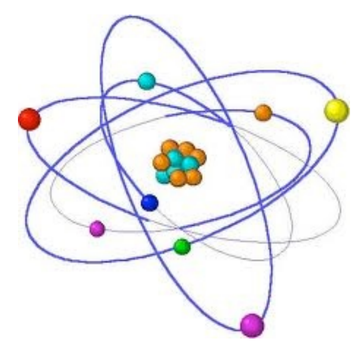
Ch05

Atomic Theory

The story of the atom.

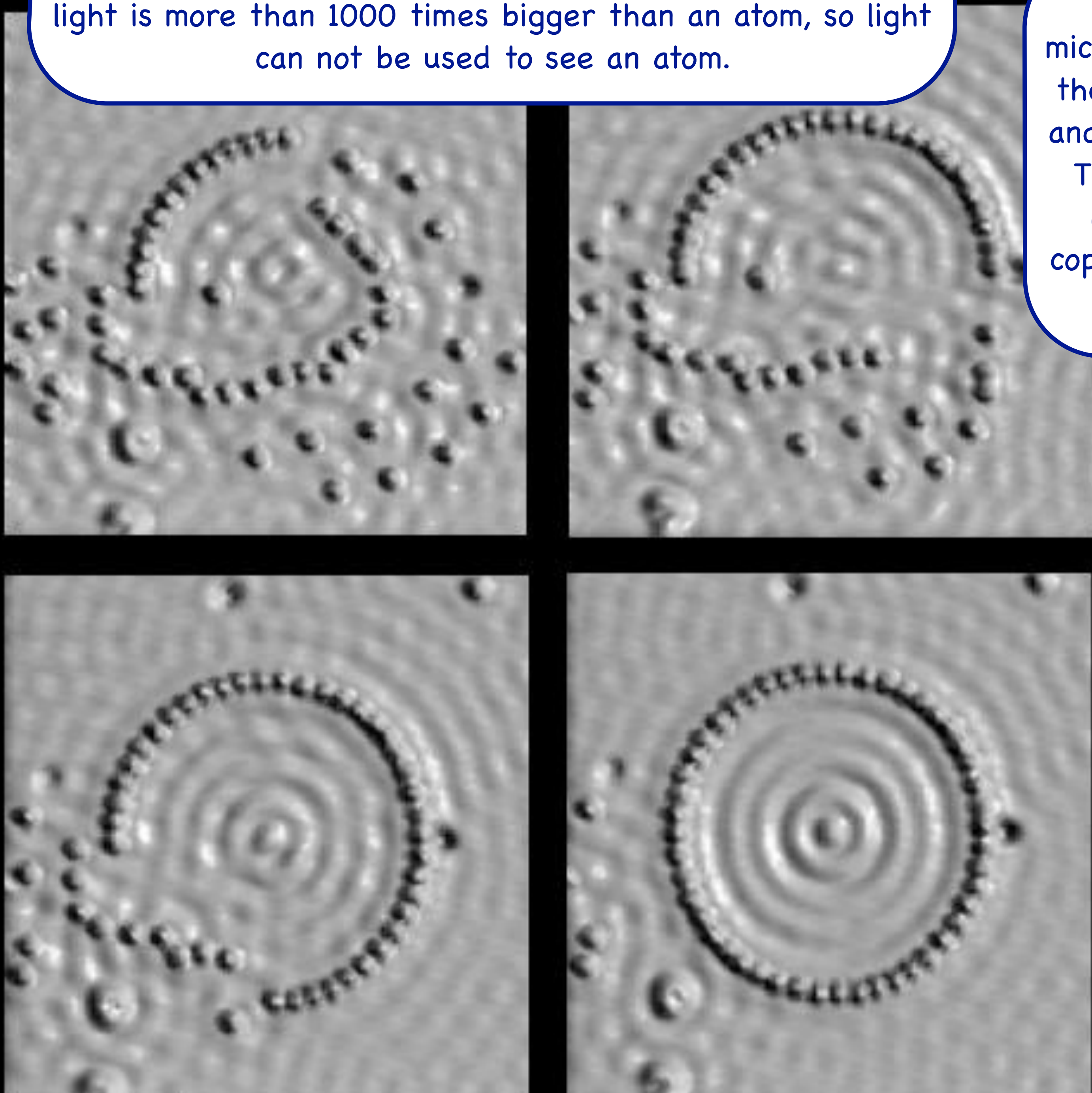
Where our understanding of atoms and nuclear structure came from.



version 1.5

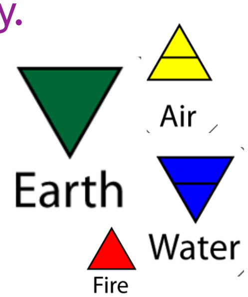
No one has ever seen an atom. The wavelength of visible light is more than 1000 times bigger than an atom, so light can not be used to see an atom.

However, ESM probe microscopes can be used to feel the surface of atomic surfaces and even move individual atoms. These pictures show 48 iron atoms on the surface of a copper crystal being arrange in a circle.



Atomic Theory

- Scientific Method
  - The iterative nature of theory.
- The Greek Contribution
  - Atomic Theory 1.0 — The idea of Atoms
  - Elemental Theory & Alchemy
    - A 2000 year search for elements



- John Dalton—Rediscovery of the Atom
  - Elemental theory led to laws we couldn't explain:
    - The Law of Conservation of Mass
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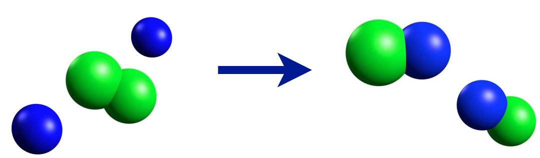
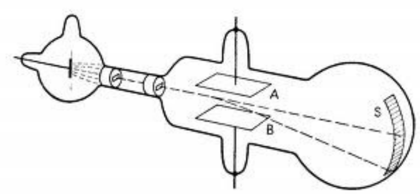
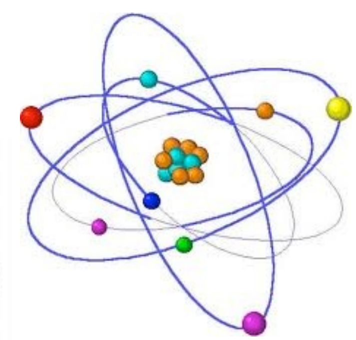
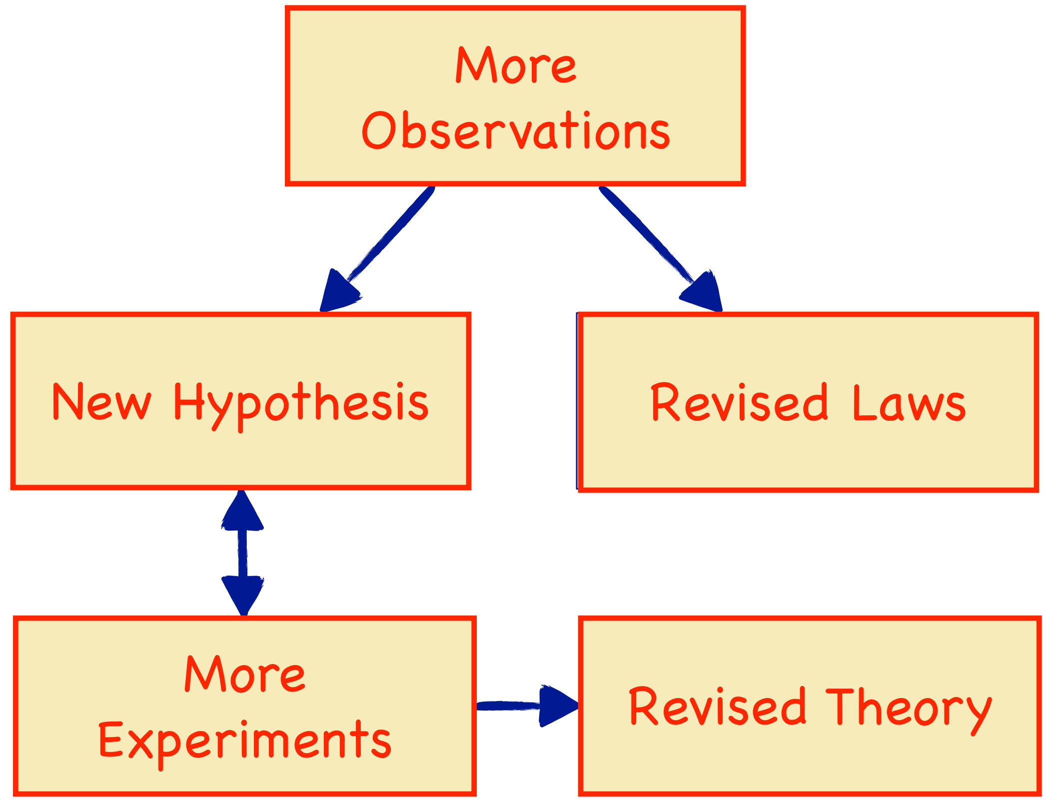


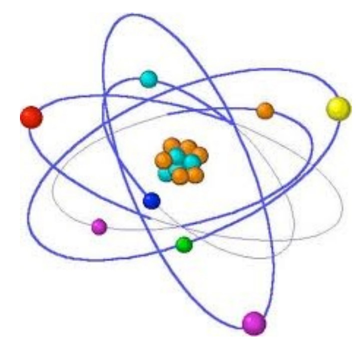




Scientific Method is Iterative

- The products of scientific method are laws and theories.
  - These laws and theories are based on the observations available at the time they're produced.
  - As time moves forward we explore further.
    - We take a more detailed look.
    - Or consider new applications.
  - Which brings up new questions and allows new observations.
  - Last years theory — which was "good enough" for many things — may not explain all our new observations.
    - So we offer new explanations (hypothesis) and experiment to disprove or improve them.
  - New research produces revised theories and improved laws.





Finding the Atom

- Scientific Method
  - No Theory is the complete story
  - Science moves in steps.
    - Each time through the cycle, we improve or replace our theories.
- The Greek Contribution
  - Atomic Theory 1.0 — Introduction of Atoms
  - Elemental Theory & Alchemy
    - A 2000 year detour
- John Dalton—Rediscovery of the Atom
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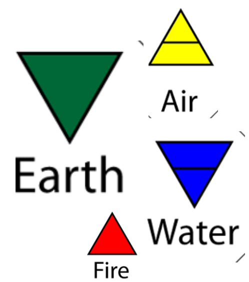
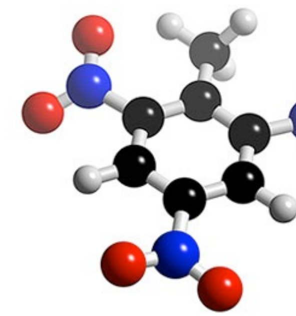
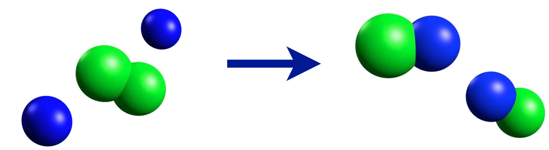
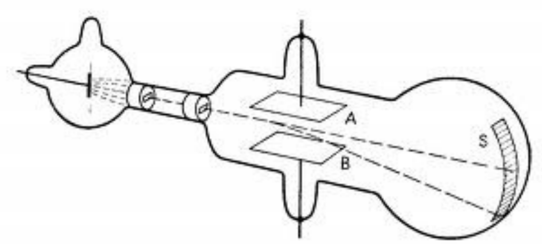
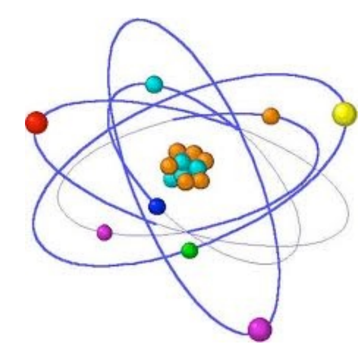


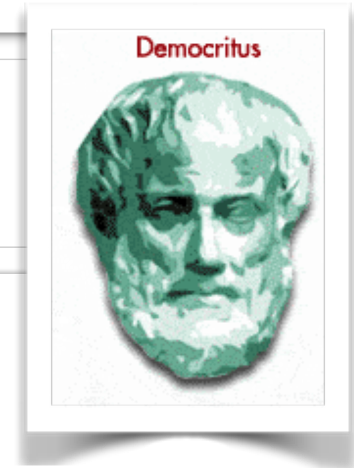




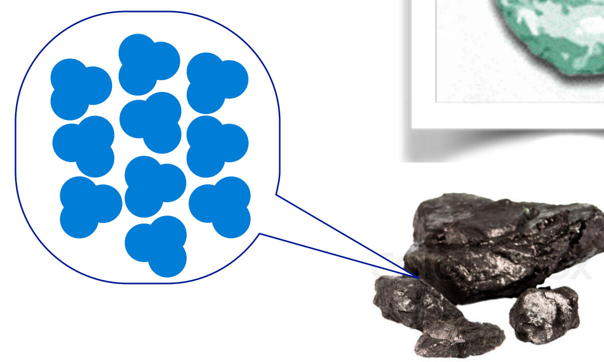


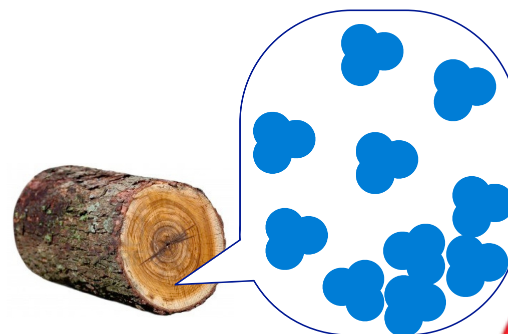


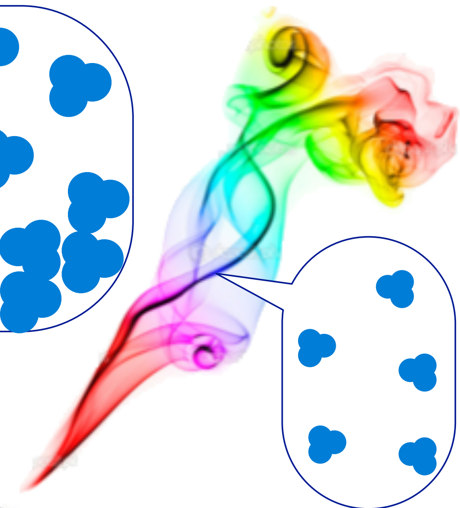
Atomic Theory

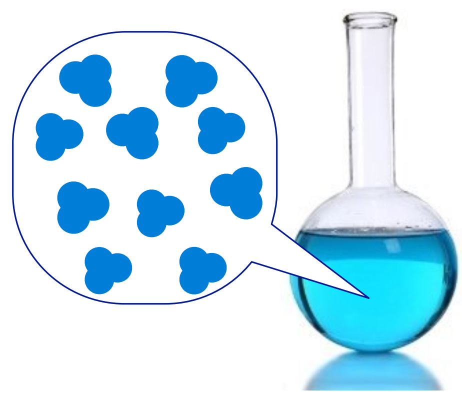


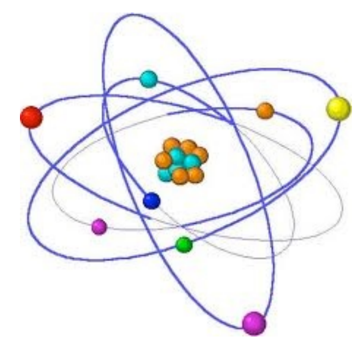
- The earliest concept of the atom came from the Greek philosopher/scientist Democritus between 460 and 370 BCE.
- Democritus thought of the world as being composed of very tiny "uncuttable" particles, which he called “atomoz.” Which is where we get the word atoms.
- These tiny, invisible particles were thought to be separated by voids -- empty space.
  - Democritus explained different substances were caused by differences in the sizes of the particles and the amount of empty space between them.
- This original Atomic Theory explained many properties of matter:
  - Solid, liquid, and gas states
    - State changes
  - Density
  - Mass
  - Hardness
  - Heterogenous Mixtures



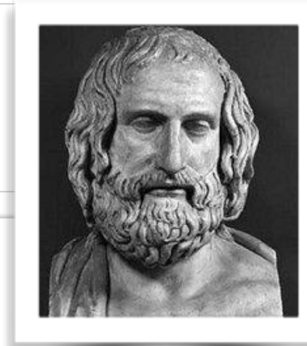






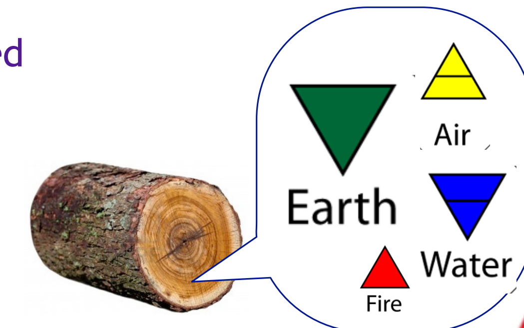


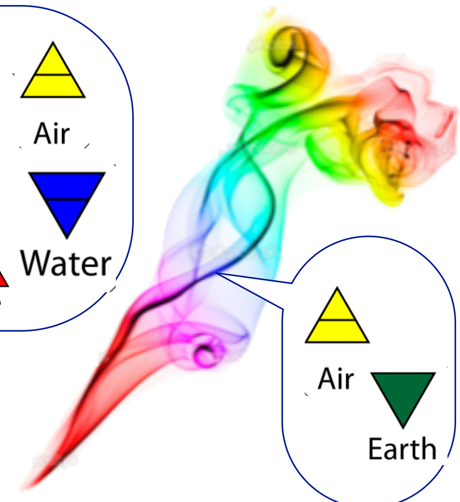
Elemental Theory

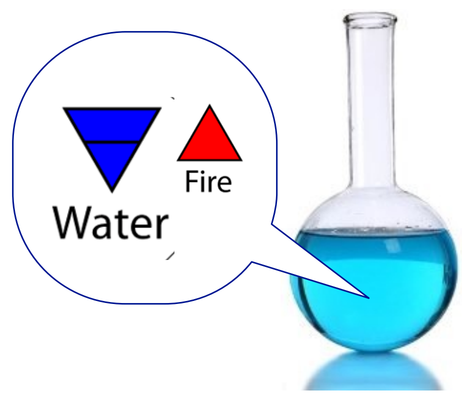


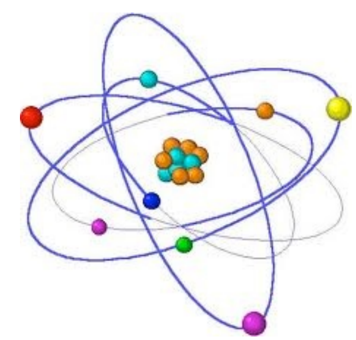
Empedocles

- Empedocles (490-430 B.C.) offered a different explanation.
- He suggested matter was made up of four basic substances: the elements **earth**, **air**, **fire**, and **water**.
- Elemental theory explained the differences in different types of matter as arising from the proportion, form, and qualities of the four basic elements that each contained.
- It explained states of matter. Liquids contained mostly water, solids contained mostly earth, gases were composed of mostly air.
- Experiments supported elemental theory.
  - Earth and fire came out of coal.
  - Smoke contained mostly air with some earth.
  - Steam contained mostly air with some water.
  - Alcohol was mostly water, but it's fire could be released.
  - Burning wood liberates ashes (earth), smoke (air), flames (fire) and water.
- Aristotle (384-322 B.C.) rejected the atomic theory of Democritus and advanced the elemental theory of Empedocles.
- Elemental theory became the dominant theory and guided science for the next 2000 years.





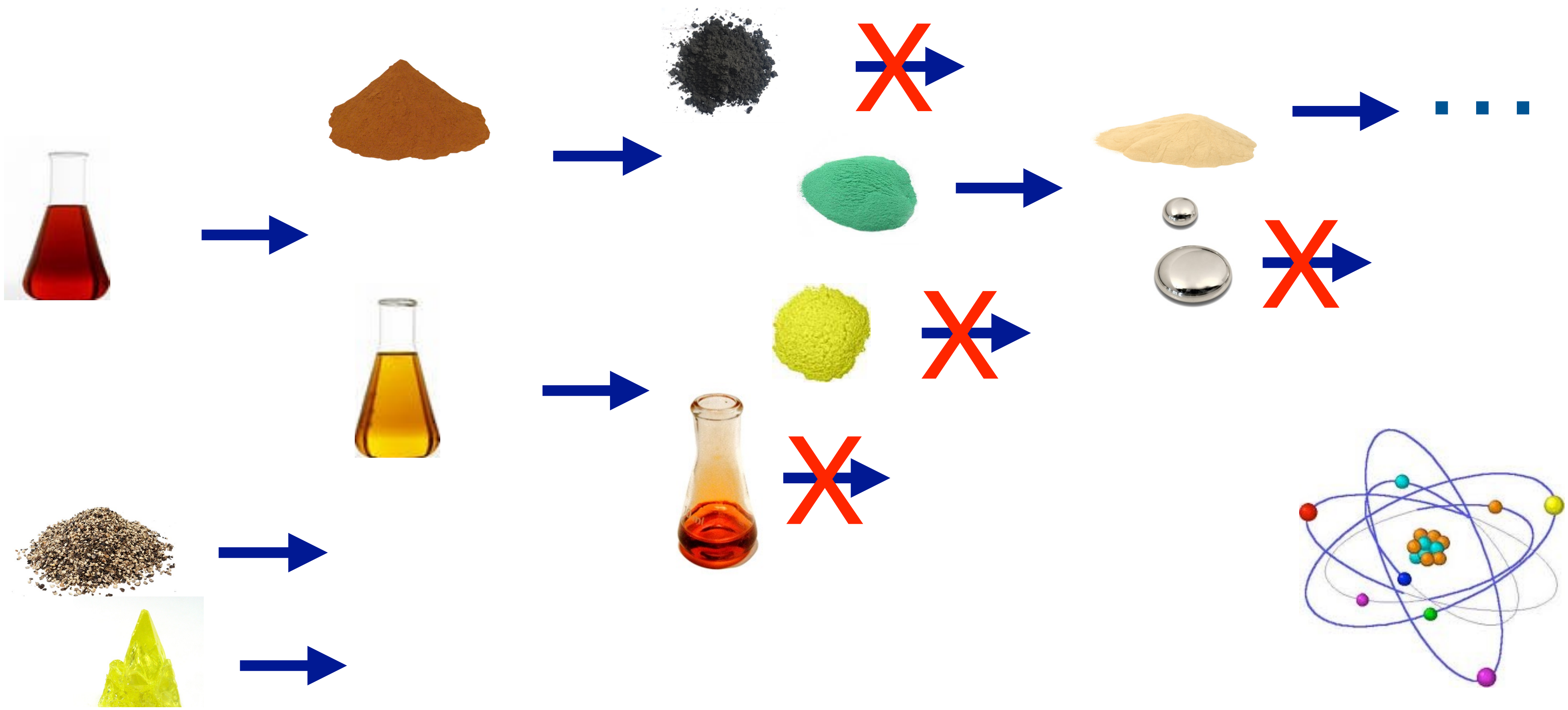




Aristotle

Discovering Elements

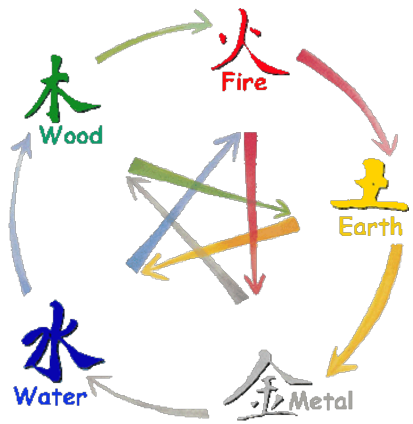
- The substances that could not be broken down into any other substance were thought to have special significance.
  - Sulfur and Mercury were two of the first elements discovered.
  - Carbon, hydrogen, oxygen, chlorine and nitrogen were discovered in the 1700s.
  - Metals like copper, lead, iron, silver and gold were isolated early in history but treated differently.

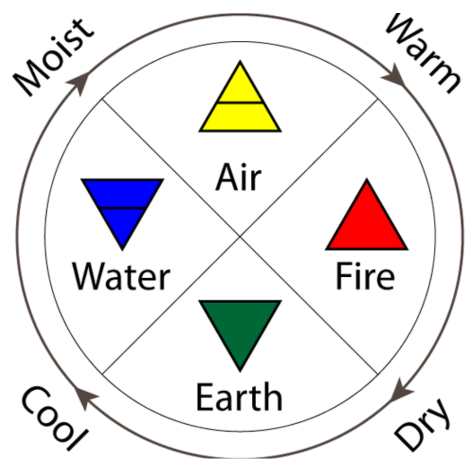


Discovering Elements

- For 2000 years scientists studied and compiled data from chemical reactions.
- Trying to isolate the four greek elements, chemists broke down all matter they found into simpler substances.
  - Materials were uniquely identified and categorized by the ratio of simpler substances they broke into.
- Alchemists like Paracelsus (1493) isolated some of the first modern elements including brimstone and quicksilver.
  - Brimstone is sulfur, Quicksilver is mercury

Paracelsus

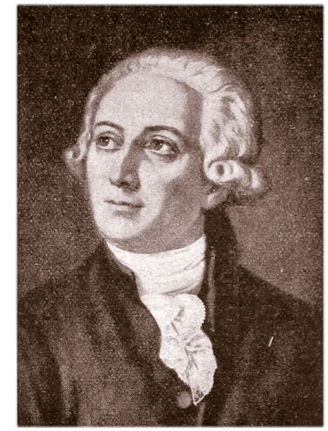




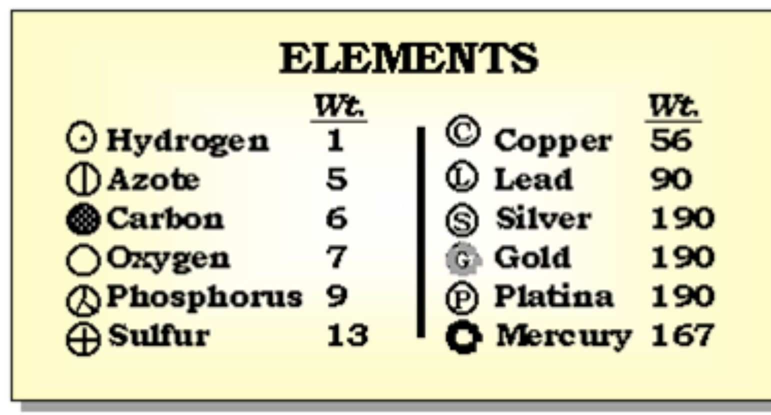
Alkahest

Discovering Elements

- In 1789 Antoine Lavoisier redefined the term element to describe the twenty three pure substances that chemists had discovered but could not break down into simpler substances.
  - This was the the first time metals other than mercury were considered elements.

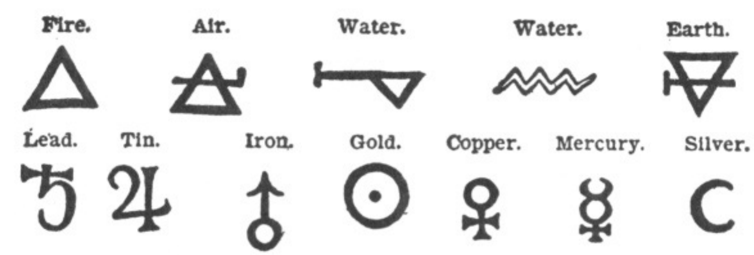


Lavoisier



ELEMENTS

	Wt.		Wt.
Hydrogen	1	Copper	56
Azote	5	Lead	90
Carbon	6	Silver	190
Oxygen	7	Gold	190
Phosphorus	9	Platina	190
Sulfur	13	Mercury	167



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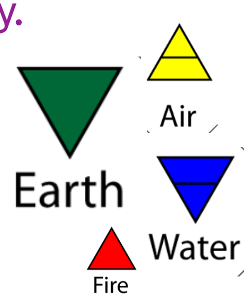

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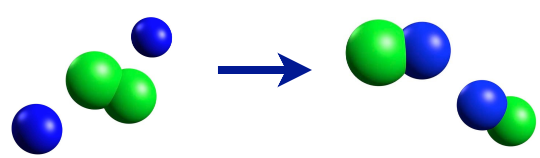
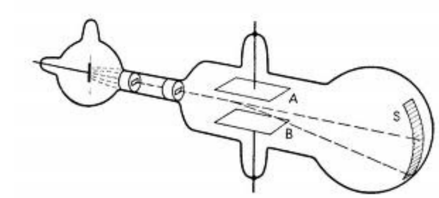
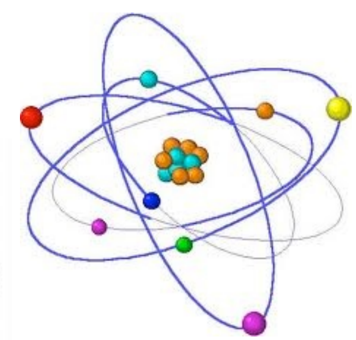






Three Laws of Stoichiometry

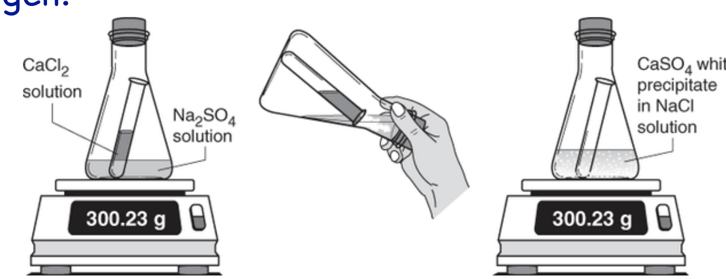
- In exploring the elements which composed all matter, chemists observed three consistent patterns. These three laws invited explanations that would result in the resurgence of atomic theory.

1. Law of Conservation of Mass

In a chemical reaction, matter is neither created nor destroyed.

eg. 9.3g of iron reacts with 10.7g sulfur to form 20.0g iron pyrite.

eg. 20.0g of water breaks down to form 17.8g oxygen and 2.2g hydrogen.

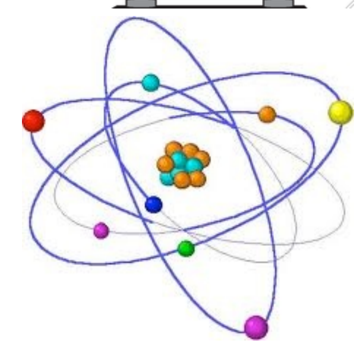


2. Law of Constant Composition
   (also called the Law of Definite Proportions)

All samples of a given compound, regardless of their source or how they were prepared, have the same proportion of their constituent elements.

Water is <u>always</u> 88.8% by weight oxygen, 11.2% hydrogen.

Table salt is <u>always</u> 39.3% by weight sodium, 60.7% chloride.



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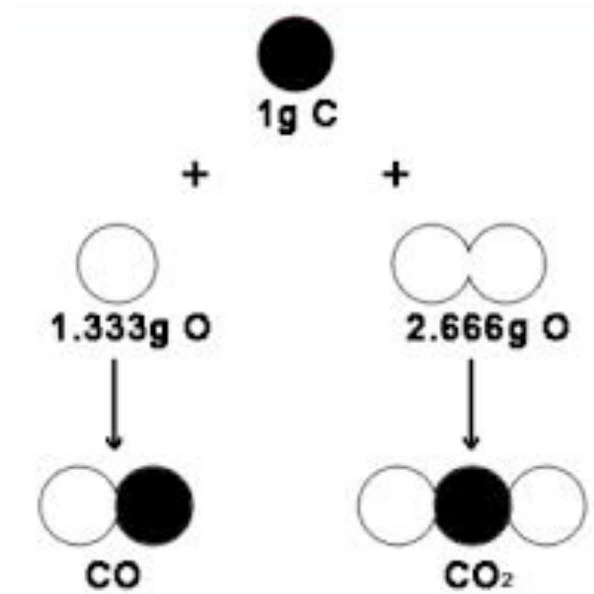
3. Law of Multiple Proportions

When two elements (call them A and B) form two different compounds, masses of element B that combine with 1g of element A can be expressed as a ratio of small whole numbers.



Law of Multiple Proportions Demonstrated with Oxygen and 1.00 gram of Nitrogen

Compound	Mass of Nitrogen	Mass of Oxygen
N_2O	1.00 grams	0.571 grams
NO	1.00 grams	1.14 grams
NO_2	1.00 grams	2.28 grams
NO_4	1.00 grams	4.57 grams

Ratio of Compounds	Ratio of Masses	Ratio	Ratio Small Number
NO_4:NO_2	4.57:2.28	2:1	2
NO_4:NO	4.57:1.14	4:1	4
NO_4:N_2O	4.57:0.571	8:1	8
NO_2:NO	2.28:1.14	2:1	2
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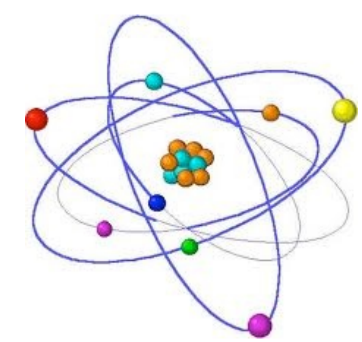
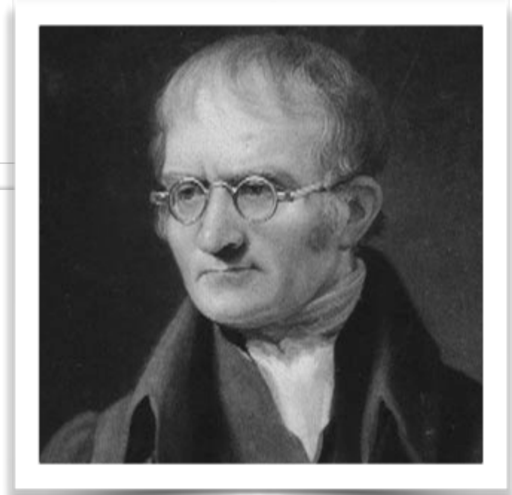
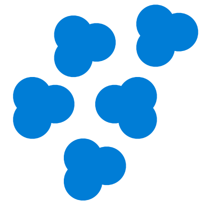


Atomic Theory 2.0



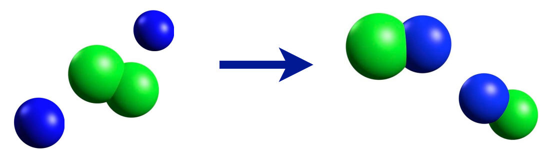
Dalton

- To explain the Laws of Stoichiometry
  John Dalton Proposed a new Atomic Theory:



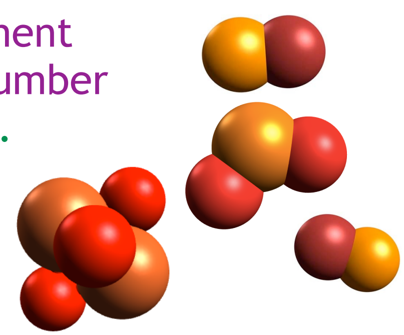
  - "Elements are composed of minute particles called atoms."
    Dalton reintroduced the atom to the world.

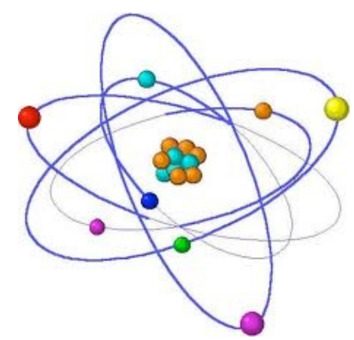
  - "Atoms of the same element are alike in mass and size. Atoms of different elements have different masses and sizes."
    Dalton suggested that atoms come in different flavors, corresponding to the different elements.



  - "The atoms of one element cannot be changed into atoms of a different element by chemical reaction; atoms are neither created nor destroyed in chemical reactions."
    Dalton said that atoms are an indivisible and unchanging component (in chemical reactions).

  - "Compounds are formed when atoms of more than one element combine; a given compound always has the same relative number and kind of atoms." The idea that atoms define substances.





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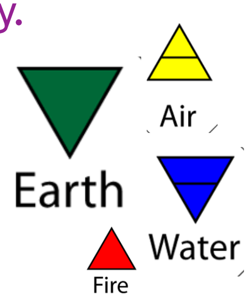

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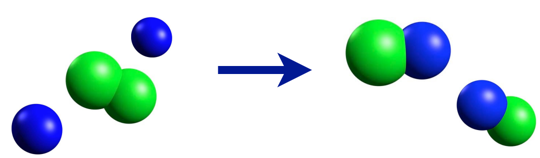
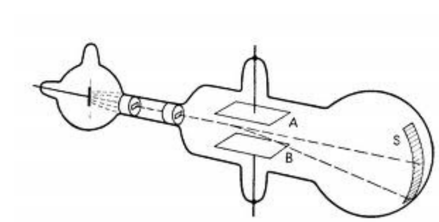
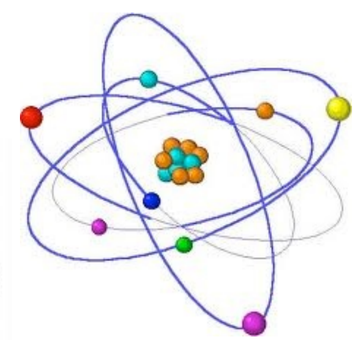
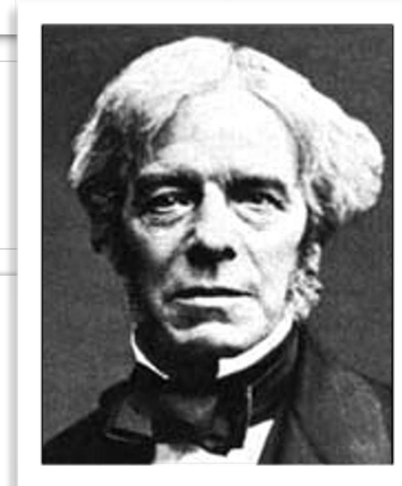






Ions vs Atoms

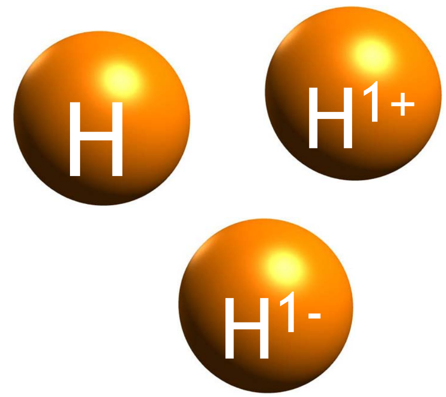


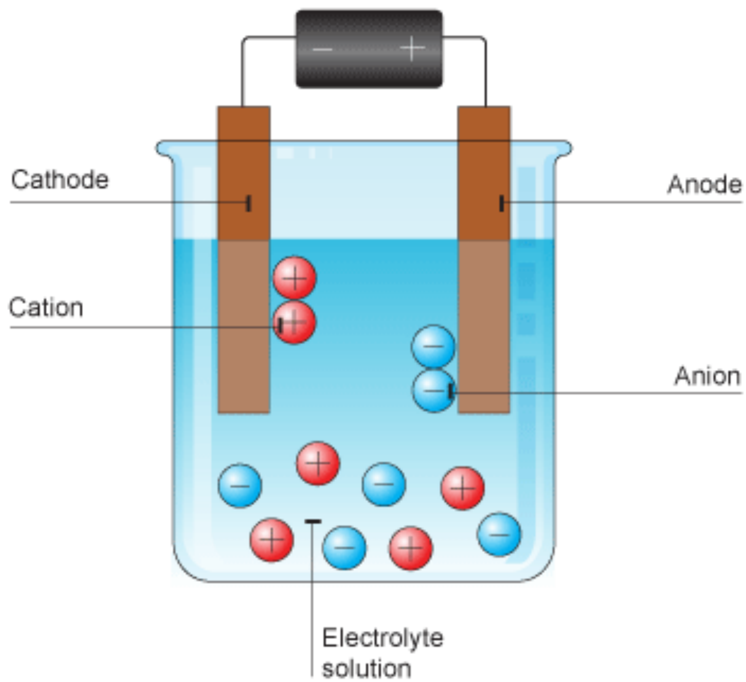
Faraday

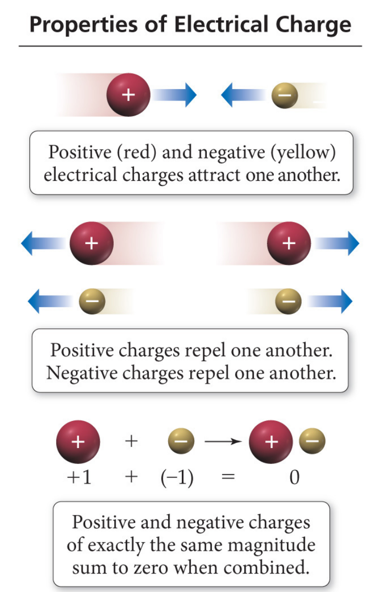
- Around the beginning of the 1900's chemists discovered some atoms could hold an electrical charge.
  - Charges can be positive or negative
  - Charges can be different sizes
- The properties of charged atoms were documented by Michael Faraday, who named them ions.
- Charged atoms move in solution, toward or away from electrically charged wires.
  - The word "ion" is greek for wanderer.
  - Ions that move towards a cathode (neg charged wire) are positively charged ions.
    - They're called cations.

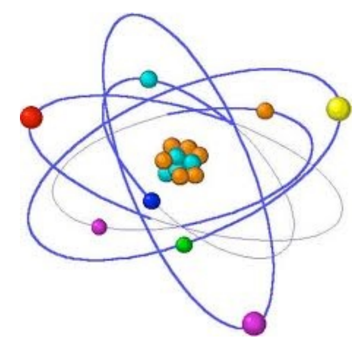
CA+IONS

  - Ions that move towards an anode (pos charged wire) are negatively charged ions.
    - They're called anions.
- Atoms and ions made from those same atoms have different properties.
  - Silver, Ag
    - Not soluble in water
    - Not attracted to magnets
  - Silver Ions, Ag^{1+}
    - Soluble in water
    - Attracted to magnets







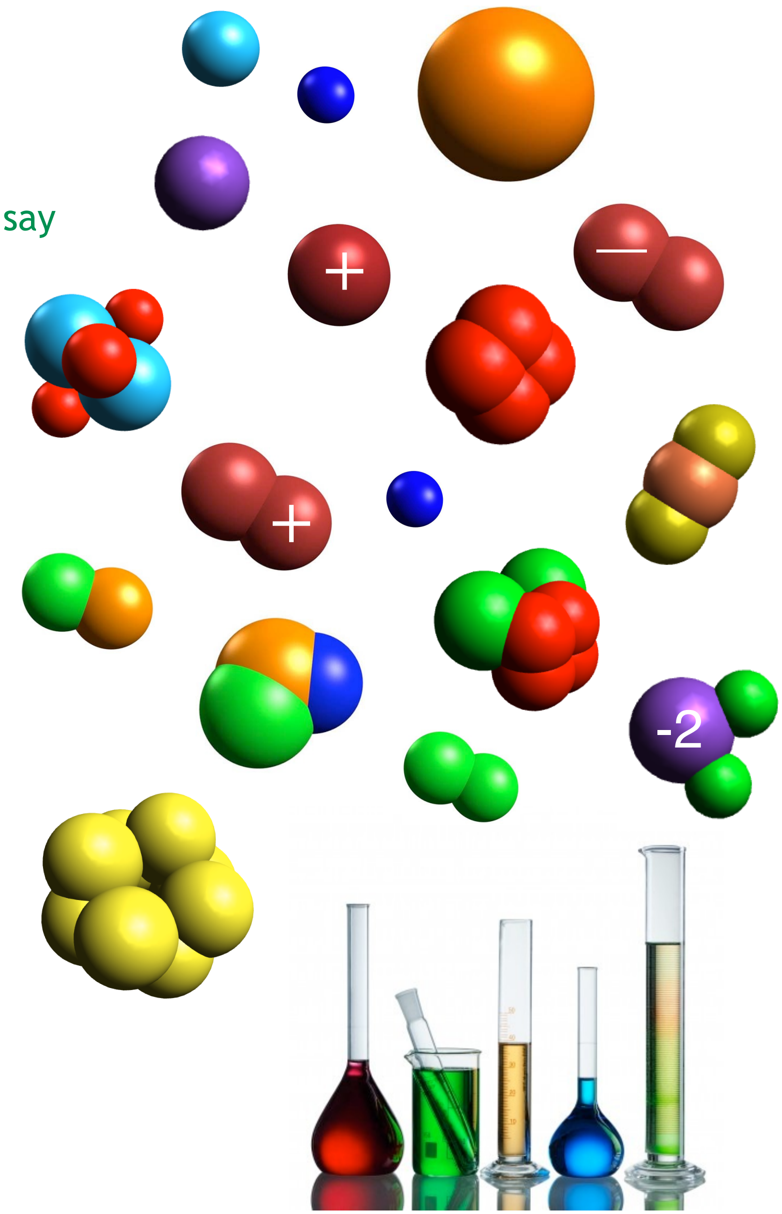


An Overview of Atomic Particles

We will discuss the details of these differences in the next few chapters. For now, I just want to share the "big picture" with you.

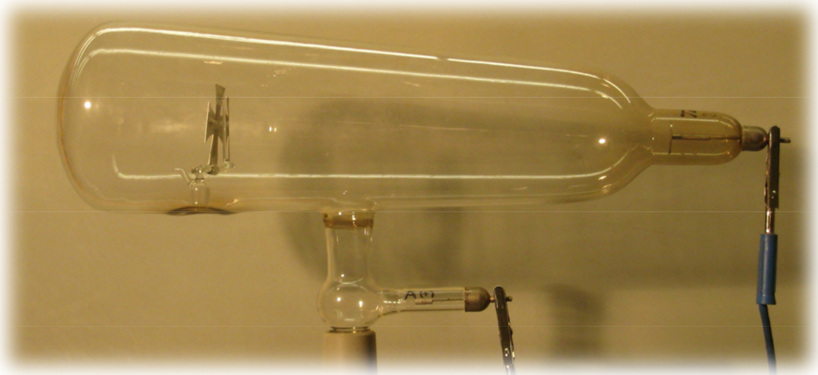
This slide will reappear a lot.

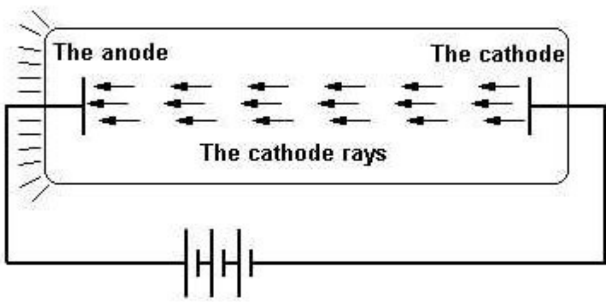
- Matter is made up of particles.
    - Particle is a generic term for small pieces of matter. We say particle when we want to be vague or comprehensive.
- Matter is made up of either ions or molecules.
    - Ions are <u>charged</u> particles (+ or -).
    - Molecules are neutral particles (no charge).
- Ions and molecules are made up of atoms.
    - Monatomic particles are just a single atom.
    - Diatomic particles are particles made of two atoms.
    - Polyatomic particles are made of more than two atoms.
- Atoms come in 118 flavors (elements).
    - If a sample of matter contains only one flavor atom, we say that sample is an element.
        - Yes, we use the word element two ways!
    - If a sample of matter contains two elements we say it is a binary compound or just a compound.
    - If a sample of matter contains more than two elements we say that sample of matter is a compound.

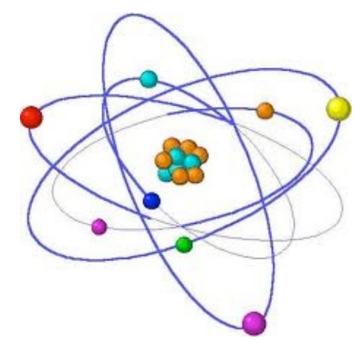


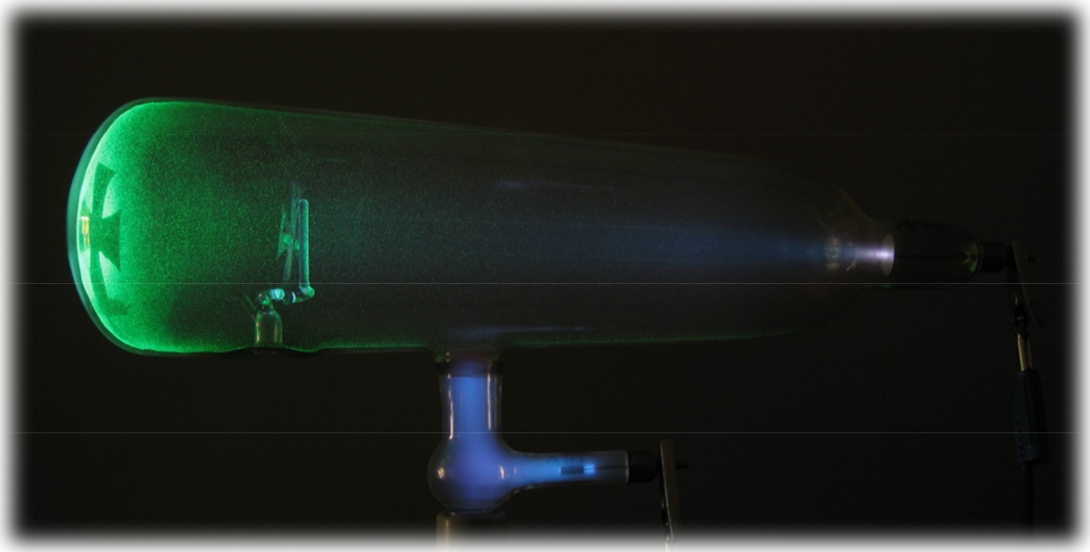
Cathode Ray Experiments

- Near the start of the 1900s electricity was one of the most exciting discoveries being explored in science.
- One electrical experiment conducted by many scientists was the exploration of cathode ray (or Röntgen ray) tubes.
- Cathode ray tubes are vacuum tubes with embedded wires, where an electrical charge is placed across the tube.
  - Different tubes were charged with different elemental gases, after being evacuated.
  - Properties of Cathode Rays
    - Travel in straight lines.
    - The ray is negatively charged.
    - The same rays come from all of the different elements explored.
    - The rays had mass (they can make a pin wheel spin).







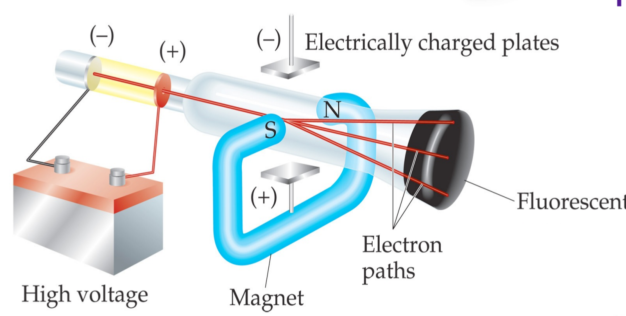


J.J. Thomson

Thomson

- Joseph John Thomson observed cathode rays in 1897.
  - Thomson hypothesized that atoms were composed of minute charged particles of mass.
  - He hypothesized that cathode rays were a stream of these small particles,
  - In seeking to demonstrate this, he observed cathode rays from various elemental gases and their behavior in electric fields.
  - He was able to demonstrate cathode ray particles have a charge to mass ratio of…

$$-1.76 \times 10^{8} \frac{C}{g}$$

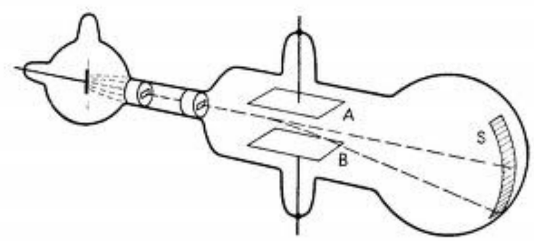


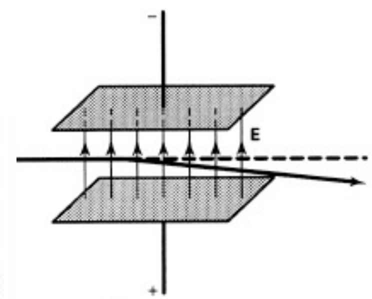
  - From the 1906 Nobel presentation speech:

    "Every day that passes witnesses electricity obtaining an ever-increasing importance in practical life. The conceptions, which a few decades ago were the subject of investigation in laboratories, have by this time become the property of the public at large. …

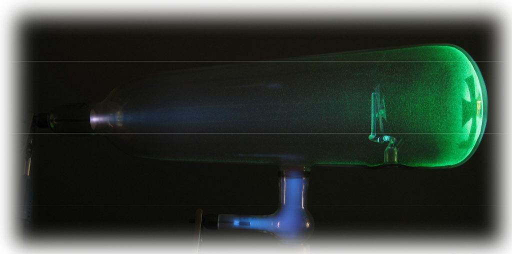
    Faraday's law may be expressed thus, that a gram of hydrogen, or a quantity equivalent thereto of some other chemical element, carries an electric charge of 28,950 x 10^{10} electrostatic units. Now if we only knew how many hydrogen atoms there are in a gram, we could calculate how large a charge there is in every hydrogen atom. …

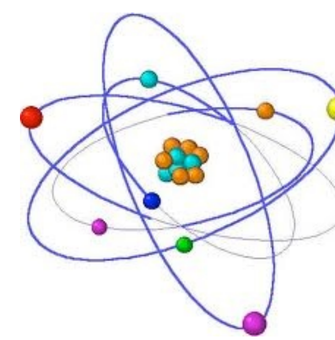
    If Thomson has not actually beheld the atoms, he has nevertheless achieved work commensurable therewith, by having directly observed the quantity of electricity carried by each atom."





- In 1906 J.J. Thomson was awarded the Nobel prize "in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases".

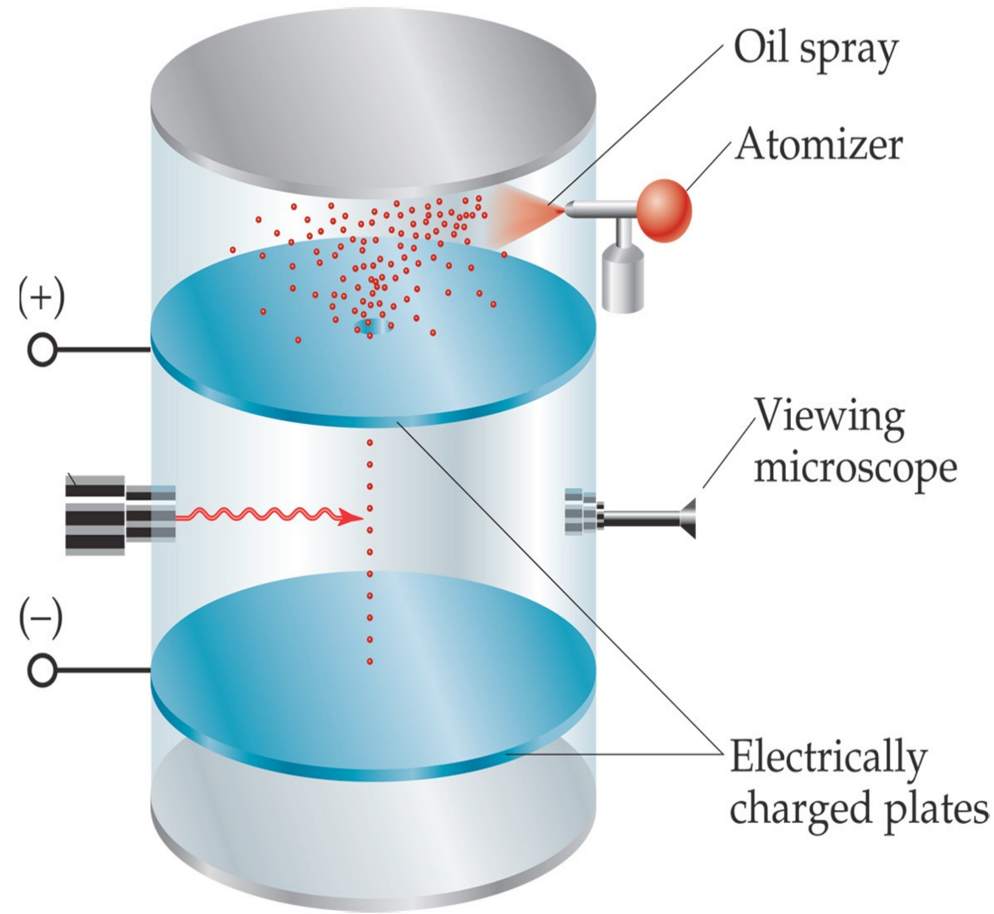




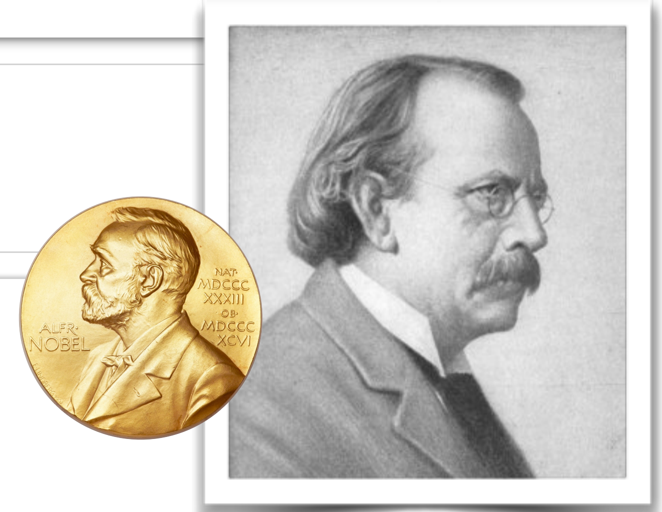
The Oil Drop Experiment

Millikan

- Robert Millikan experimented with oil drops in 1909:
  - He charged oil drops with cathode ray particles.
  - He determined the mass and charge of minute oil drops by suspending them between electrically charged plates.
    - By measuring the diameter of the drop he could calculate it's size and therefore it's mass. He therefore knew how much force gravity applied.
    - By carefully tuning the electrical field to provide just enough electrical force to offset the force of gravity he could determine it's charge.
  - He recorded data for tens of thousands of oil drops.
  - He found every drop he created had a charge that was a multiple of 1.60×10^{-19}
  - He reasoned that the charge on a single cathode ray particle must be at least as small as 1.60×10^{-19}
  - Milikan proposed that the fundamental unit of electrical charge was 1.60×10^{-19} C (coulombs)
- Robert Millikan was awarded the Nobel prize in 1923 for "for his work on the elementary charge of electricity and on the photoelectric effect."

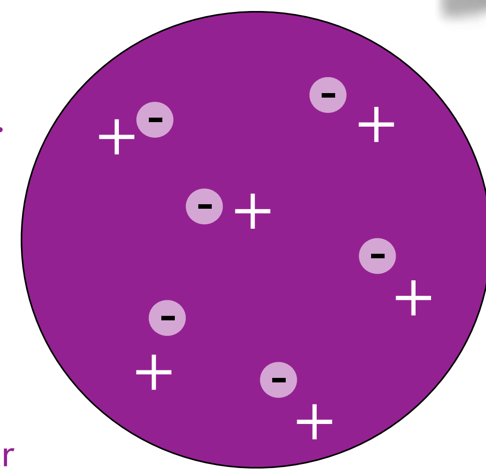


Atomic Theory 3.0



Thomson

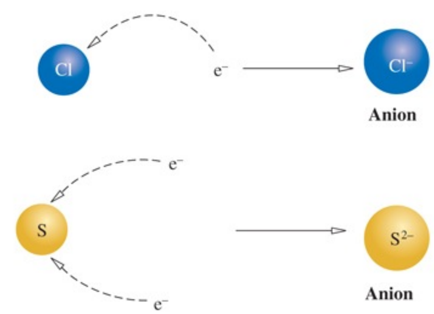
- Combining Thomson's mass to charge ratio and Millikan's smallest unit of charge disproves the theory that the atom is the smallest particle of matter.
  - The mass of the cathode particles is 9.10×10^{-28} g
  - The smallest known particle was the hydrogen atom, it weighs 1.673×10^{-24} g — 2000 times heavier.
  - This demonstrated that there was something smaller than atoms.
  - … something from which atoms were built.
  - Thomson named this particle the electron.
- JJ Thompson proposed a new model of the atom (1903).
  - Proposed that atoms were positively charged spheres.
  - With embedded smaller negatively charged particles (electrons).
  - Thomson's Model was also called the plum pudding model (similar to the way raisins are embedded in plum pudding)
  - This improved model of the atom, explained the existence of ions.

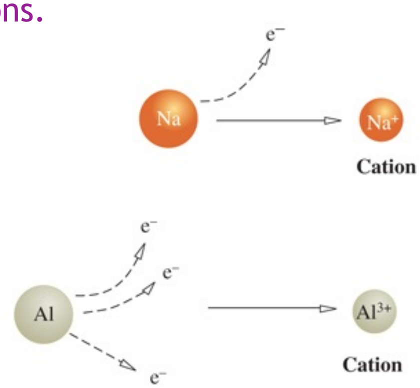


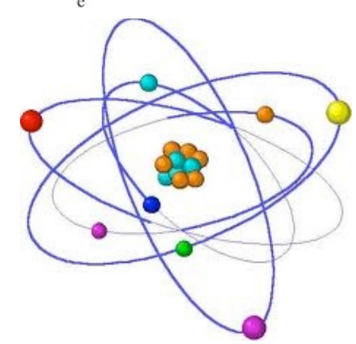
Dimensional Analysis

$$\text{charge} \times \frac{\text{mass}}{\text{charge}} = \text{mass}$$

$$-1.60 \times 10^{-19}\,\text{C} \times \frac{1\,\text{g}}{-1.76 \times 10^{8}\,\text{C}} = 9.10 \times 10^{-28}\,\text{g}$$

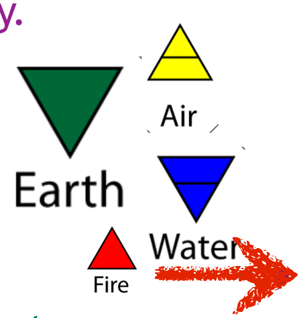




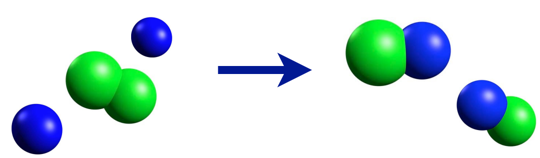


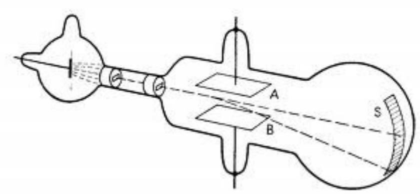
Atomic Theory

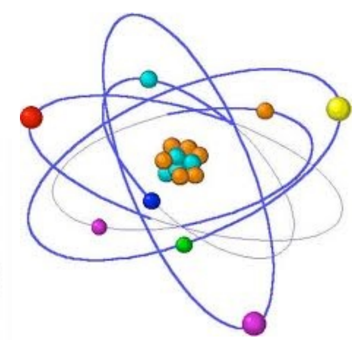
- Scientific Method
  - The iterative nature of theory.
- The Greek Contribution
  - Atomic Theory 1.0 — The idea of Atoms
  - Elemental Theory & Alchemy
    - A 2000 year search for elements



- John Dalton—Rediscovery of the Atom
  - Elemental theory led to laws we couldn't explain:
    - The Law of Conservation of Mass
    - The Law of Constant Composition
    - The Law of Multiple Proportions
  - Atomic Theory 2.0 — Modern Elements
    - Dalton reimagined the atom and explained the elemental laws.
- JJ Thomson—Subatomic Particles
  - Electrical Charge
    - Ions, Cathode Rays, Millikan's Oil Drop
  - The Electron
  - Atomic Theory 3.0 — Plum Pudding
- Rutherford—the Nucleus
  - Radiation, Gold Foil, the Nucleus
    - Protons & Neutrons
  - Atomic Theory 4.0 — Nuclear Theory



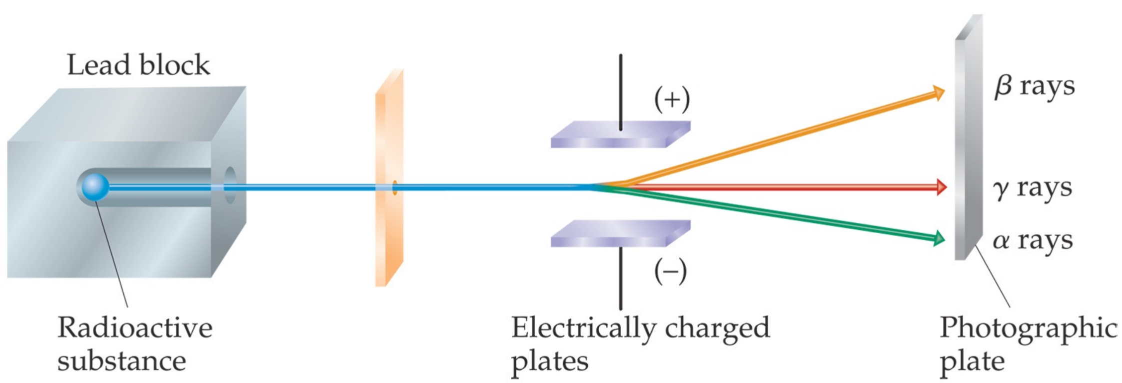


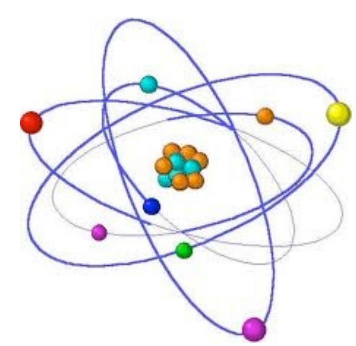


Radiation & Radioactivity

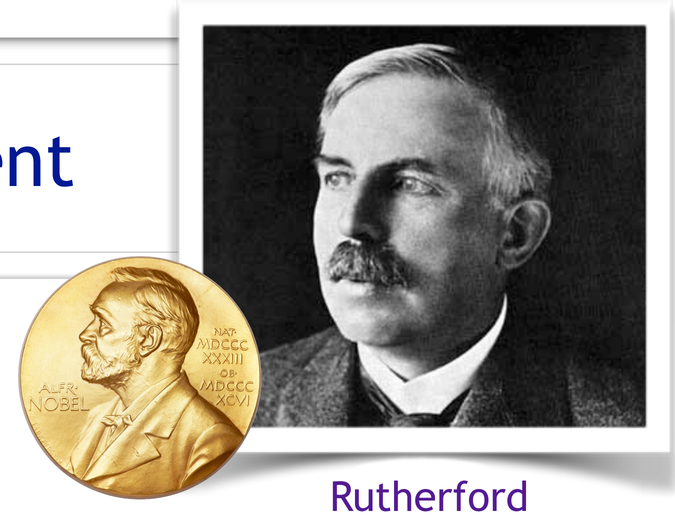
- Radiation is the emission of matter or energy.
- It can come from many sources.
  - Heating a wire produces radiant light (the lightbulb).
  - Running electricity through metal produces heat (stove).
- In 1986 Henri Becquerel discovered that some substances breakdown and emit radiation without any apparent cause.
  - No electricity, no heating… they just emit radiation.
  - Radioactivity is the property of a substance to spontaneously emit radiation.
- Marie and Pierre Curie identified, explored and documented many elements that are naturally radioactive.
- Ernest Rutherford discovered three forms of emissions that come from radioactive elements.
  - Gamma rays have no charge and and have no mass.
  - Beta particles have a negative charge, beta radiation like cathode rays, are a stream of electrons.
  - Alpha particles have a positive charge and as much mass as a helium atom. (four times the mass of a hydrogen atom)

	Mass	Charge
α particles	A Helium atom	positive
β particles	Electrons	negative
γ rays	none	none



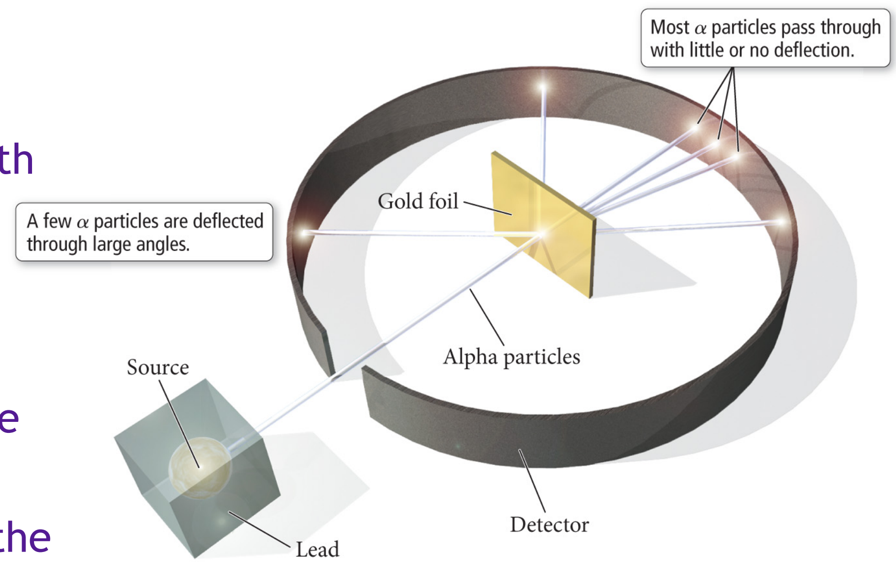


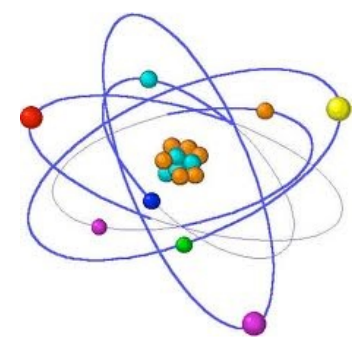
The Gold Foil Experiment



Rutherford

- Ernest Rutherford was a student of J.J. Thomson.
- In an attempt to support Thomson’s plum-pudding theory of the atom Rutherford used alpha radiation to explore the structure of the atom.
  - His experiments disproved some of Thomson’s theories,
- Rutherford shot a stream of alpha particles at a gold foil.
- Most of the alpha particles passed through the foil with little or no deflection.
- He found that a few were deflected at large angles .
- Some alpha particles even bounced back.
- An electron with a mass of 1/1837 amu could not have deflected an alpha particle with a mass of 4 amu.
- Because alpha particles have relatively high masses, the particles that bounced back led Rutherford to conclude that the nucleus was very heavy and dense.
- In 1908 Ernest Rutherford was awarded the Nobel prize "for his investigations into the disintegration of the elements, and the chemistry of radioactive substances".





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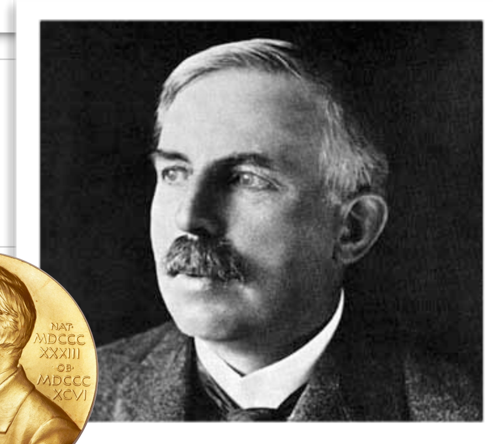
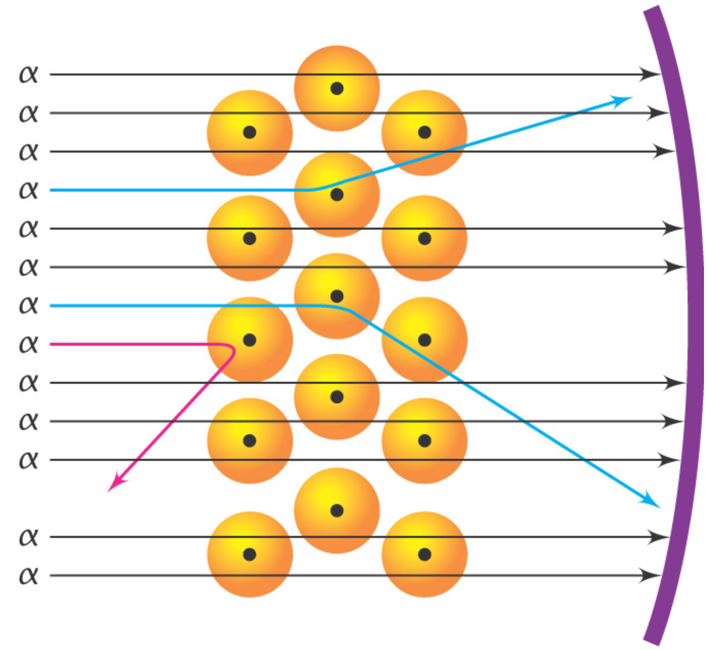
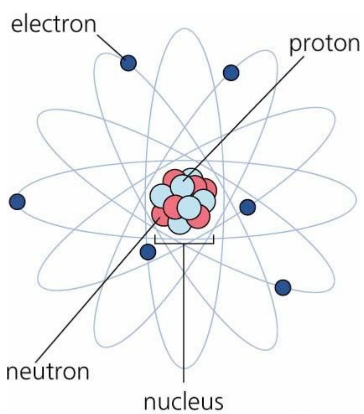
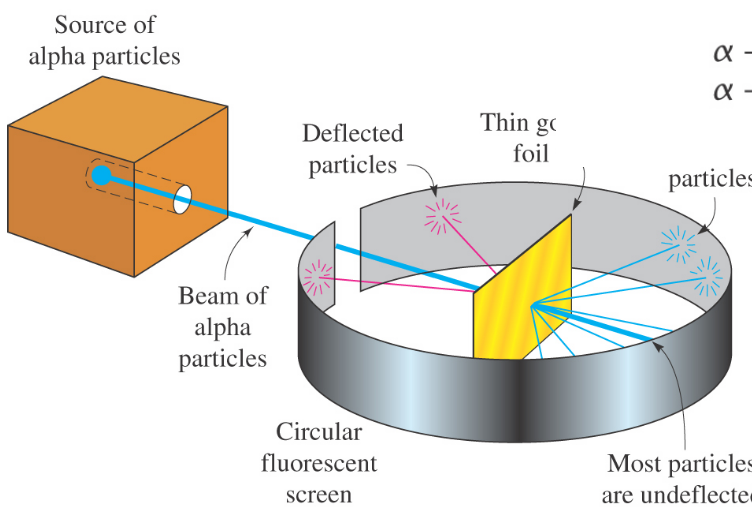
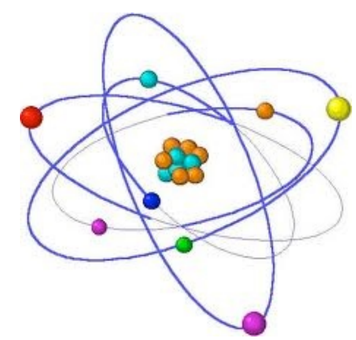


Observations		Hypothesis
Alpha particles mostly passed right through the gold.	→	Atoms are mostly empty space.
A small number bounced back.	→	There was something tremendously massive but very small inside the atom (more massive than a helium atom).
Some deflected as they passed through the atom..	→	The massive part was positively charged.



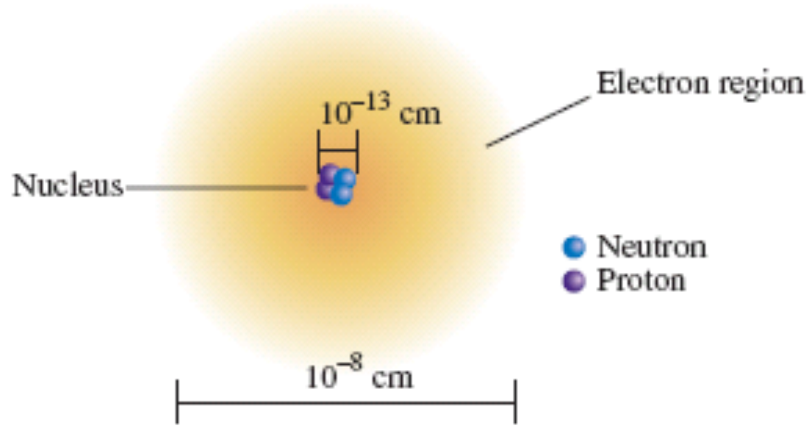


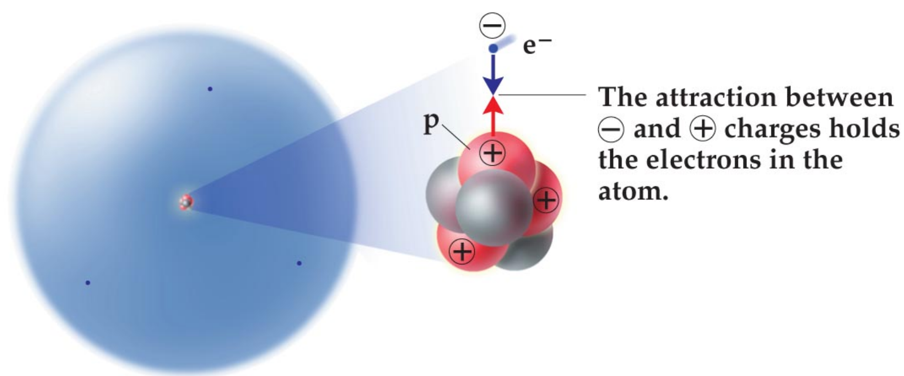




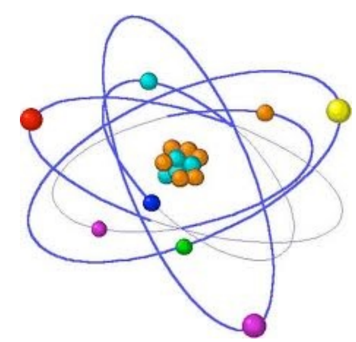
Atomic Theory 4.0 — The Nuclear Atom

- The smallest particle of an element that can enter into a chemical reaction is the atom.
- Atoms are neutral, containing the same number of positive and negative charges.
  - Atoms have a dense positively charged nucleus.
  - Electrons occupy the empty space outside the nucleus.
    - Ions are made by adding or removing electrons to produce a positive or negative net charge.
- Rutherford went on to explore the structure of the nucleous.
  - Rutherford discovered protons in 1919 (eight years after discovery of the nucleus)
    - Protons are positively charged particles 2000 times as massive as electrons.
  - Neutrons were discovered by James Chadwick in 1932.
    - Neutrons are slightly (0.1%) more massive than protons and have no charge.
  - The nucleus is composed of protons and neutrons.
  - A neutral atom contains the same number of electrons and protons.





Particle	Charge	Mass (amu)
Proton	Positive (1+)	1.0073
Neutron	None (neutral)	1.0087
Electron	Negative (1−)	5.486×10^{-4}



Up to the Nuclear Age

A Brief History of Atomic Theory

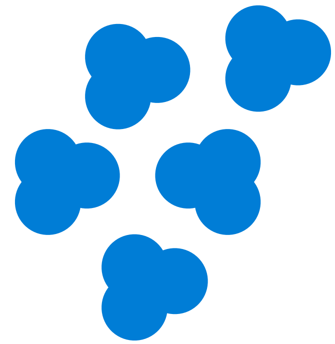
Greeks were the first to suggest that matter is made up of atoms

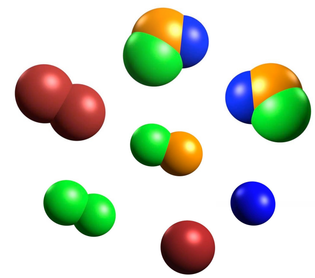
Early chemists performed experiments

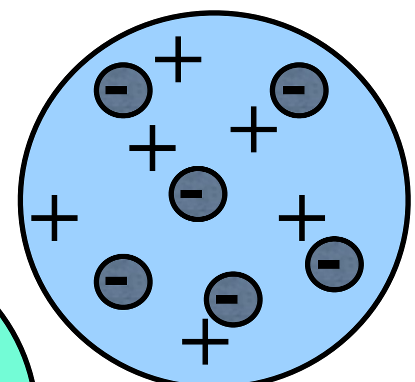
Their experiments led to Dalton's Atomic Theory

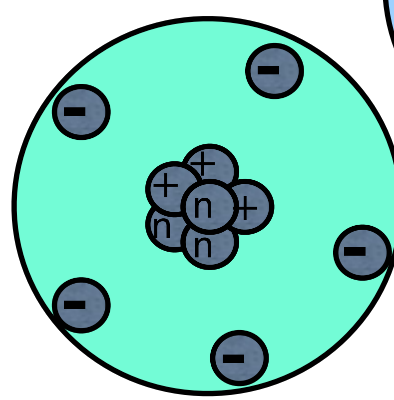
Limitations of Dalton's model led to the Thompson and Rutherford models of the atom.

While these models work reasonably well their limitatons have led to more modern theories as to the nature of the atom.









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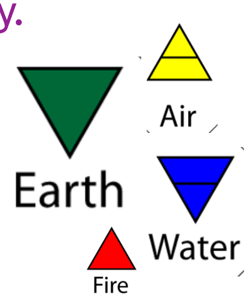

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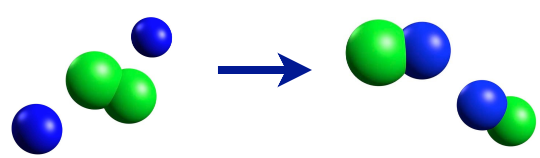

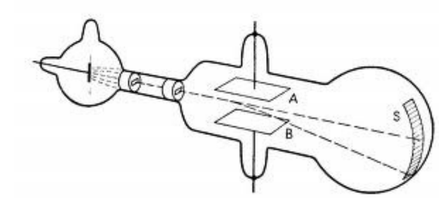

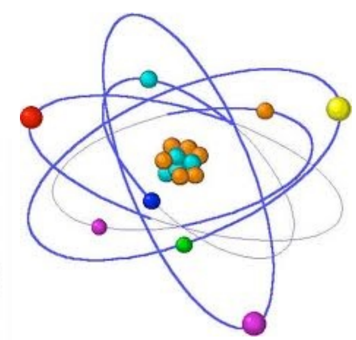

Questions?