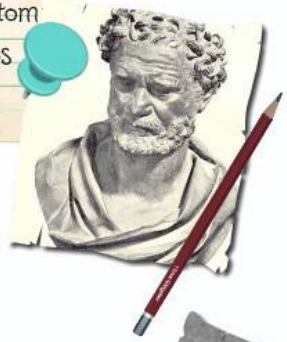
What is Atom?

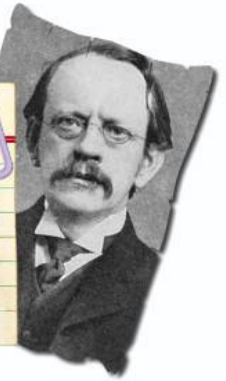
Democritus said that all atom are small, hard particles

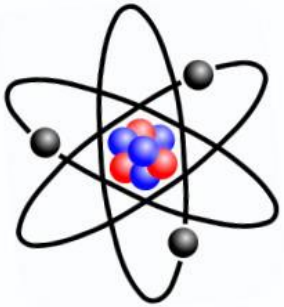


John Dalton developed his atomic theory from observations of many experiments

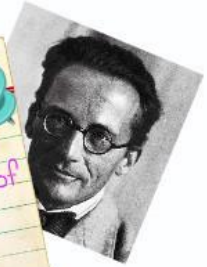
Glogster

J.J Thomson discovered that there are small particles inside the atom.





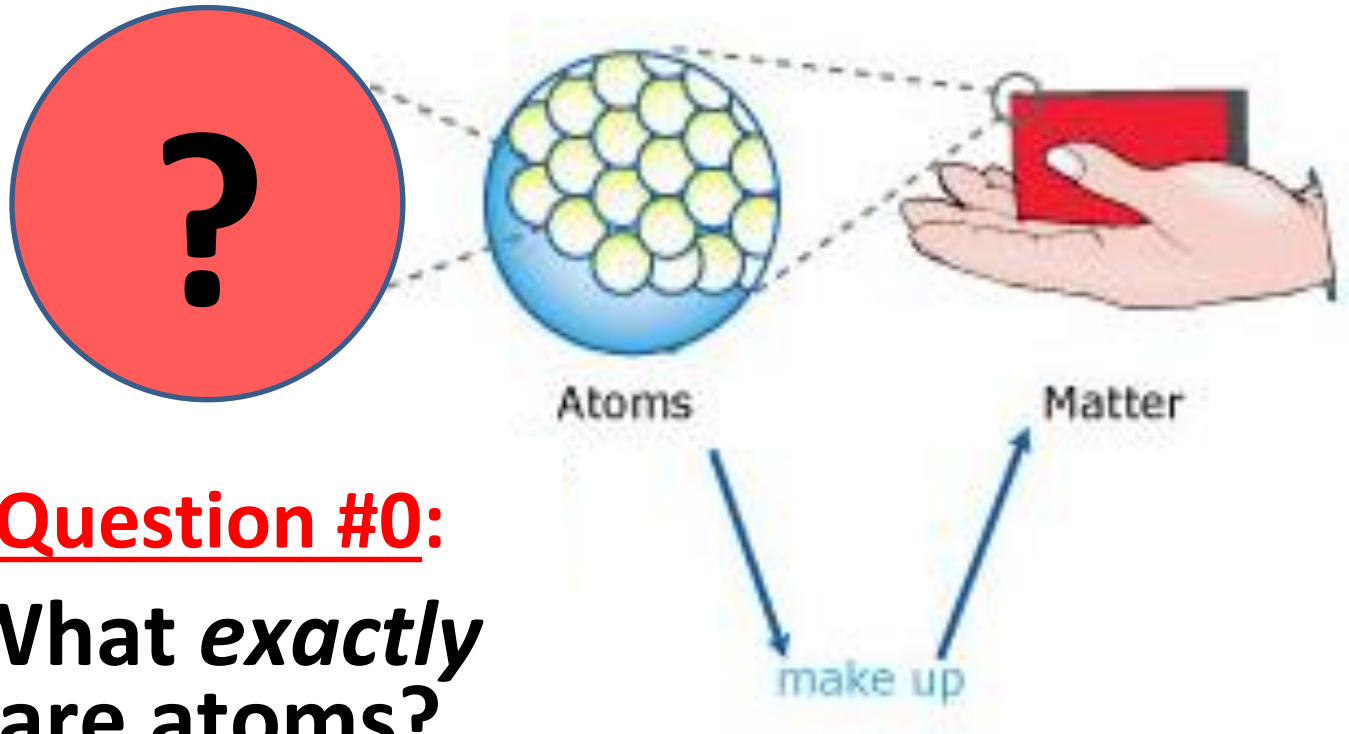
Schodinger and Heisenberg further explained the nature of electrons in the atom



Rutherford decided to test Thomson's theory by an experiment to study the parts of an atom

Bohr's results led him to propose that electorns move around nucleus in certain paths or energy levels.

Structure of Matter



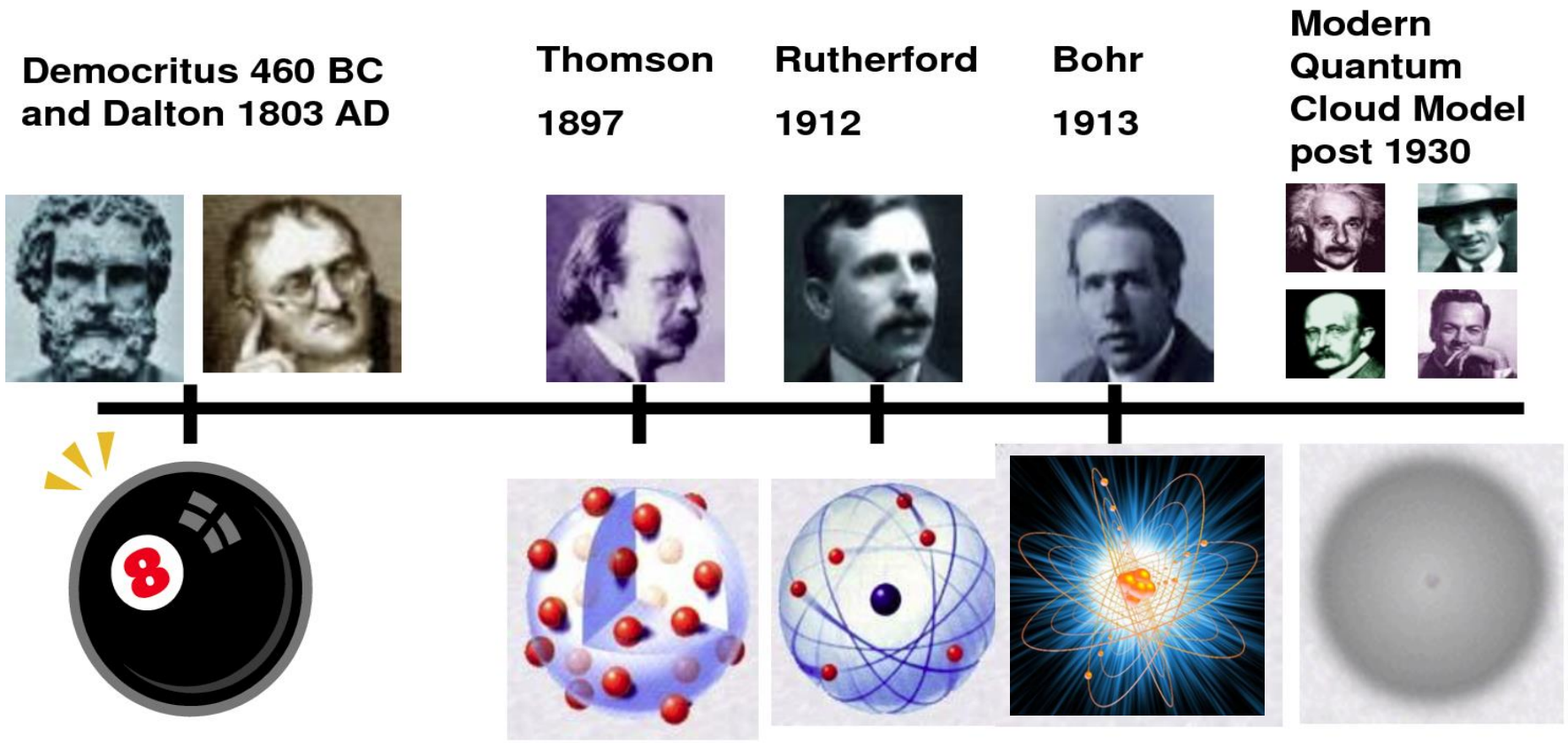
Question #0:

What *exactly* are atoms?

Are they all the same?

If not, what makes them different?

Atomic Theory Development



Born **as early as 400 BC**, it took more than 2000 years before Science was ready to accept the idea of atomic structure of matter…***and another 150 years to develop a good model!***

What is a Model?

- In Science, a model is a physical, mathematical, or conceptual (abstract) representation of a real phenomenon that is difficult to observe directly – that is, a *convenient substitute*.
- Scientific models are used in a variety of scientific disciplines to explain and predict the behavior of real objects or systems.
- A model is a basic element of the scientific method: both theory and hypothesis often take form of an abstract model.
- Scientific models are approximations of the objects and systems that they represent; scientists are constantly working to improve and refine models.
- Building and disputing models is an essential and inseparable part of scientific activity. It is important to be able to recognize models when you see them and appreciate their limitations.

A Model is Never Perfect

essentially,
all models are wrong,
but some are useful

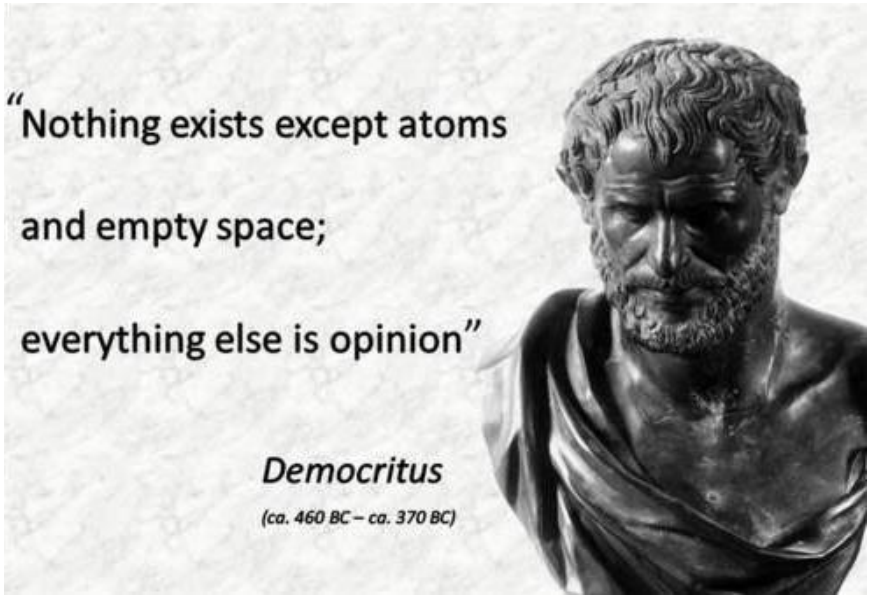
George E. P. Box

(one of the most influential statisticians of the 20th century)

Scientific models are approximations of the objects and systems that they represent!

Scientists are constantly working to improve and refine models.

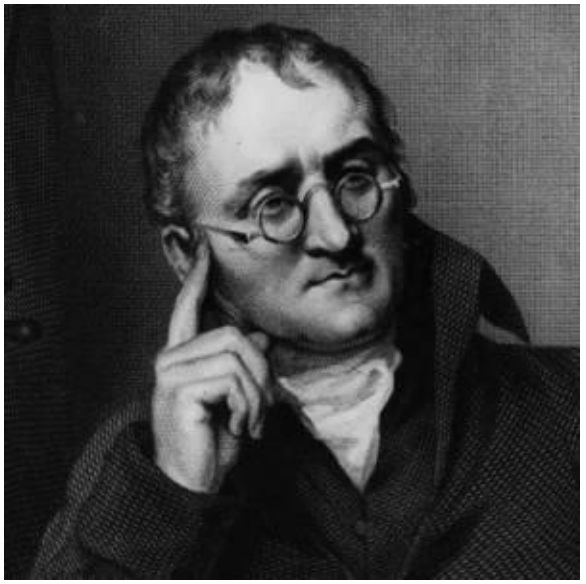
Democritus
~400 BC



"atomos"="not to be cut"

- **Matter could not be divided into smaller and smaller pieces forever, eventually the smallest possible piece would be obtained.**
- **This piece, atomos (atom), would be indivisible.**
- **Between atoms, there would be empty space.**
- **To Democritus, atoms were small, hard particles of different shapes and sizes that were all made of the same material.**
- **Atoms were infinite in number, always moving and capable of joining together.**

John Dalton
early 1800s



The first truly scientific theory of the atom: conclusions were reached by experimentation and examination of the results in an empirical fashion.

- **All elements are composed of atoms.**
- **Atoms are indivisible and indestructible particles.**
- **Atom model: a billiard ball or a *marble*.**

Color?
Size?

Mass!

HOW?

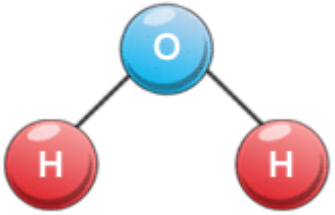
- **Atoms of the same element are exactly alike.**
- **Atoms of different elements are different.**
- **Compounds are formed by the joining of atoms of two or more elements.**

How to find Atomic Weight?

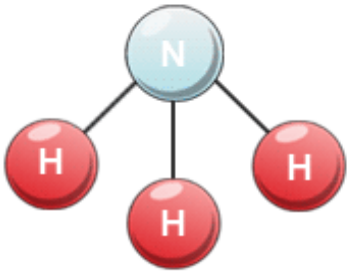
- **Assumption #1**: atoms of a given chemical element are identical in size, **mass**, and all other properties.

- **Assumption #2**: chemical **compounds** are formed when atoms of different elements combine in simple whole-number ratios.

WATER

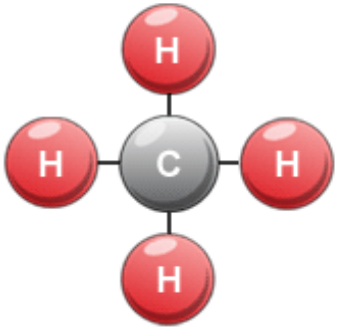


AMMONIA



CARBON DIOXIDE

METHANE



Atomic weights of elements can be determined by careful *weighing* of chemical reactions!

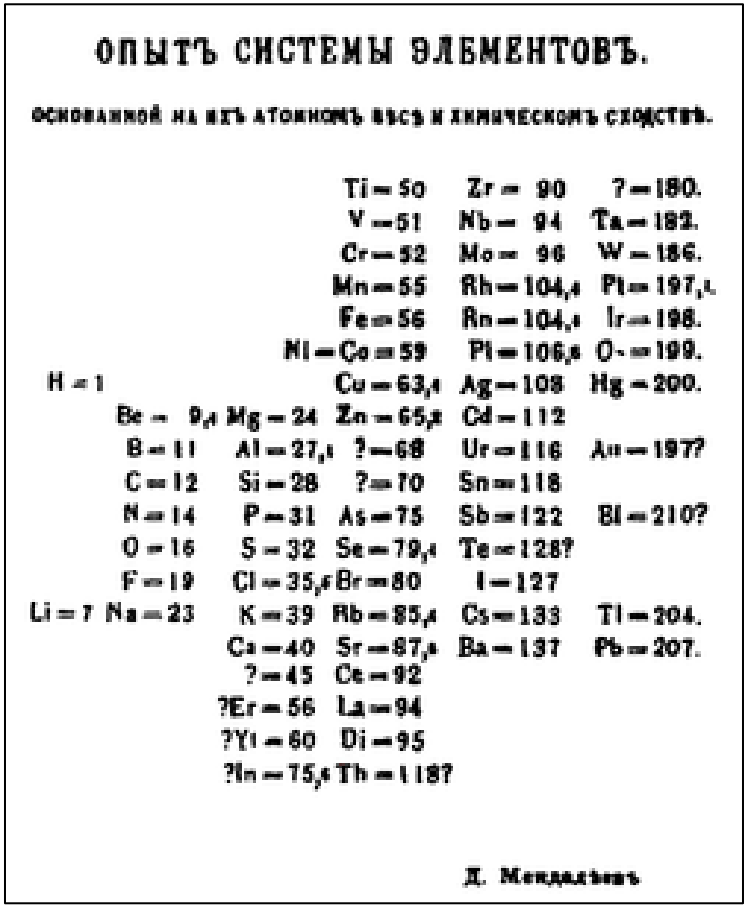
John Dalton

- **1803-1805**: first *list* of relative atomic weights containing just 6 elements, namely *hydrogen* (conventionally assumed to weigh 1), *oxygen, nitrogen, carbon, sulfur,* and *phosphorus*.

- **1808**: expanded list of elements

Dmitri Mendeleev

- **1869**: original periodic *table* of 66 elements ordered and grouped according to their atomic weight.



ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti = 50	Zr = 90	? = 180.	
			V = 51	Nb = 94	Ta = 182.	
			Cr = 52	Mo = 96	W = 186.	
			Mn = 55	Rh = 104,4	Pt = 197,1.	
			Fe = 56	Ru = 104,4	Ir = 198.	
			Ni = Co = 59	Pl = 106,6	O = 199.	
H = 1			Cu = 63,4	Ag = 108	Hg = 200.	
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112		
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?	
	C = 12	Si = 28	? = 70	Sn = 118		
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?	
	O = 16	S = 32	Se = 79,4	Te = 128?		
	F = 19	Cl = 35,5	Br = 80	I = 127		
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204.	
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207.	
		? = 45	Ce = 92			
		?Er = 56	La = 94			
		?Yt = 60	Di = 95			
		?In = 75,6	Th = 118?			

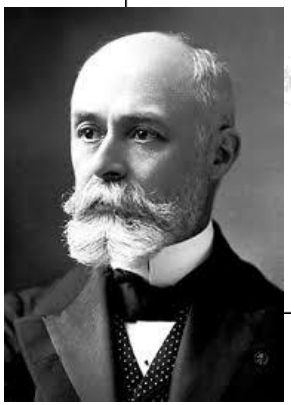
Д. Менделѣевъ

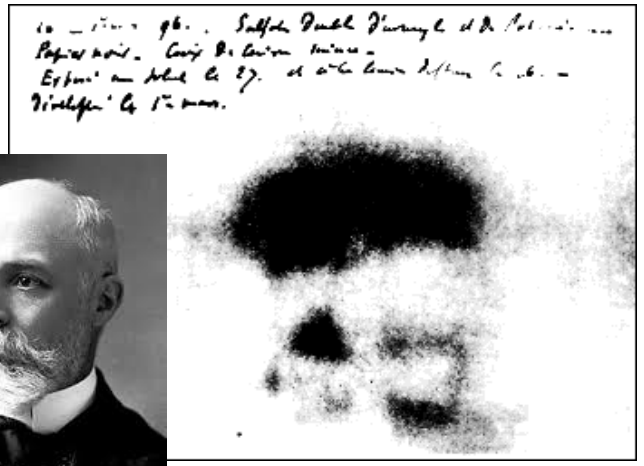
How can we study *the inside* of atom?

See what "comes out"!

- **Electric current – originates within matter; can flow through matter but also…in vacuum!**
  - **Cathode rays, 1869: streams of *something travelling in straight lines* observed in vacuum tubes when voltage is applied across the evacuated tube equipped with two electrodes.**
- **Radioactivity (alpha, beta, gamma)**
  - **Henri Becquerel, 1896:**

    - radioactivity was first discovered in uranium salts during his work on phosphorescence.
- **Light** (later!)



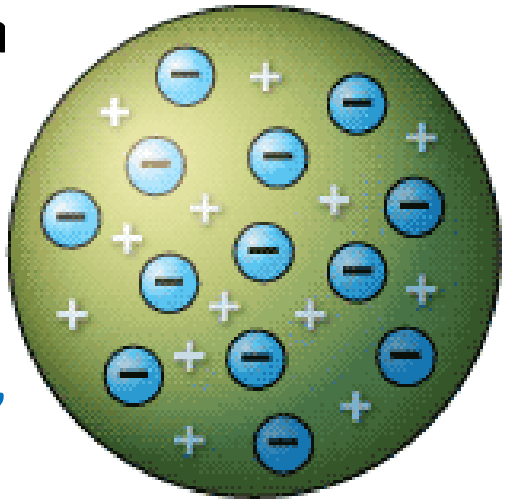


Discovery of Electron

Joseph John Thomson

1897: Studying cathode rays, Thomson detected charged particles that were around 1800 times lighter than the lightest atom, hydrogen. Therefore they were not atoms, but a new particle, the first subatomic particle to be discovered. Originally it was called "corpuscle" but was later named *electron*.

- **many elements were shown to emit electrons…**
- **…all atoms must contain electrons as universal building blocks**
- **atoms are neutral, so there must be a balancing "cloud" of opposite charge**



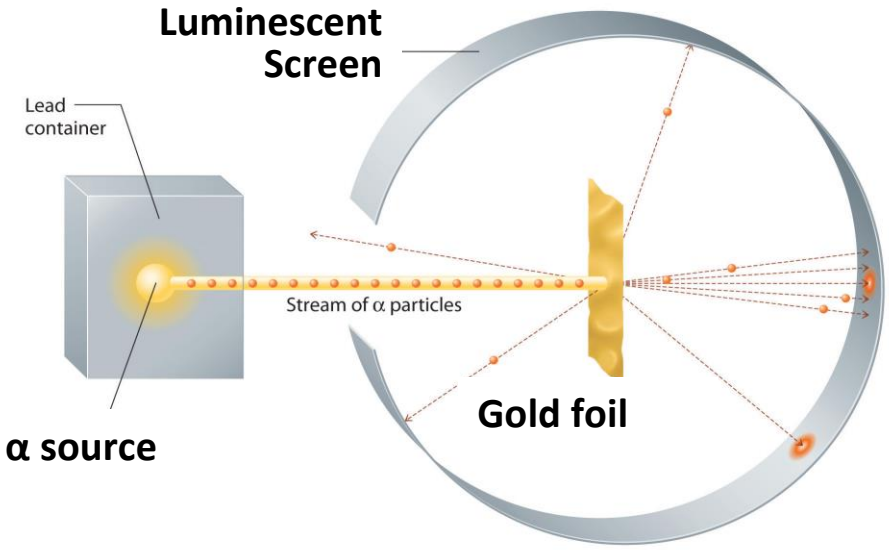
Plum Pudding Model, 1904

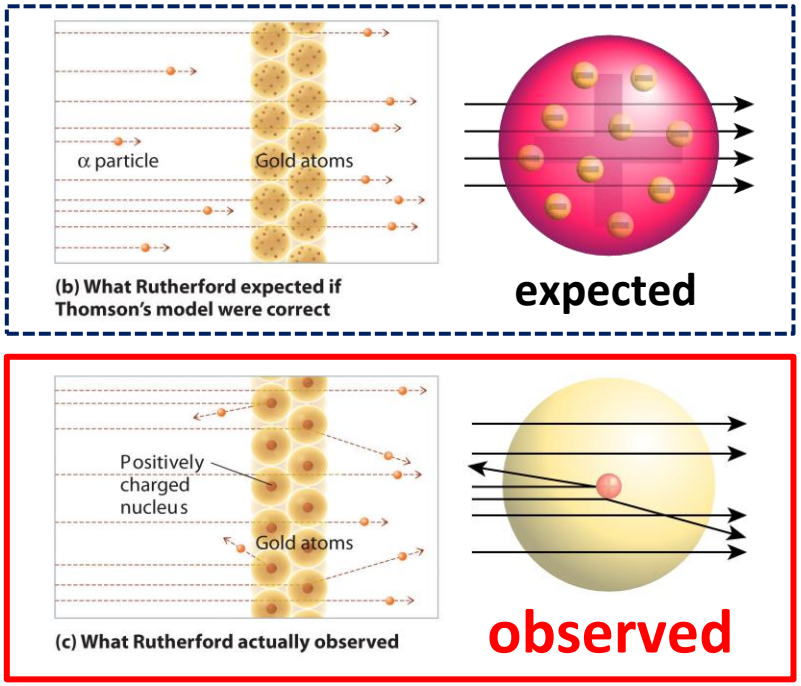
1906 Nobel prize in Physics

Discovery of the Nucleus

Rutherford (Geiger–Marsden), 1908-1913: Gold Foil Experiment

- "Father of nuclear physics"
- Bombarded a thin metal foil with alpha particles. A majority of the particles passed through the sheet, but a small percentage were deflected.

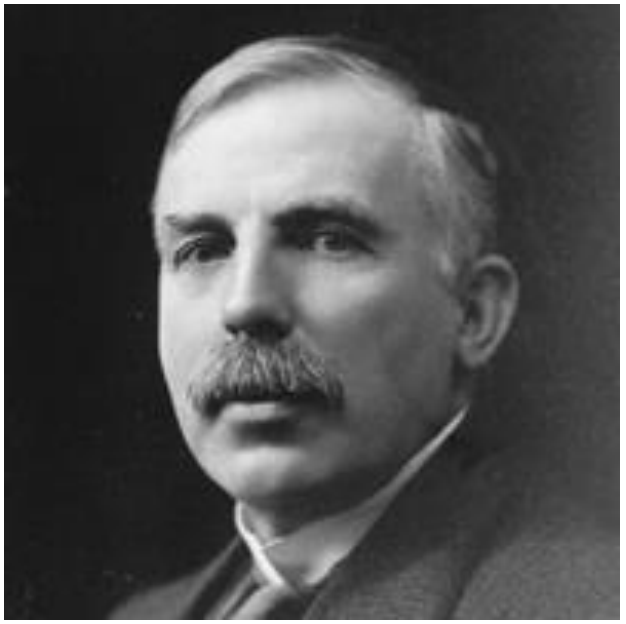




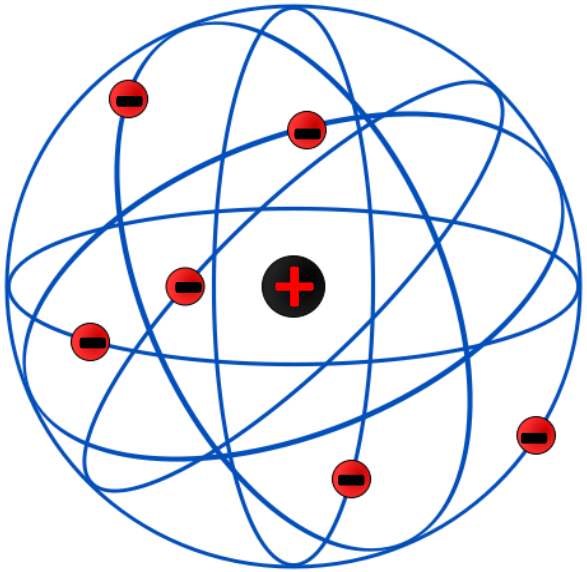
- **Rutherford's conclusion:** "the greater part of the mass of the atom was concentrated in a minute nucleus… carrying a charge".

Rutherford Model

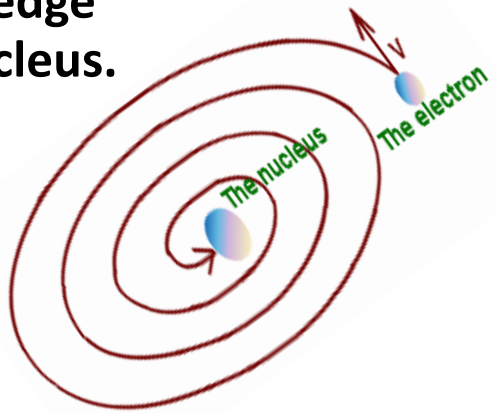
Ernest Rutherford, 1912



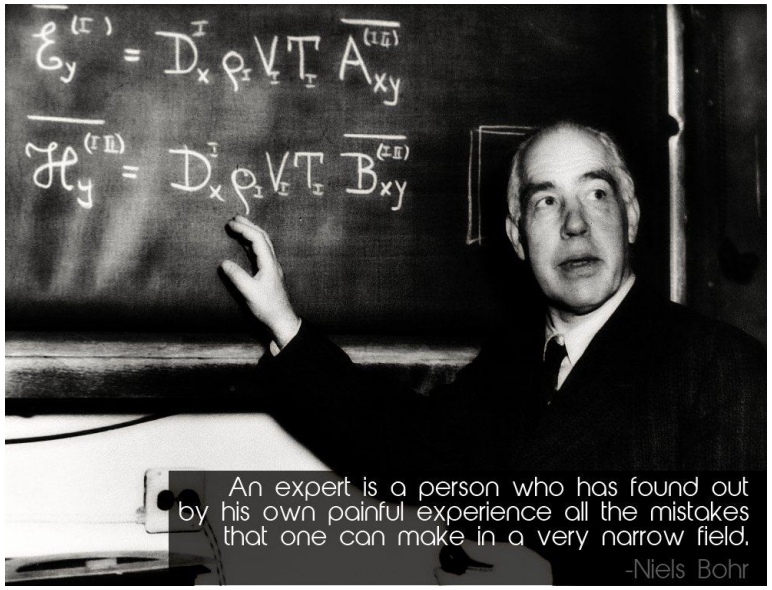
The outcome of Gold Foil Experiment led Rutherford to conclusion: "the greater part of the mass of the atom was concentrated in a minute nucleus… carrying a (positive) charge".



- **In Rutherford's model the atom consisted predominantly of empty space.**
- **The negatively charged particles were scattered around the atom's edge (presumably) orbiting the nucleus.**
- **A problem: the model could not explain the stability of an atom - revolving electrons should emit energy and spirally fall on the nucleus…**

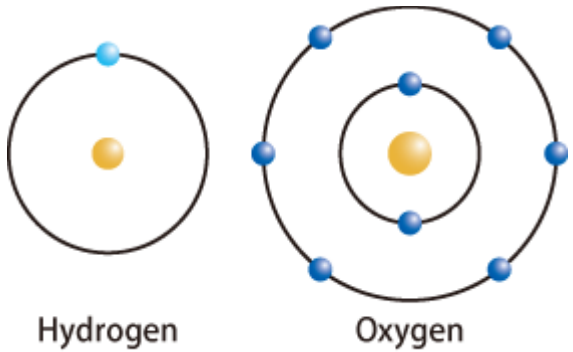


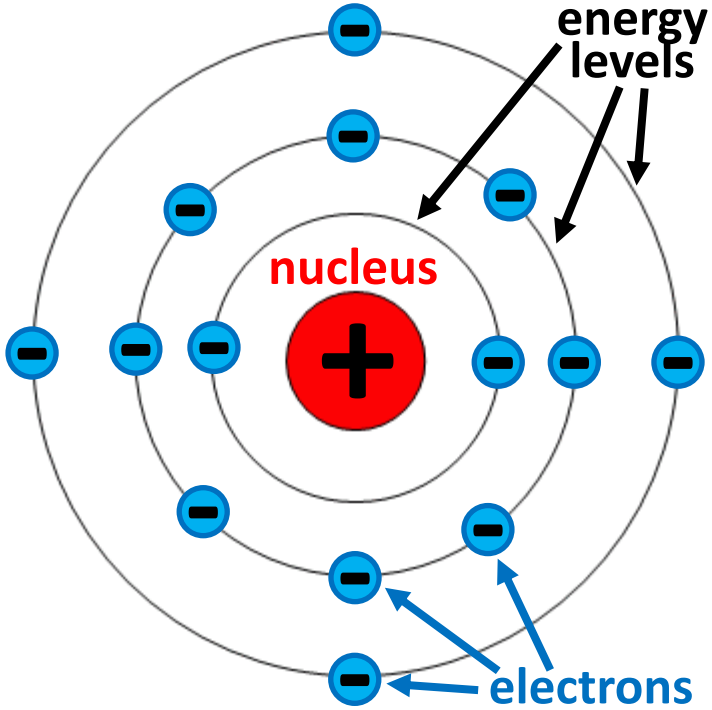
Planetary Model
Niels Bohr, 1913



Electrons move in definite orbits around the nucleus, much like planets circle the Sun.

- **These circular orbits, or energy levels, are located at certain distances from the nucleus.**
- **Electrons can jump between levels emitting (or absorbing) energy.**



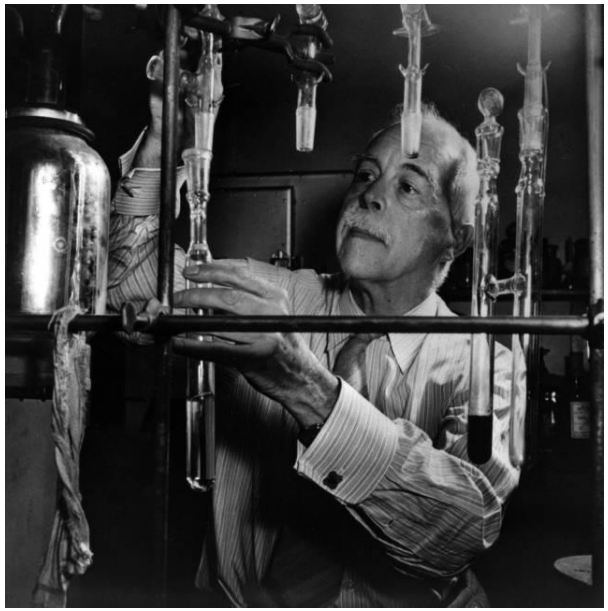


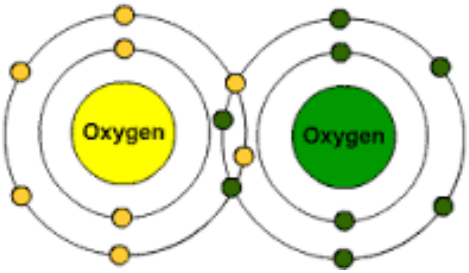
Here comes Quantum Theory…

Chemical Bond Explained

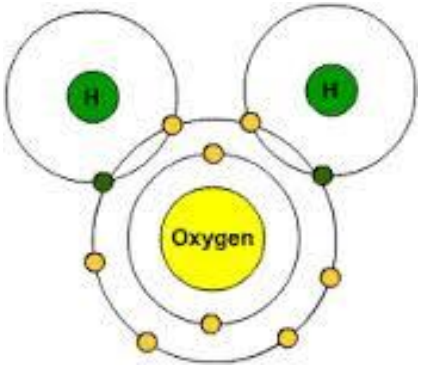
Gilbert Newton Lewis, 1916:

a covalent bond between two atoms is maintained by a pair of electrons shared between them.

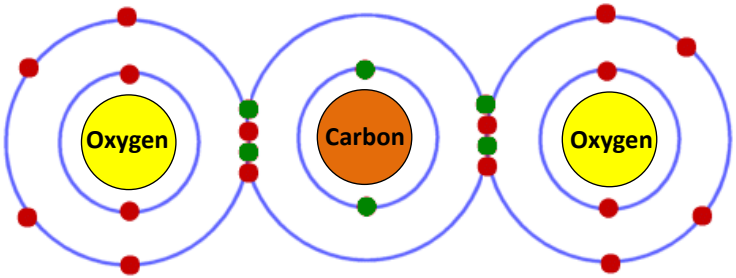




Oxygen molecule



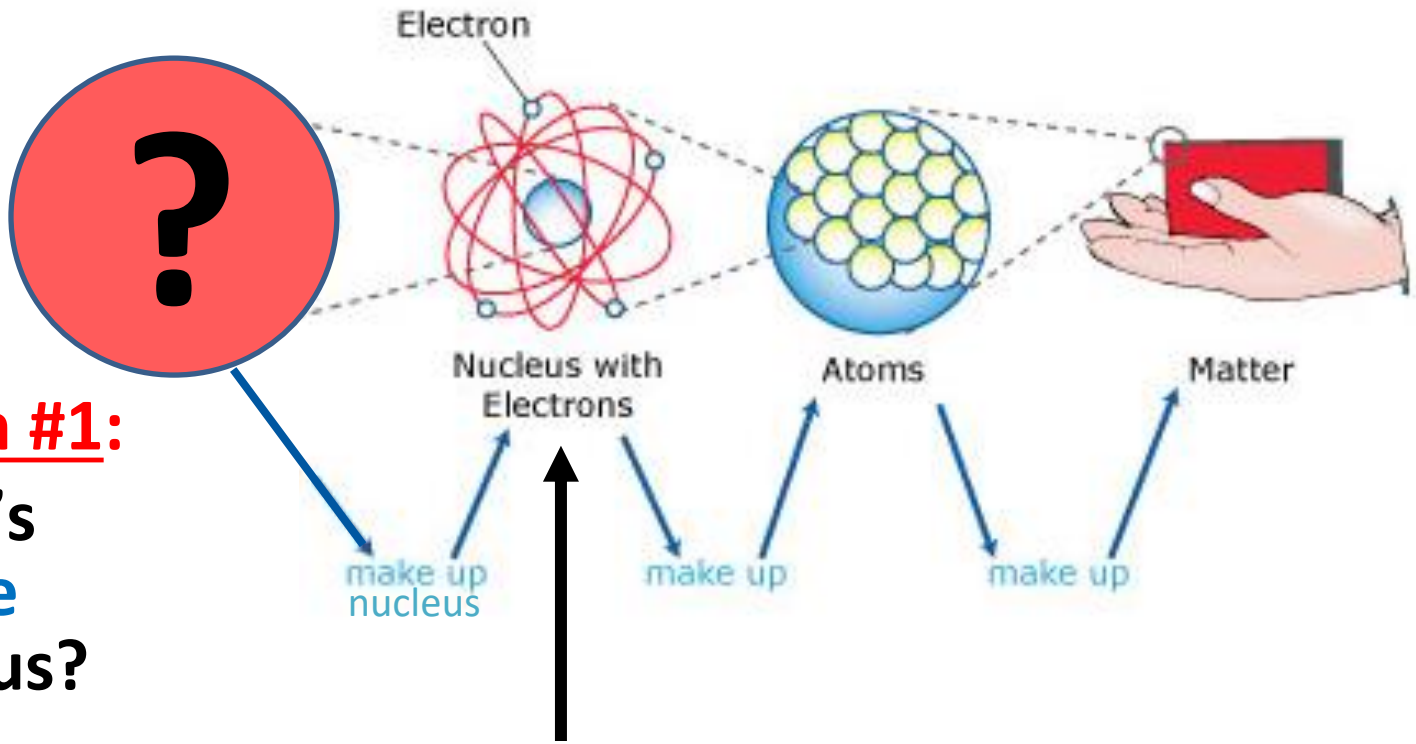
Water



Carbon dioxide

Although nominated 35 times (!), Lewis *never won* the Nobel Prize in Chemistry…

Summary: Structure of Matter



Question #1:

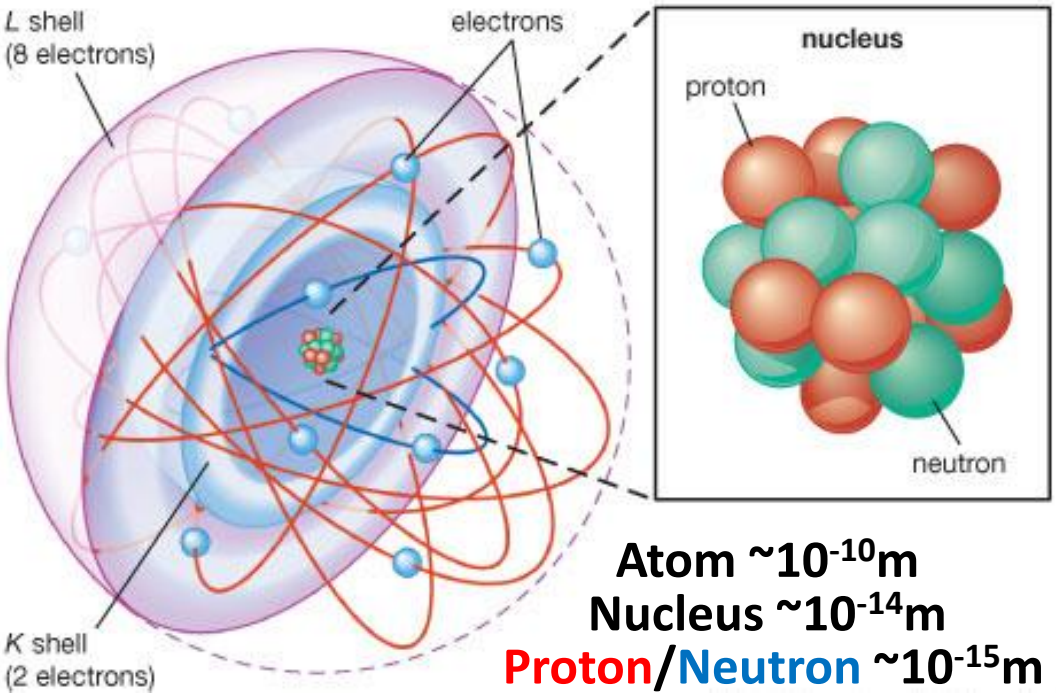
What's inside a nucleus?

Question #2: Is planetary model of the atom *good enough* to explain all experimental observations?

Shell Model (Bohr-Sommerfeld, 1915)

German theoretical physicist Arnold Sommerfeld introduced a certain modification of the Bohr model to explain the fine spectroscopic structure (later about that!) of some elements:

- **Elliptical electron orbits form electron shells.**
- **Orbits within a shell are slightly different.**
- **Each shell can contain only a fixed number of electrons: the n^{th} shell can in principle hold up to $2n^2$ electrons.**



Atom ~10^{-10}m
Nucleus ~10^{-14}m
Proton/Neutron ~10^{-15}m
Electron <10^{-18}m

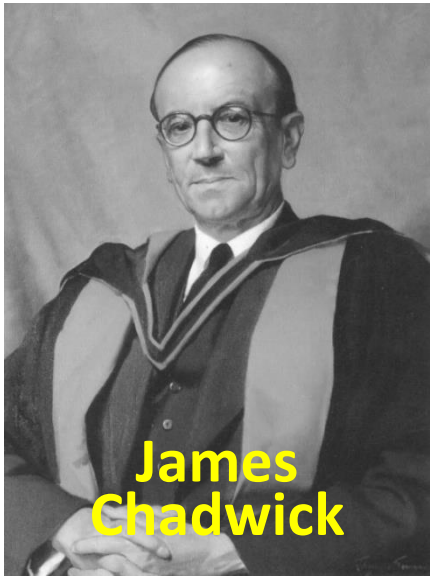
- **The electron shells are labeled K, L, M, N, O, P, and Q (or 1, 2, 3, 4, 5, 6, and 7) starting from the innermost.**

Rutherford Transmutation Experiments

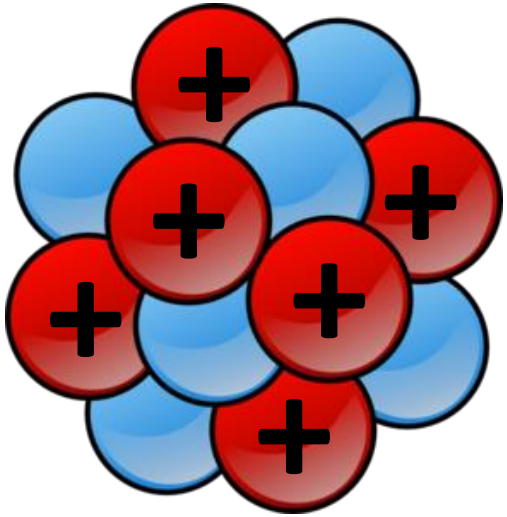
- **1919: "splitting the atom" - it is possible to change one element into another by striking it with energetic alpha particles.**
- **Early 1920's: a number of experiments, *transmuting* one atom into another (*ex. Nitrogen into Oxygen etc.*)**
  - **Observation #1: in every case, hydrogen nuclei were emitted in the process.**
  - **Therefore hydrogen nucleus must play a fundamental role in atomic structure.**
  - **Observation #2: the positive charge of any nucleus could be accounted for by an integer number of hydrogen nuclei.**
  - **Observation #3: the total mass of any given atomic nucleus IS LARGER than the total mass of the number of hydrogen nuclei corresponding to its charge.**
  - **Therefore the nucleus must also contain a neutral particle.**

Inside a Nucleus

- Rutherford, 1920: discovery of a **proton** (Greek: "first"), a **positively charged** subatomic particle.
- 1920-1932: search for a *neutral* particle.
- Chadwick, 1932: detected **zero charged** particles with about the same mass as the proton, eventually called **neutron** (**1935 Nobel Prize in Physics**).



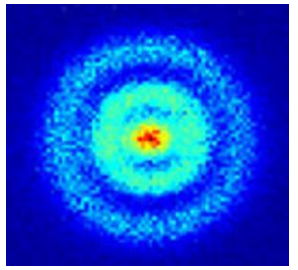
Atomic Nucleus Structure



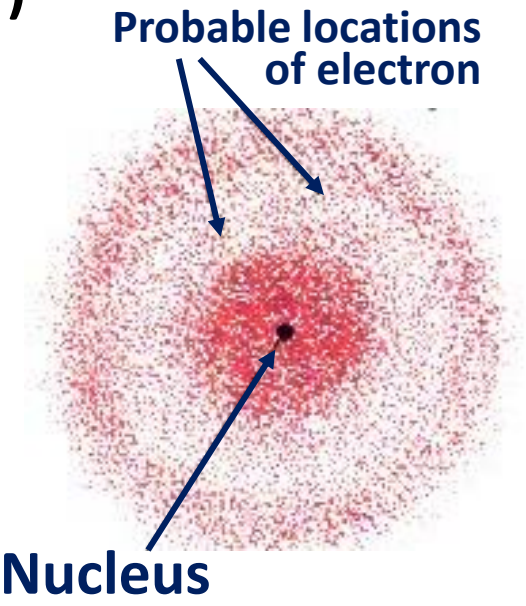
Atom ~10^{-10}m

Nucleus ~10^{-14}m
Proton ~10^{-15}m
Neutron ~10^{-15}m

Wave Model of the Atom
(contemporary model)



Atom has a small positively charged nucleus surrounded by a large region (*"electron cloud"*) in which there are enough electrons to make an atom neutral.



Quantum Theory states that the electrons inside an atom possess both particle- and wave-like properties:

- **There is always an integer number of electrons orbiting the nucleus.**
- **It is impossible to determine the exact location of an electron. Electrons do not have a definite path around the nucleus. The probable location of an electron is based on how much energy it has.**
- **The modern term "atomic orbital" refers to the physical region or space where the electron can be calculated to be present.**
- **Electrons whirl about the nucleus billions of times in one second and can jump between orbitals in a particle-like fashion, losing or gaining energy.**