus)
- Volume of nucleus: small; mass: large

Led to the Initial *Planetary* Model of the Atom





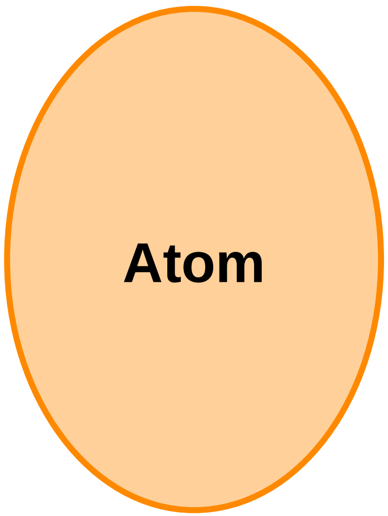
Dense, positive nucleus of atom orbited by electrons

Relative Size of the Hydrogen Atom

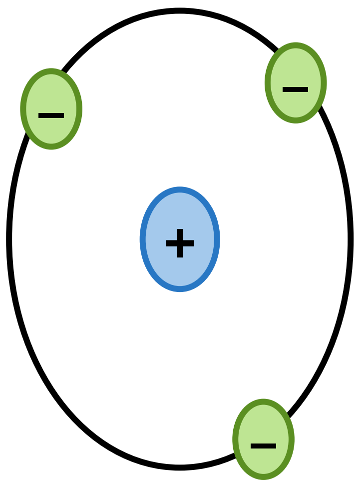
Diameter of the ATOM ~ the size of Houston astrodome with a NUCLEUS the size of a marble

Modifying the Atomic Model

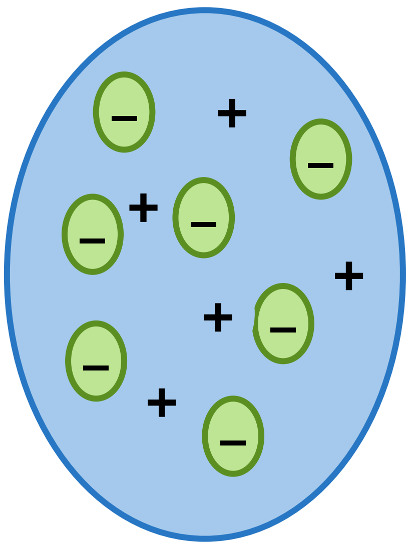
Place the models in chronological order and state who is responsible for each model (Dalton, Rutherford, Thomson)?



A



B



C

Modifying the Atomic Model

QUICK CHECK

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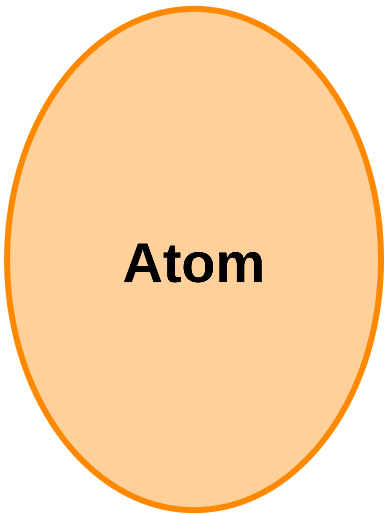
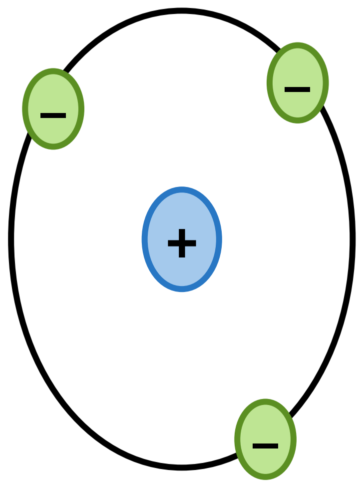


Dalton

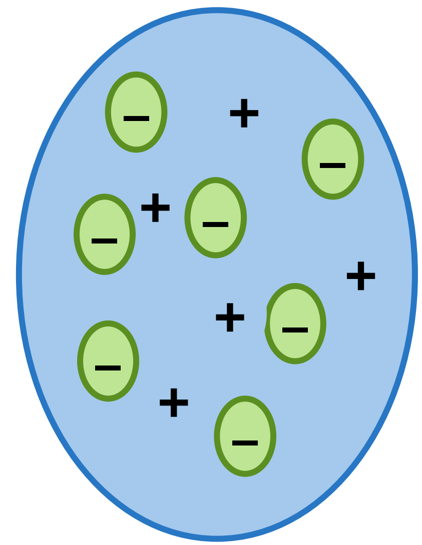
Indivisible particle



Rutherford

“nucleus”

(positive center) with orbiting electrons



Thomson

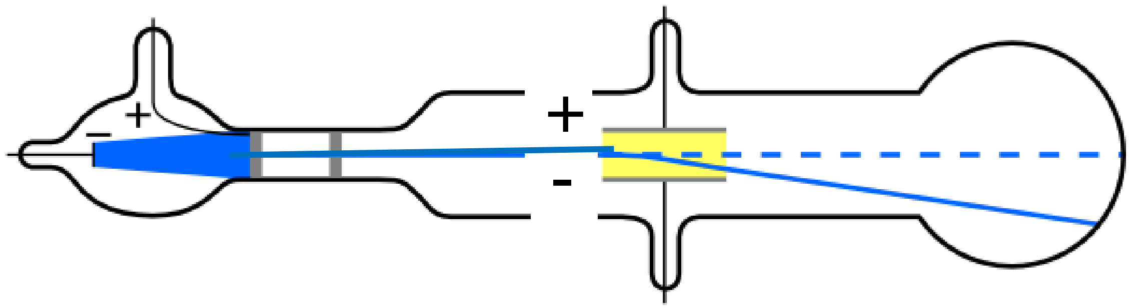
Plum pudding

Protons

In 1886, Eugen Goldstein (1850–1930) observed a cathode-ray tube to discover a new particle.

Protons were originally called "canal rays" in the CRT, electrons were called "cathode rays"

"Canal Rays" responded opposite to the "cathode rays" (electrons) indicating an opposite charge.



Neutrons

Physicist James Chadwick (1891–1974) confirmed the existence of yet another subatomic particle: the neutron.

- Chadwick bombarded Beryllium with alpha particles and found a new particle was released
- **No charge** (*did not deflect under electric or magnetic field influence*)
- Essentially the same mass as the proton
- Highly penetrable particle (*could penetrate 10-20 cm into lead*)

Atomic Mass Unit

The **atomic mass unit** is the unit used to express the mass of an atom.

- One-twelfth the mass of a C-12 atom
- Corresponds to $\mathbf{1.660538921 \times 10^{-24}\ g}$

This table summarizes the properties of the subatomic particles.

Properties of Subatomic Particles

Particle	Symbol	Relative charge	Relative mass (mass of proton = 1)	Actual mass (g)
Electron	e^-	1–	1/1840 amu	9.11×10^{-28}
Proton	p^+	1+	1 amu	1.66×10^{-24}
Neutron	n^0	0	1 amu	1.66×10^{-24}

Atom History Song

http://somup.com/cFQ22rVSKR

Mark Rosengarten Atom History (4:14)

KEY

Relative atomic masses are based on ^{12}C = 12.00000

Atomic Mass	12.0111
Selected Oxidation States	−4, +2, +4
Symbol	**C**
Atomic Number	6
Electron Configuration	$1s^2 2s^2 2p^2$

New Designation

Former Designation (prior to 1984 IUPAC decision)

s-block GROUP 1 IA, 2 IIA

d-block — Transition Elements — GROUP 3 IIIB, 4 IVB, 5 VB, 6 VIB, 7 VIIB, 8, 9, 10 (VIII)

Period	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9	10	
1	1.00794 +1 −1 **H** 1 $1s^1$										
2	6.941 +1 **Li** 3 $1s^2 2s^1$	9.01218 +2 **Be** 4 $1s^2 2s^2$									
3	22.98977 +1 **Na** 11 $[Ne]3s^1$	24.305 +2 **Mg** 12 $[Ne]3s^2$									
4	39.0983 +1 **K** 19 $[Ar]4s^1$	40.08 +2 **Ca** 20 $[Ar]4s^2$	44.9559 +3 **Sc** 21 $[Ar]3d^1 4s^2$	47.88 +2 +3 +4 **Ti** 22 $[Ar]3d^2 4s^2$	50.9415 +2 +3 +4 +5 **V** 23 $[Ar]3d^3 4s^2$	51.996 +2 +3 +6 **Cr** 24 $[Ar]3d^5 4s^1$	54.9380 +2 +3 +4 +7 **Mn** 25 $[Ar]3d^5 4s^2$	55.847 +2 +3 **Fe** 26 $[Ar]3d^6 4s^2$	58.9332 +2 +3 **Co** 27 $[Ar]3d^7 4s^2$	58.69 +2 +3 **Ni** 28 $[Ar]3d^8 4s^2$	63.54 29 [Ar]3d
5	85.4678 +1 **Rb** 37 $[Kr]5s^1$	87.62 +2 **Sr** 38 $[Kr]5s^2$	88.9059 +3 **Y** 39 $[Kr]4d^1 5s^2$	91.224 +4 **Zr** 40 $[Kr]4d^2 5s^2$	92.9064 +3 +5 **Nb** 41 $[Kr]4d^4 5s^1$	95.94 +3 +6 **Mo** 42 $[Kr]4d^5 5s^1$	(98) +4 +6 +7 **Tc** 43 $[Kr]4d^6 5s^1$	101.07 +3 **Ru** 44 $[Kr]4d^7 5s^1$	102.906 +3 **Rh** 45 $[Kr]4d^8 5s^1$	106.42 +2 +4 **Pd** 46 $[Kr]4d^{10} 5s^0$	107.86 47 [Kr]4d
6	132.905 +1 **Cs** 55 $[Xe]6s^1$	137.33 +2 **Ba** 56 $[Xe]6s^2$	**La-Lu** 57 71	178.49 +4 **Hf** 72 $[Xe]4f^{14}5d^2 6s^2$	180.948 +5 **Ta** 73 $[Xe]4f^{14}5d^3 6s^2$	183.85 +6 **W** 74 $[Xe]4f^{14}5d^4 6s^2$	186.207 +4 +6 +7 **Re** 75 $[Xe]4f^{14}5d^5 6s^2$	190.2 +3 +4 **Os** 76 $[Xe]4f^{14}5d^6 6s^2$	192.22 +3 +4 **Ir** 77 $[Xe]4f^{14}5d^7 6s^2$	195.08 +2 +4 **Pt** 78 $[Xe]4f^{14}5d^9 6s^1$	196.96 79 [Xe]4f
7	(223) +1 **Fr** 87 $[Rn]7s^1$	226.025 +2 **Ra** 88 $[Rn]7s^2$	**Ac-Lr** 89 103	(261) **Unq*** 104	(262) **Unp** 105	(263) **Unh** 106	(262) **Uns** 107	**Uno** 108	**Une** 109		

* The sys 103 wil

nasses are
2.00000

ation States

s-block

10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 O
								4.00260 0 **He** 2 $1s^2$
			10.81 +3 **B** 5 $1s^2 2s^2 2p^1$	12.0111 −4 +2 +4 **C** 6 $1s^2 2s^2 2p^2$	14.0067 −3 −2 −1 +1 +2 +3 +4 +5 **N** 7 $1s^2 2s^2 2p^3$	15.9994 −2 **O** 8 $1s^2 2s^2 2p^4$	18.998403 −1 **F** 9 $1s^2 2s^2 2p^5$	20.179 0 **Ne** 10 $1s^2 2s^2 2p^6$
			26.98154 +3 **Al** 13 $[Ne] 3s^2 3p^1$	28.0855 −4 +2 +4 **Si** 14 $[Ne] 3s^2 3p^2$	30.97376 −3 +3 +5 **P** 15 $[Ne] 3s^2 3p^3$	32.06 −2 +4 +6 **S** 16 $[Ne] 3s^2 3p^4$	35.453 −1 +1 +3 +5 +7 **Cl** 17 $[Ne] 3s^2 3p^5$	39.948 0 **Ar** 18 $[Ne] 3s^2 3p^6$
58.69 +2 +3 **Ni** 28 $[Ar] 3d^8 4s^2$	63.546 +1 +2 **Cu** 29 $[Ar] 3d^{10} 4s^1$	65.39 +2 **Zn** 30 $[Ar] 3d^{10} 4s^2$	69.72 +3 **Ga** 31 $[Ar] 3d^{10} 4s^2 4p^1$	72.59 −4 +2 +4 **Ge** 32 $[Ar] 3d^{10} 4s^2 4p^2$	74.9216 −3 +3 +5 **As** 33 $[Ar] 3d^{10} 4s^2 4p^3$	78.96 −2 +4 +6 **Se** 34 $[Ar] 3d^{10} 4s^2 4p^4$	79.904 −1 +1 +5 **Br** 35 $[Ar] 3d^{10} 4s^2 4p^5$	83.80 0 +2 **Kr** 36 $[Ar] 3d^{10} 4s^2 4p^6$
106.42 +2 +4 **Pd** 46 $[Kr] 4d^{10} 5s^0$	107.868 +1 **Ag** 47 $[Kr] 4d^{10} 5s^1$	112.41 +2 **Cd** 48 $[Kr] 4d^{10} 5s^2$	114.82 +3 **In** 49 $[Kr] 4d^{10} 5s^2 5p^1$	118.71 +2 +4 **Sn** 50 $[Kr] 4d^{10} 5s^2 5p^2$	121.75 −3 +3 +5 **Sb** 51 $[Kr] 4d^{10} 5s^2 5p^3$	127.60 −2 +4 +6 **Te** 52 $[Kr] 4d^{10} 5s^2 5p^4$	126.905 −1 +1 +5 +7 **I** 53 $[Kr] 4d^{10} 5s^2 5p^5$	131.29 0 +2 +4 +6 **Xe** 54 $[Kr] 4d^{10} 5s^2 5p^6$
195.08 +2 +4 **Pt** 78 $[Xe] 4f^{14} 5d^9 6s^1$	196.967 +1 +3 **Au** 79 $[Xe] 4f^{14} 5d^{10} 6s^1$	200.59 +1 +2 **Hg** 80 $[Xe] 4f^{14} 5d^{10} 6s^2$	204.383 +1 +3 **Tl** 81 $[Xe] 4f^{14} 5d^{10} 6s^2 6p^1$	207.2 +2 +4 **Pb** 82 $[Xe] 4f^{14} 5d^{10} 6s^2 6p^2$	208.980 +3 +5 **Bi** 83 $[Xe] 4f^{14} 5d^{10} 6s^2 6p^3$	(209) +2 +4 **Po** 84 $[Xe] 4f^{14} 5d^{10} 6s^2 6p^4$	(210) **At** 85 $[Xe] 4f^{14} 5d^{10} 6s^2 6p^5$	(222) 0 **Rn** 86 $[Xe] 4f^{14} 5d^{10} 6s^2 6p^6$

p-block

GROUP