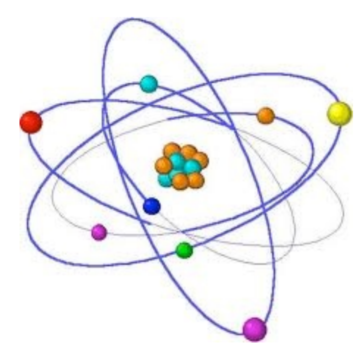
Ch02

Atoms

Into the atom.

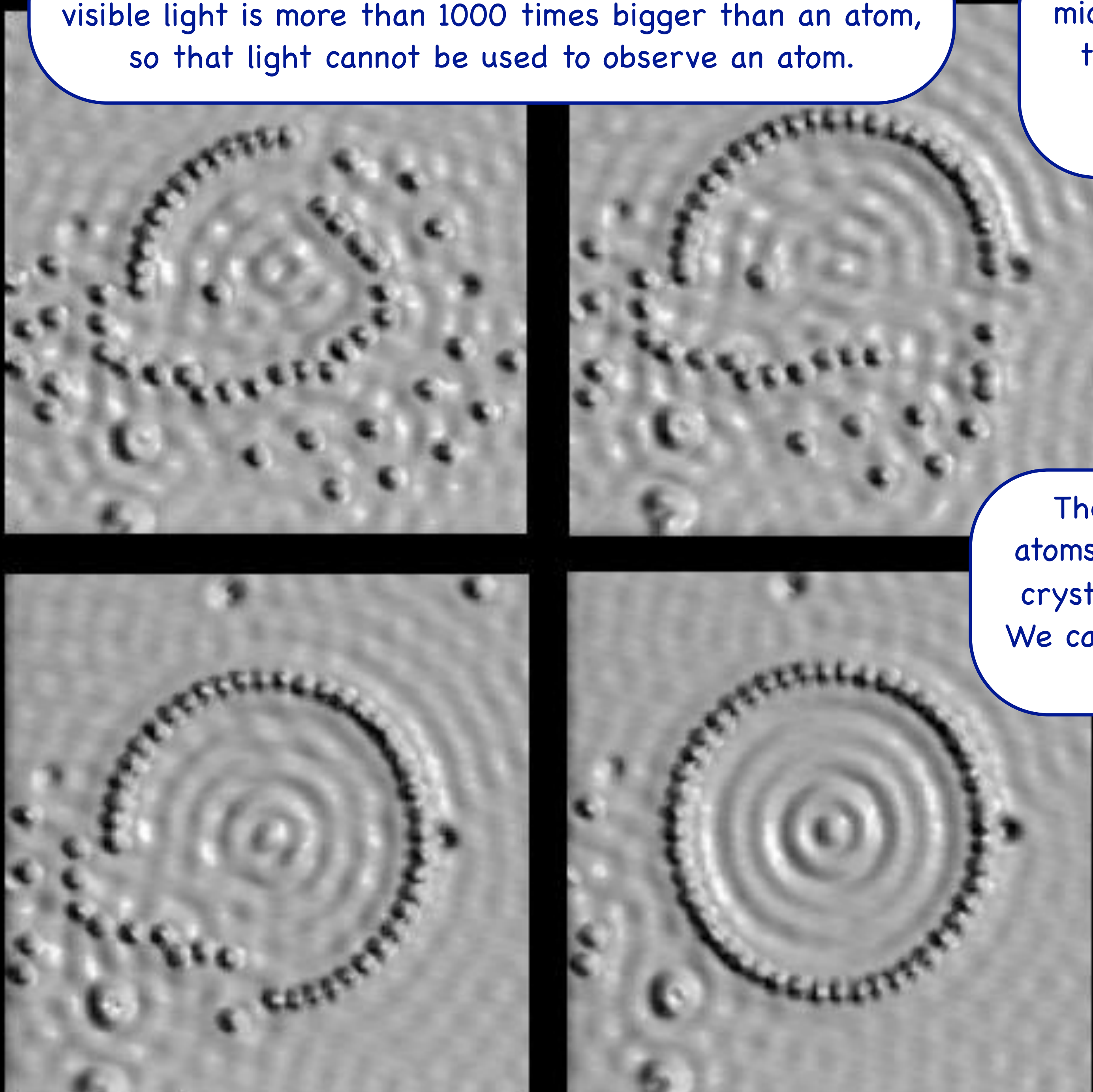
The discovery of subatomic particles and the structure atoms.



version 1.5

No one had ever seen an atom. The wavelength of visible light is more than 1000 times bigger than an atom, so that light cannot be used to observe an atom.

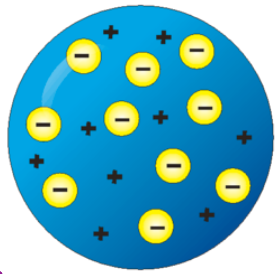
However, ESM probe microscopes can be now be used to feel the surface of atomic surfaces and even move individual atoms.

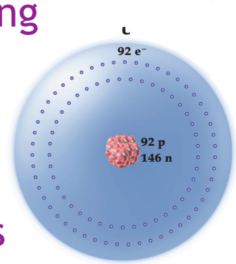


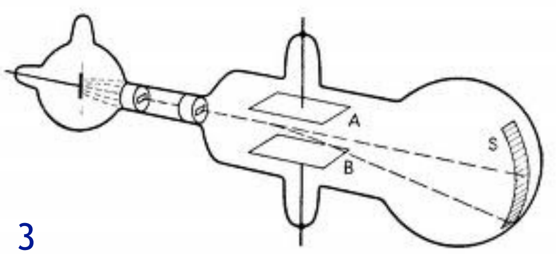
These pictures show 48 iron atoms on the surface of a copper crystal being arrange in a circle. We can now "see" and even "touch" the atom.

Atoms

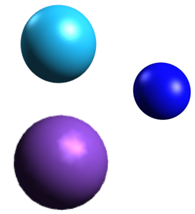
- Wandering Atoms
  - Charge
- Subatomic Particles
  - Smaller than an Atom
    - Ions, Cathode Rays, Millikan's Oil Drop
  - The Electron
  - Atomic Theory 3.0 — Plum Pudding
- Radioactive Matter
- Rutherford—the Nuclear Age
  - Radiation, Gold Foil, the Nucleus
    - Protons & Neutrons
  - Atomic Theory 4.0 — Nuclear Atom
  - Moseley Law
    - Atomic Number







- Flavors of the Atom
  - Ions, electron count
  - Elements, proton count
  - Isotopes, mass
    (because they differ in neutron count)
    - Isotopic Notation
- Counting Atoms
  - Counting by weight
    - the AMU
    - Natural Abundance
    - Atomic Mass
  - The Mole
    - Avogadro's Number
    - Molar Mass



$^{A}_{Z}E$

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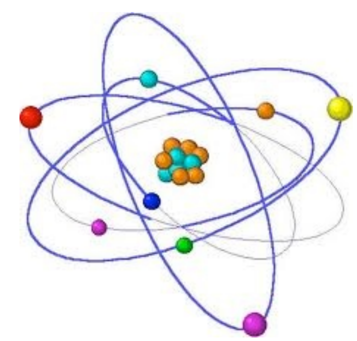
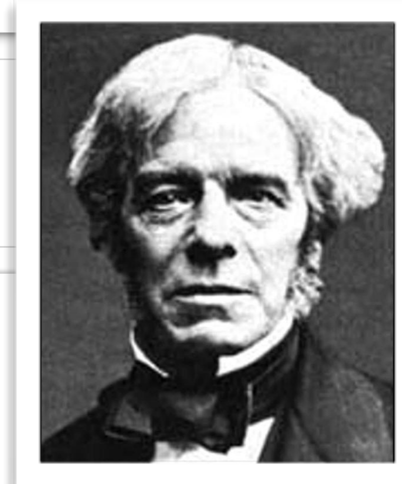


Ions vs Atoms

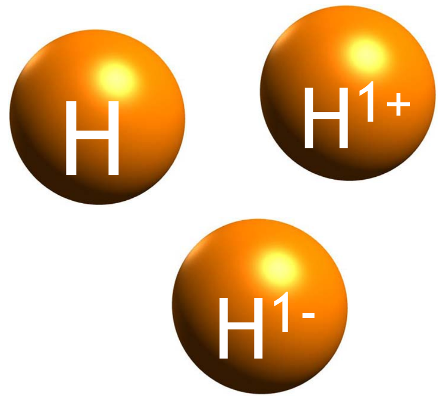


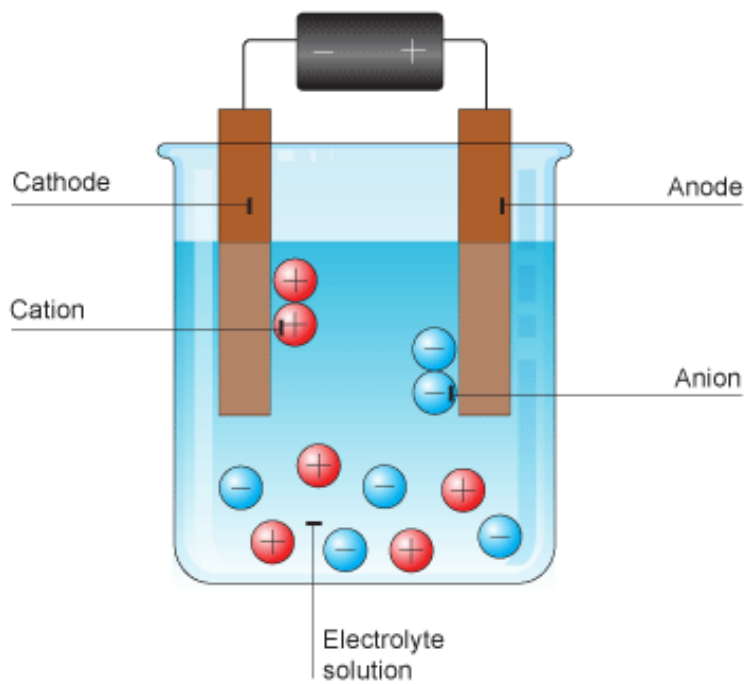
Faraday

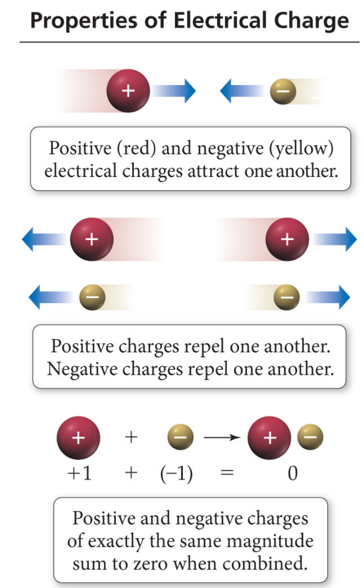
- Around the beginning of the 1900’s chemists discovered some atoms could hold an electrical charge.
  - Charges can be positive or negative
  - Charges can be different sizes
- The properties of charged atoms were documented by Michael Faraday, who named them ions.
- Charged atoms move in solution, 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.

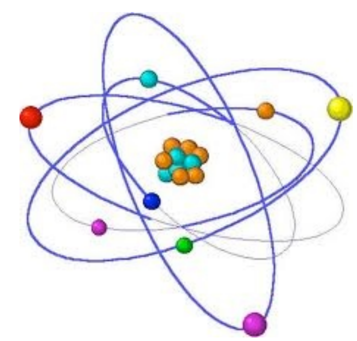
CA+IONS

  - 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

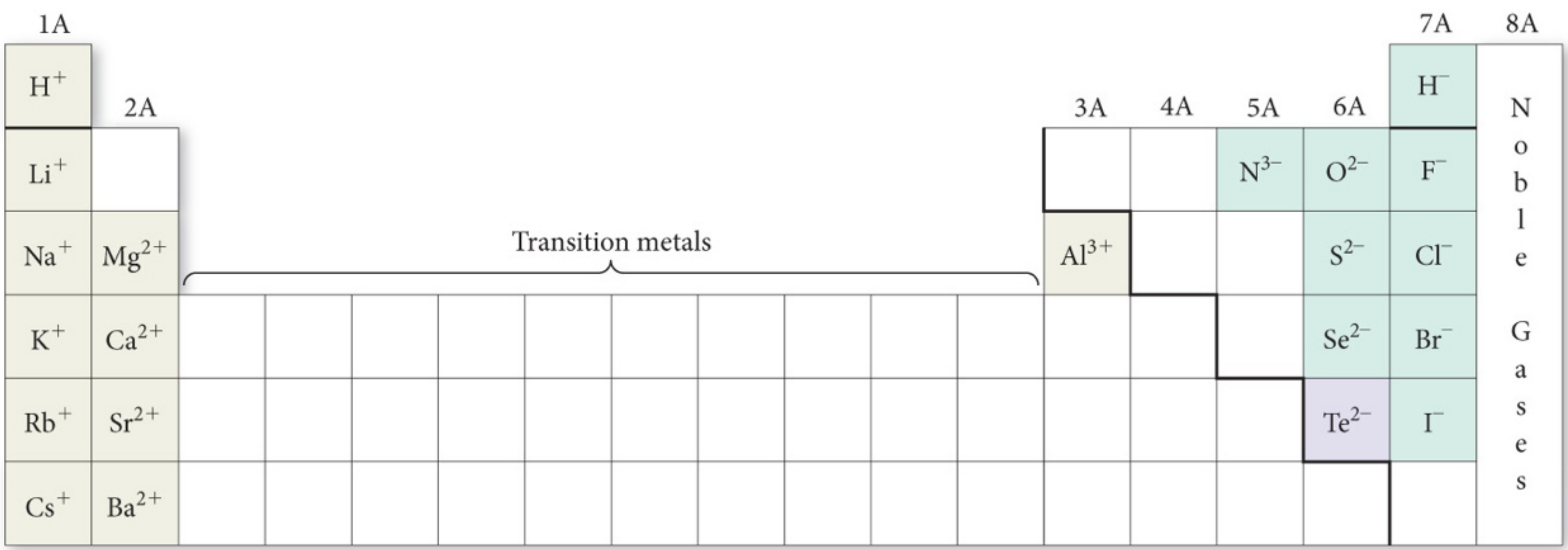








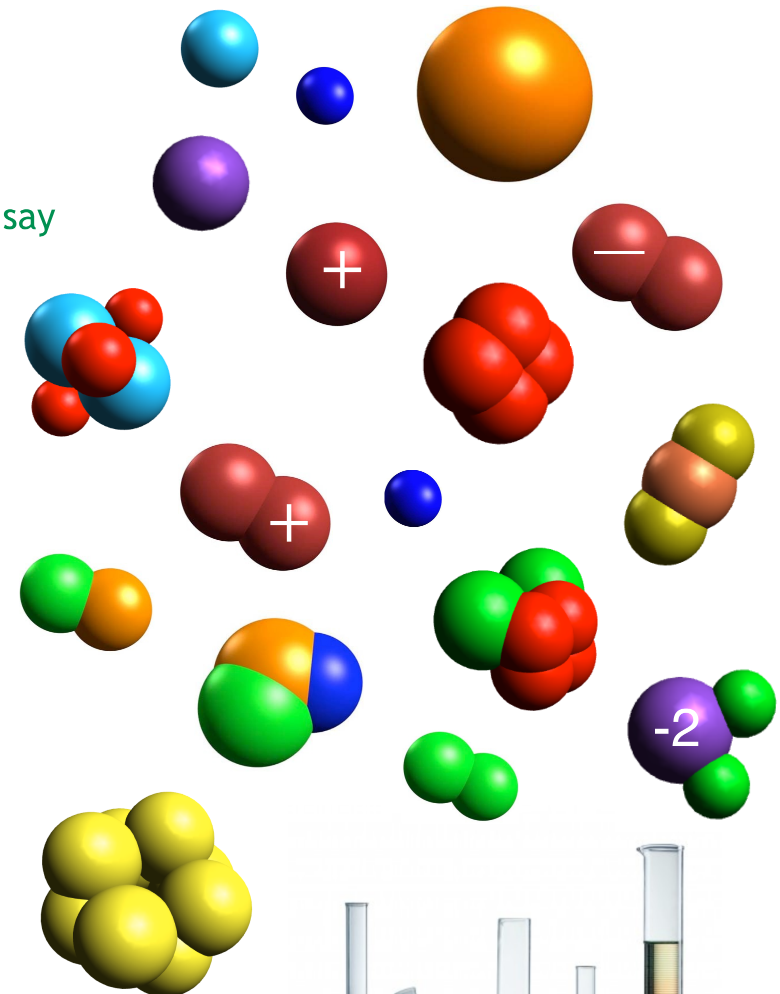
Many Ionic Charges are Predictable



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.

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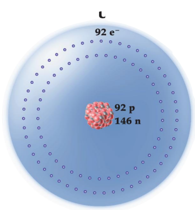

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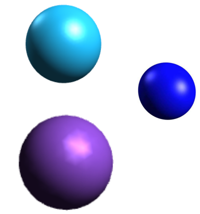

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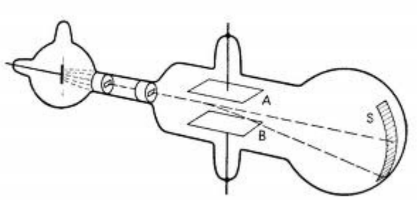
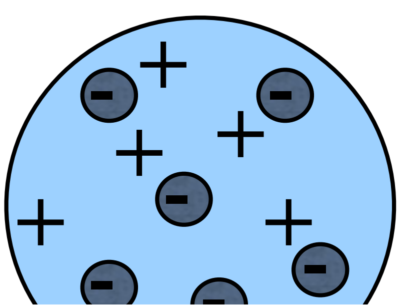
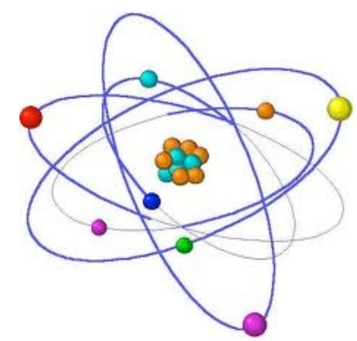
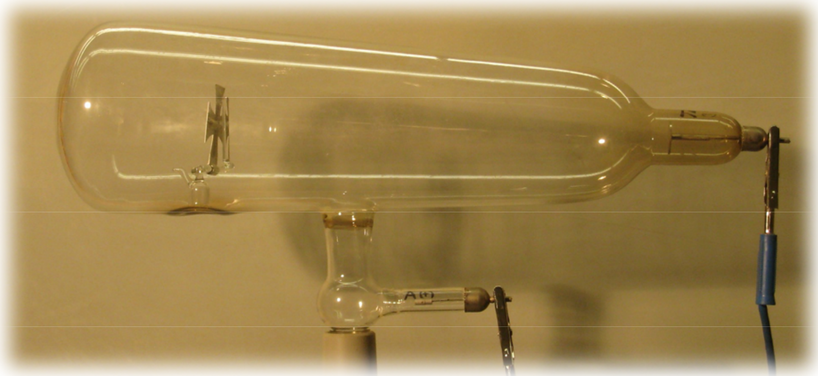


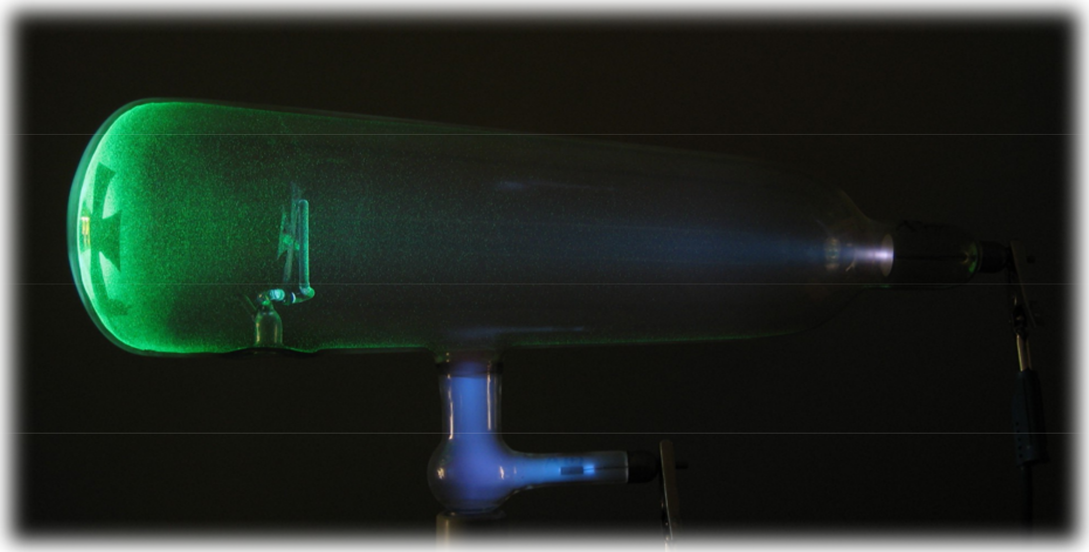


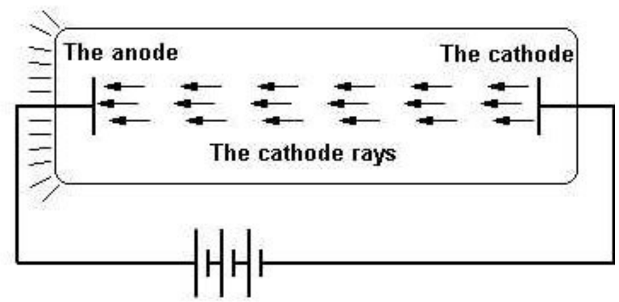


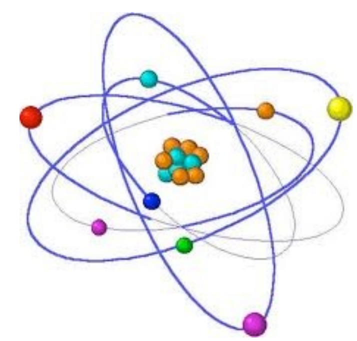
Cathode Ray Experiments

- 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...

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

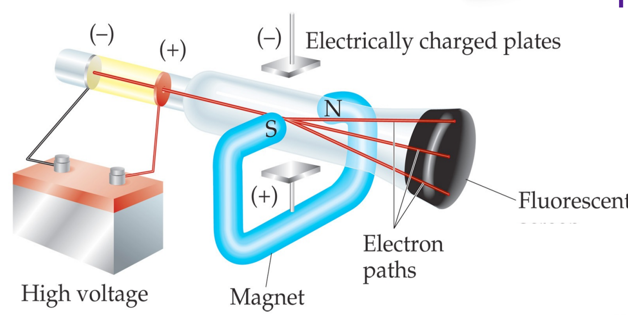
  - From the 1906 Nobel presentation speech:

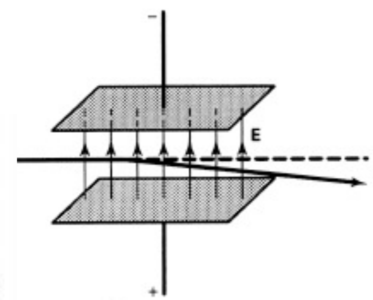
"Every day that passes witnesses electricity obtaining an ever-increasing importance in practical life. The conceptions, which a few decades ago were the subject of investigation in laboratories, have by this time become the property of the public at large. ...

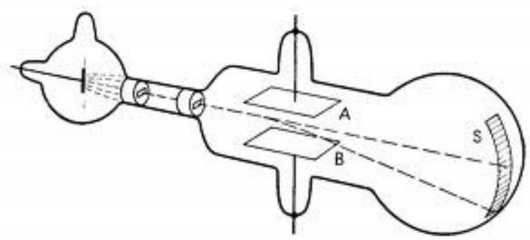
Faraday's law may be expressed thus, that a gram of hydrogen, or a quantity equivalent thereto of some other chemical element, carries an electric charge of 28,950 x 10^{10} electrostatic units. Now if we only knew how many hydrogen atoms there are in a gram, we could calculate how large a charge there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

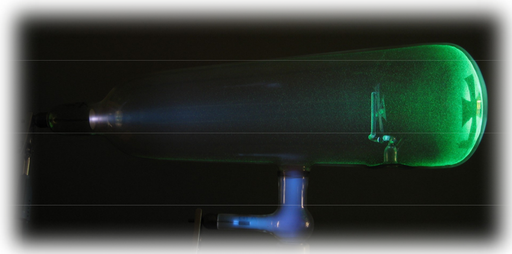
If Thomson has not actually beheld the atoms, he has nevertheless achieved work commensurable therewith, by having directly observed the quantity of electricity carried by each atom."

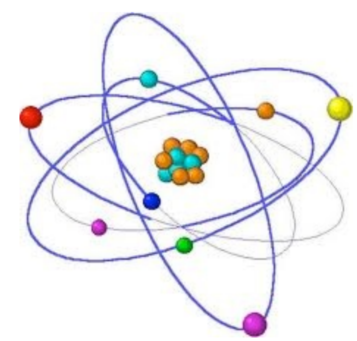
- In 1906 J.J. Thomson was awarded the Nobel prize "in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases".







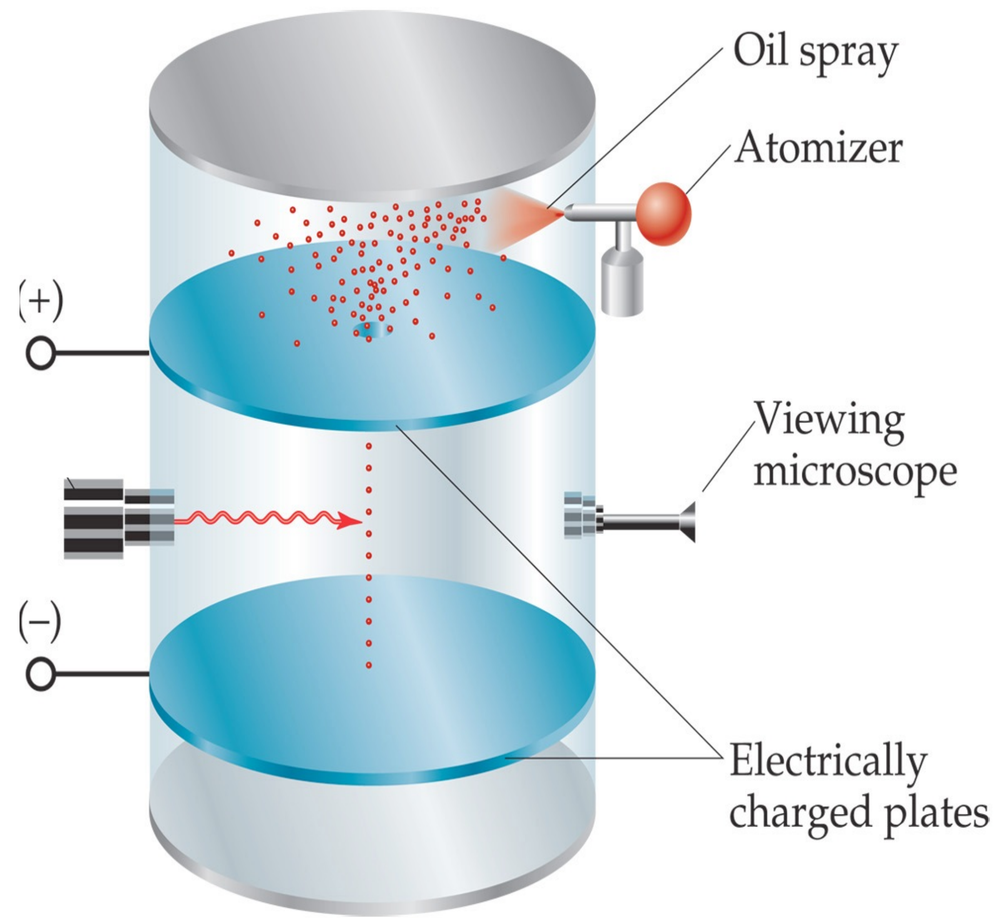




The Oil Drop Experiment

Millikan

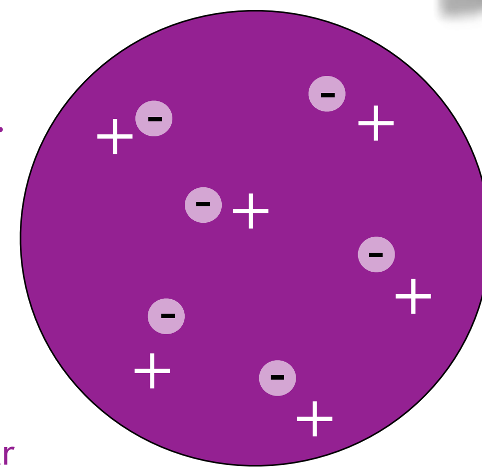
- Robert Millikan experimented with oil drops in 1909:
  - He charged oil drops with cathode ray particles.
  - He determined the mass and charge of minute oil drops by suspending them between electrically charged plates.
    - By measuring the diameter of the drop he could calculate it's size and therefore 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

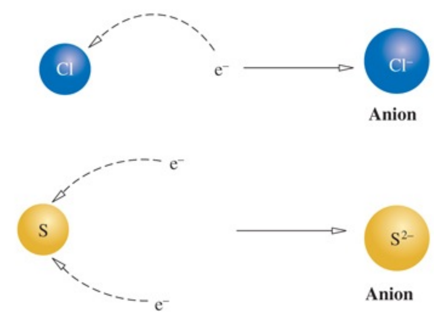
- Combining Thomson's mass to charge ratio and Millikan's smallest unit of charge disproves the theory that the atom is the smallest particle of matter.
  - The mass of the cathode particles is 9.10×10^{-28} g
  - The smallest known particle was the hydrogen atom, it weighs 1.673×10^{-24} g — 2000 times 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.

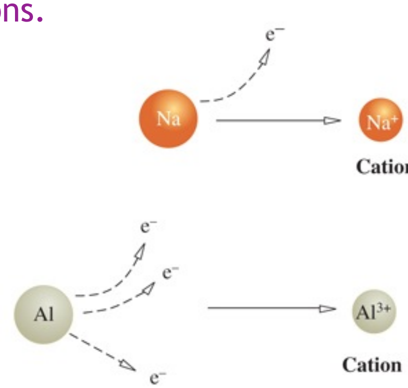


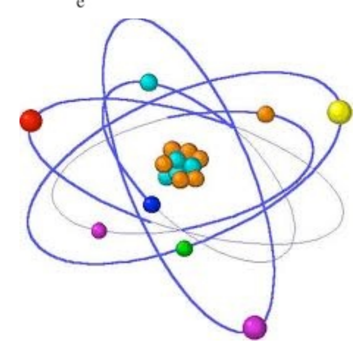
Dimensional Analysis

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

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







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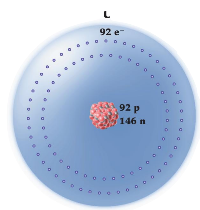

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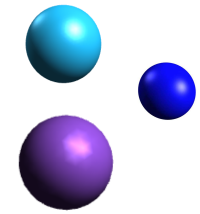

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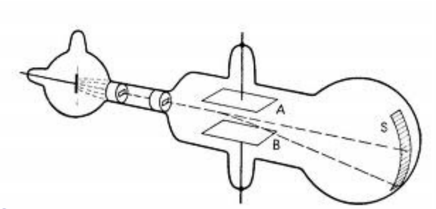
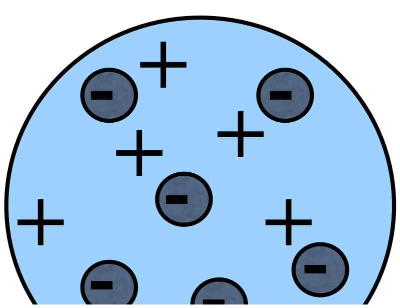
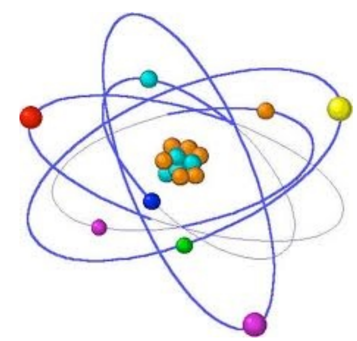


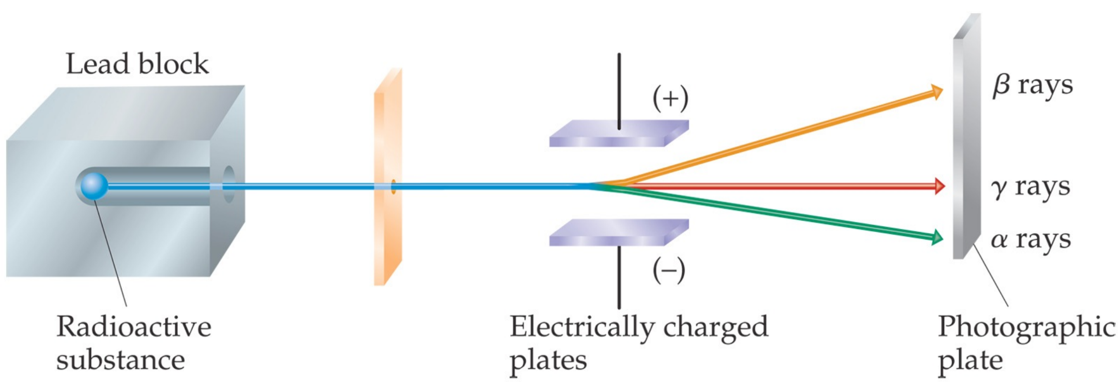


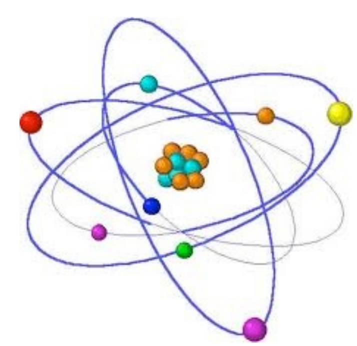


Radiation & Radioactivity

- 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





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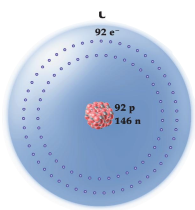

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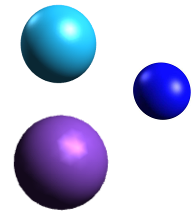

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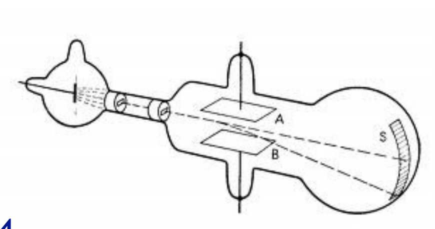
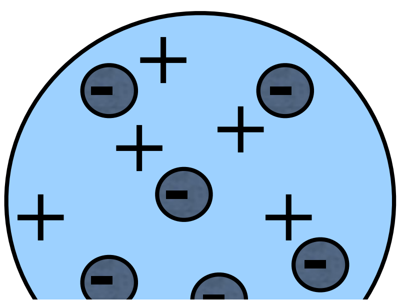
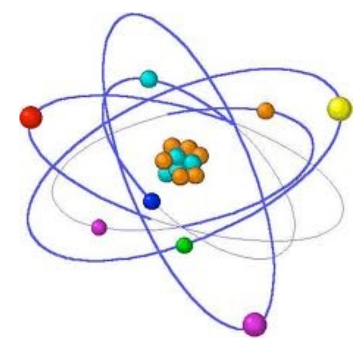
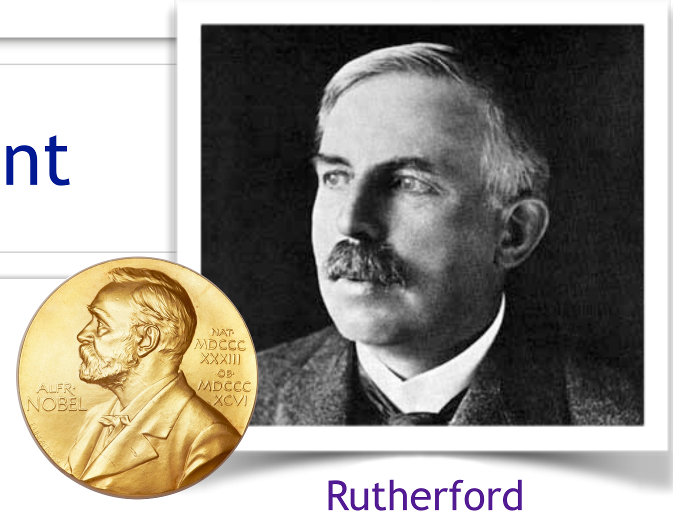




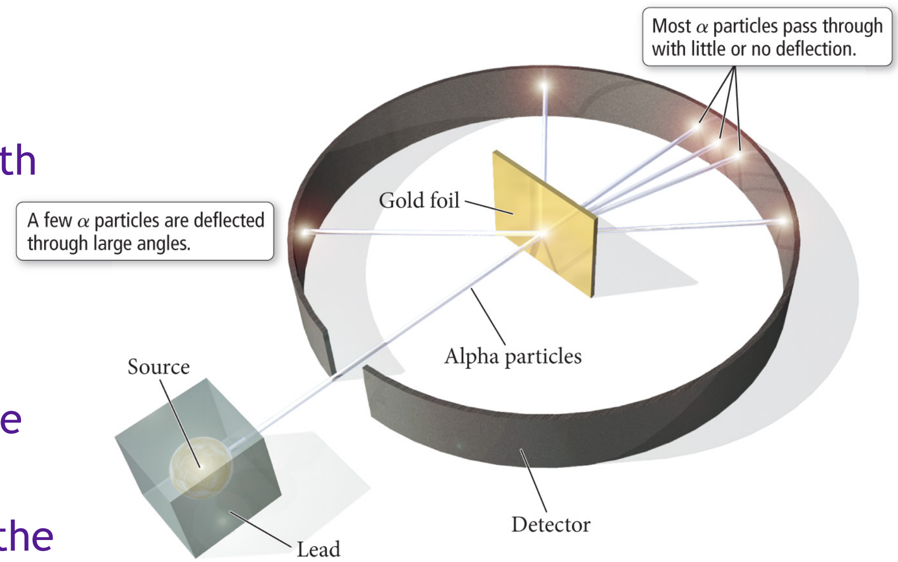


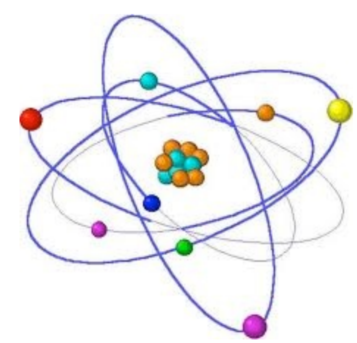
The Gold Foil Experiment



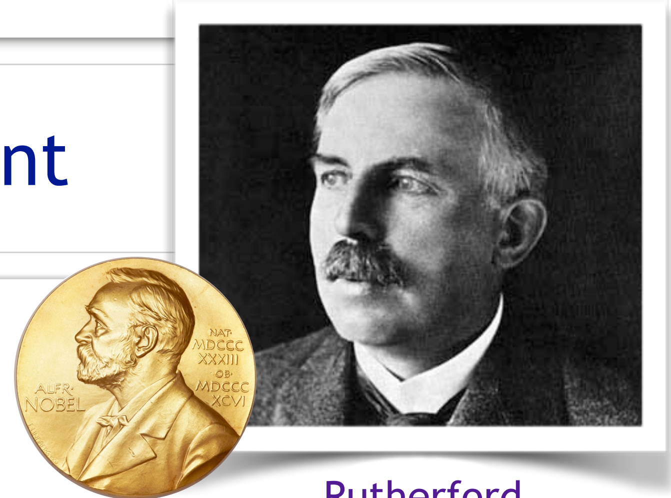
Rutherford

- 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".



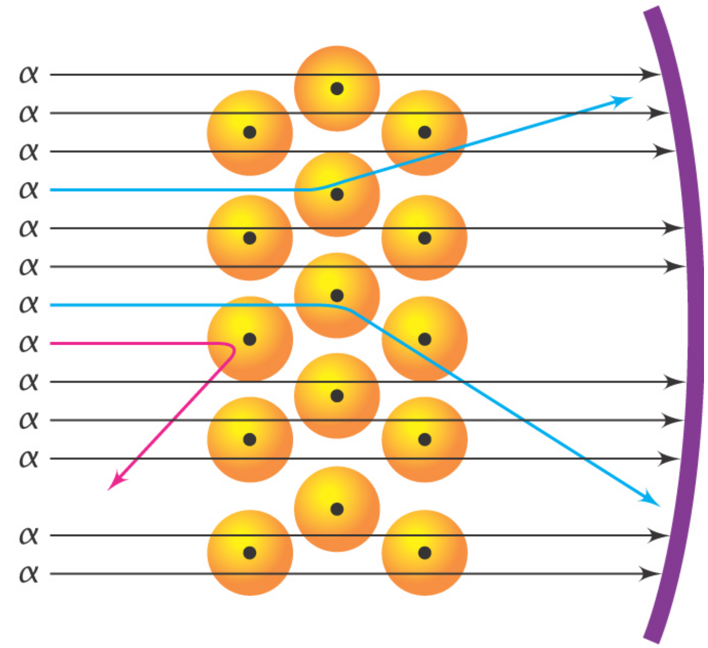


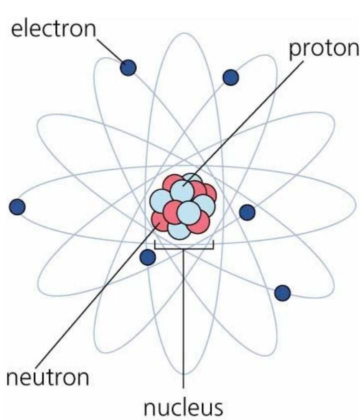
The Gold Foil Experiment

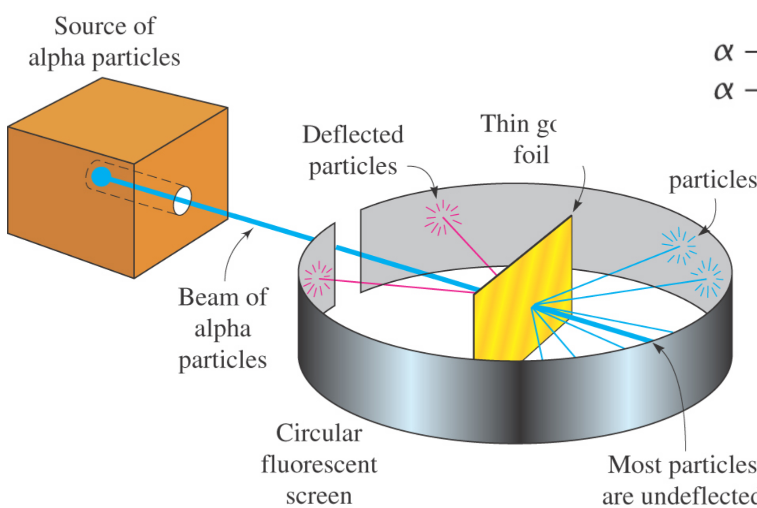


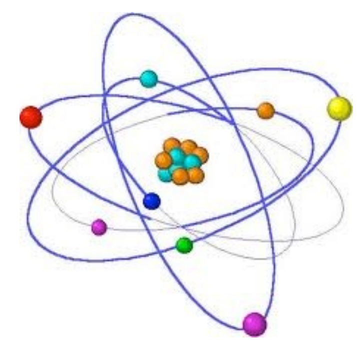
Rutherford

Observations		Hypothesis
Most alpha particles passed right through the gold as if it didn't exist.	→	Atoms are mostly empty space.
A very small number reflected back.	→	A very small but tremendously massive area existed inside the atom (more massive than an entire helium atom).
Some deflected as they passed through the atom.	→	The massive part was positively charged.



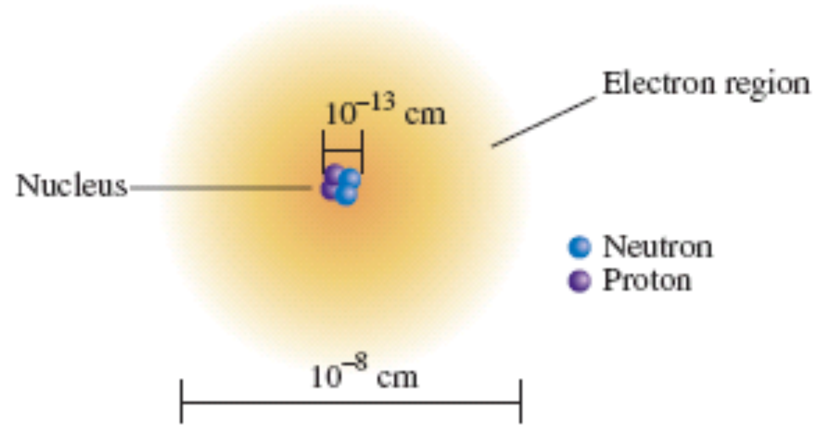


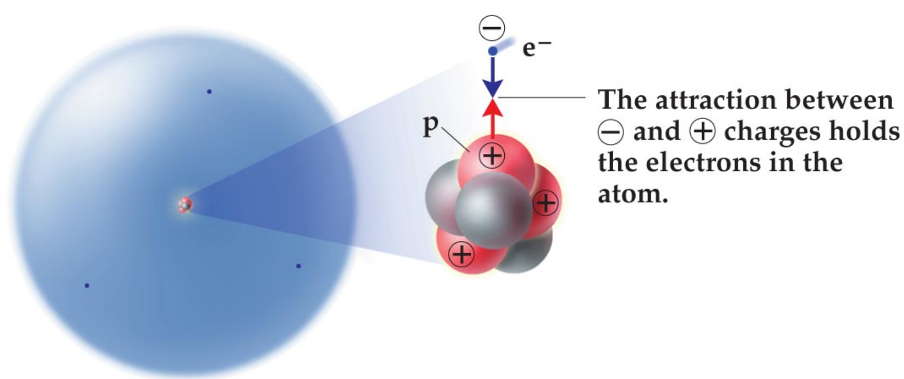


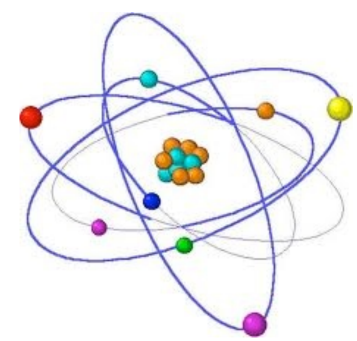


Atomic Theory 4.0 — The Nuclear Atom

- 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.





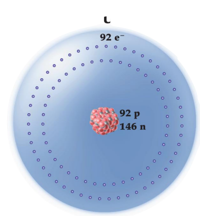


Particle	Charge	Mass (amu)
Proton	Positive (1+)	1.0073
Neutron	None (neutral)	1.0087
Electron	Negative (1−)	5.486×10^{-4}

Ch02

Atoms

- Wandering Atoms
  - Charge
- Subatomic Particles
  - Smaller than an Atom
    - Ions, Cathode Rays, Millikan’s Oil Drop
  - The Electron
  - Atomic Theory 3.0 — Plum Pudding
- Radioactive Matter
- Rutherford—the Nuclear Age
  - Radiation, Gold Foil, the Nucleus
    - Protons & Neutrons
  - Atomic Theory 4.0 — Nuclear Atom
  - Moseley Law
    - Atomic Number



- Flavors of the Atom
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    - Isotopic Notation
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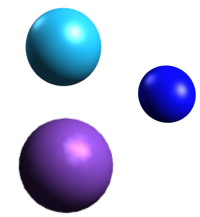

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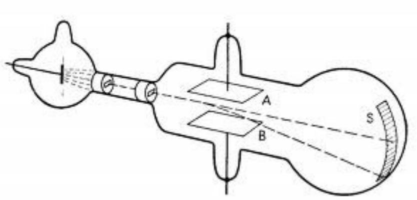
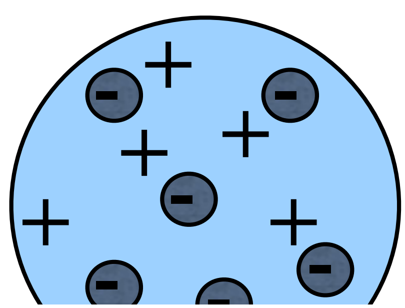
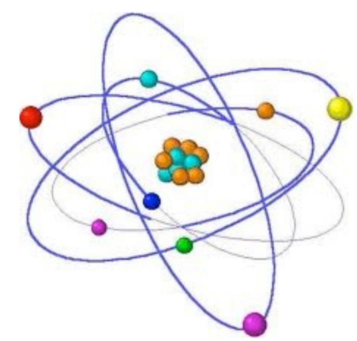


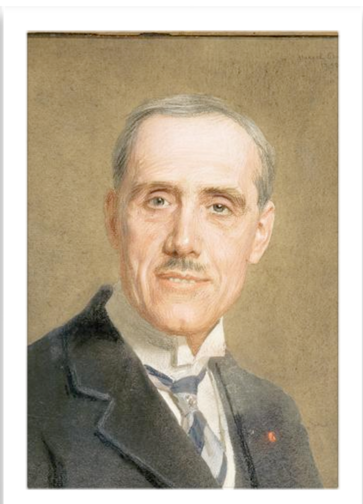


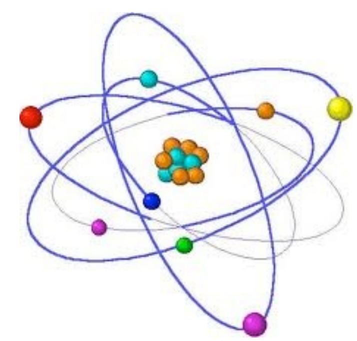


X-Ray Spectroscopy

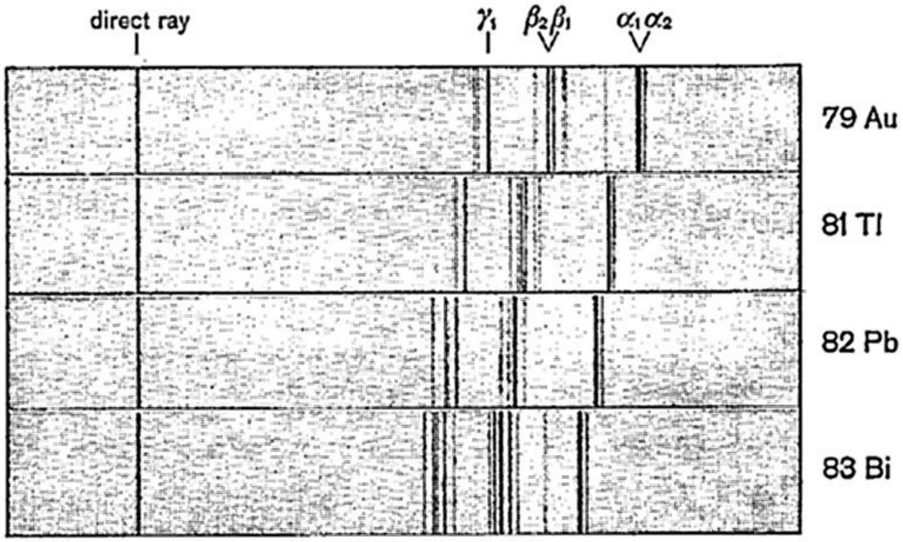
- While Rutherford probed for the nucleus of atoms with alpha particles other scientists approached the atom with radiant energy, like gamma radiation.
- Maurice de Broglie used radiant energy to probe crystals of pure elements and capture the energy radiated back with photographic plates.
- Of the rays that came back, Maurice found that ones in the K band gave the strongest, clearest signal.
- Henry Moseley examined these rays.


Henry Moseley
1887–1915

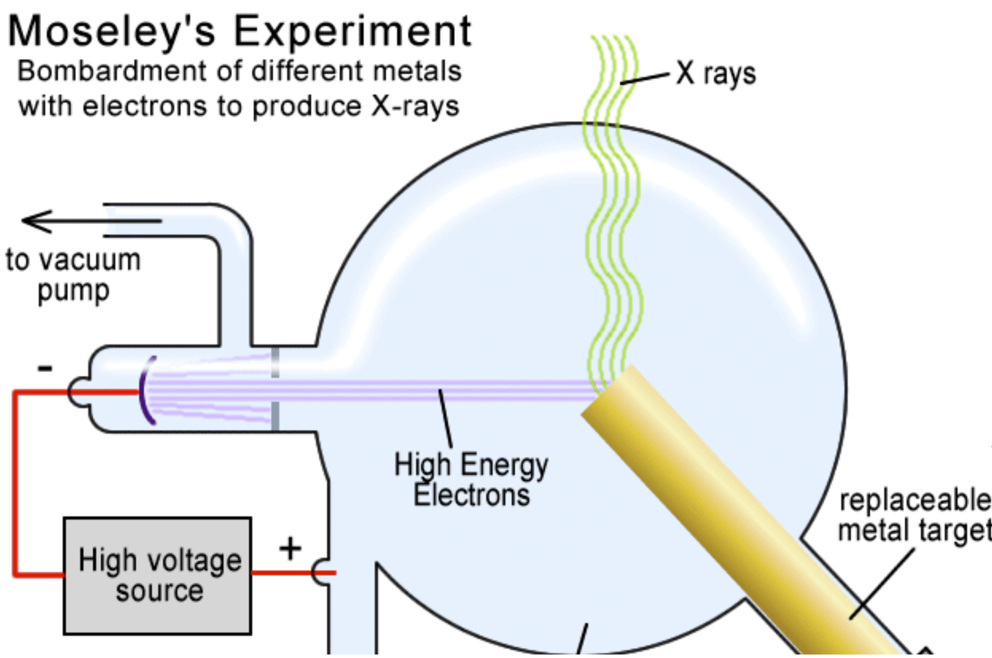

Maurice de Broglie
1875-1960



X-Ray Spectroscopy



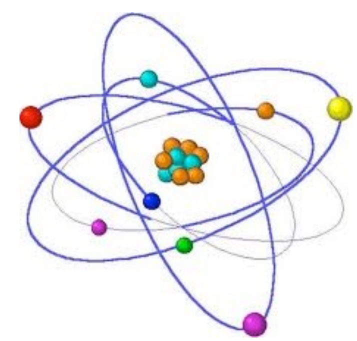
- Moseley found a pattern in these lines.
- Studying the elements $_{19}$Ca to $_{29}$Zn Moseley was able to show that the square root of the frequencies of the K-lines progressed linearly with the atomic number.
- He then measured several lines belonging to the L-series $_{40}$Zr to $_{79}$Au — and found the same pattern.
- The result became known as Moseley's law.



Moseley's Law

$$\nu = \frac{(10.2eV)(Z-1)^2}{h}$$

$$E = (10.2eV)(Z-1)^2$$



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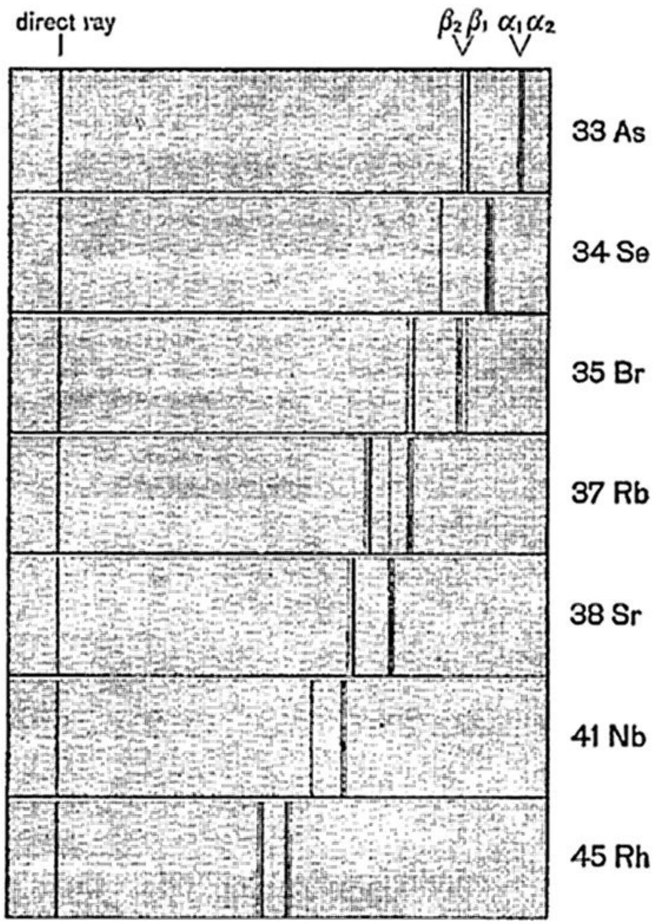
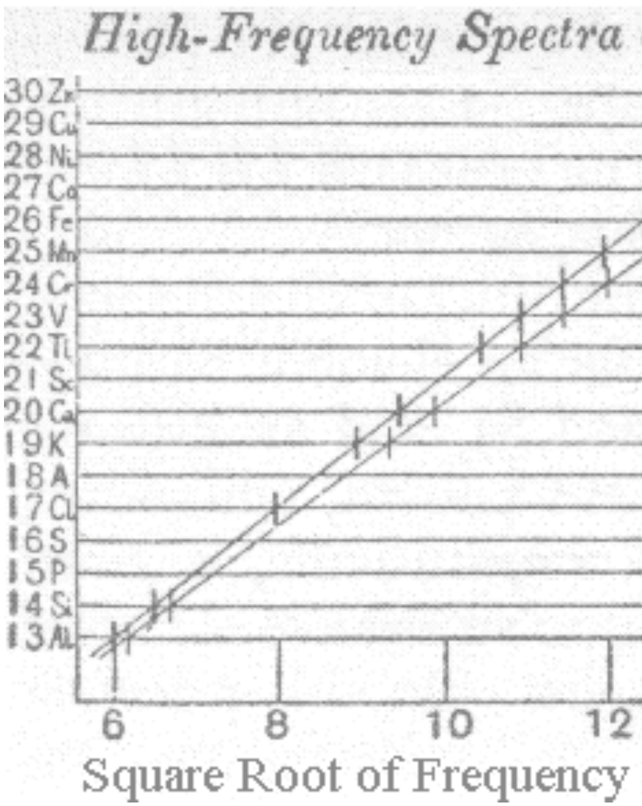
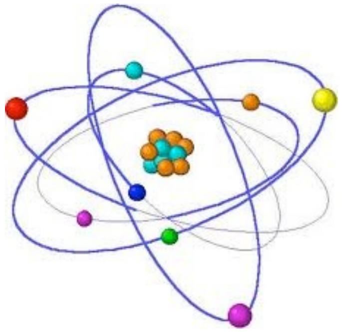


- Using Moseley's Law chemists were able to interpolate the K-alpha line for unknown elements representing gaps in the periodic table.
- … and then use that data to search for those unknown elements.
- George de Hevesy in 1923 used this technique to find element number 72 (Hafnium).
- Element 75 (Rhenium) was also found this way.





Atoms

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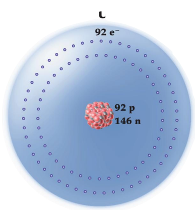

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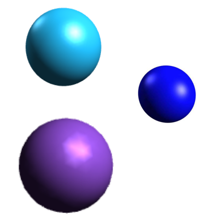

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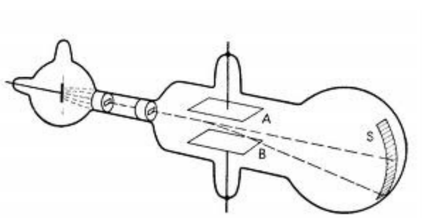
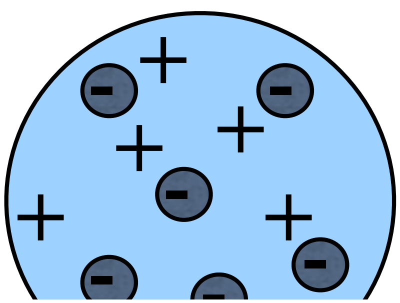
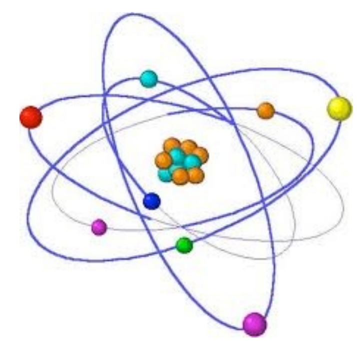






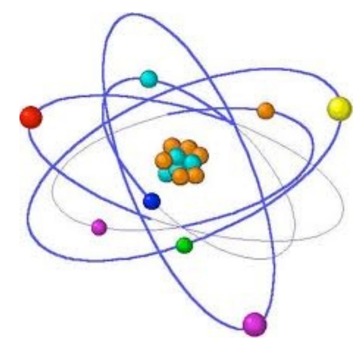
What do atomic numbers mean?

- Moseley proposed, and later experimentation supported, the idea that this fundamental integer, which must reflect some property of the nucleus, represented the positive nuclear charge of an atom.
  - Z is unique for each element.
  - Z increases roughly the same way an elements relative mass increases.
  - Moseley was able to demonstrate Z represented the positive charge on the nucleus of the atom.

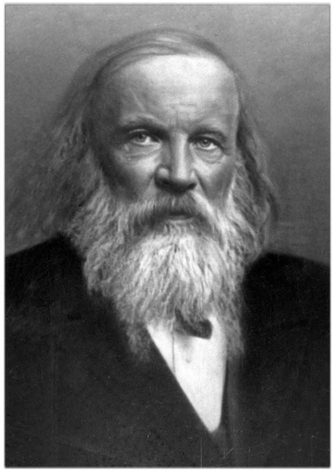
Henry Moseley 1887–1915

"We have here a proof that there is in the atom a fundamental quantity, which increases by regular steps as we pass from one element to the next. This quantity can only be the charge on the central positive nucleus, of the existence of which we already have definite proof." Henry Moseley

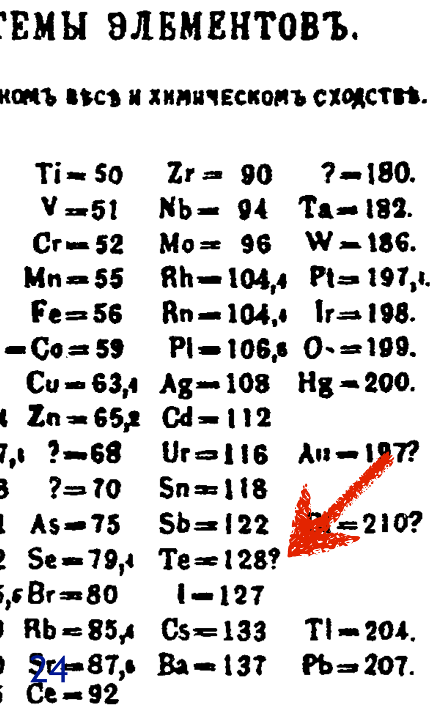
Moseley discovered that the number of protons in a nucleus is what defines an element.



It’s about protons.



Dmitri Mendeleev
1834-1907


ЕМЫ ЭЛЕМЕНТОВЪ.

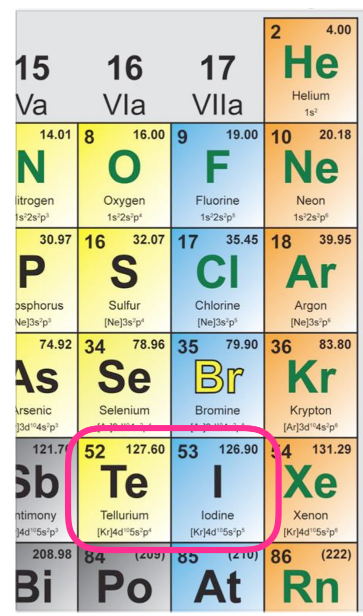
КОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

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	Rn=104,4	Ir=198.
Co=59	Pl=106,6	Os=199.
Cu=63,4	Ag=108	Hg=200.
Zn=65,2	Cd=112	
?=68	Ur=116	Au=197?
?=70	Sn=118	
As=75	Sb=122	Bi=210?
Se=79,4	Te=128?	
Br=80	I=127	
Rb=85,4	Cs=133	Tl=204.
Sr=87,6	Ba=137	Pb=207.
Ce=92		

- Mendeleev had organized his periodic table by the increasing relative mass of the elements.
  - He had issued each element a serial number, it’s Atomic Number.
- But periodic law had required him to put some heavier elements before lighter ones.
- The element tellurium (mass 128) is heaver than iodine (mass 127).
  - But iodine has the same periodic properties of F, Cl, and Br.
  - … and tellurium has the same properties as oxygen, sulfur, and selenium.
  - So Tellurium became #52 and Iodine #53.
- Mendeleev was smart enough to know he needed to swap the atomic numbers of these two elements… because of periodic law…
  but he never understood why because atomic theory hand’t caught up to that question yet.
- Moseley offered the explanation.

Moseley showed Tellurium has 52 protons, and Iodine has 53.

Henry Moseley
1887–1915



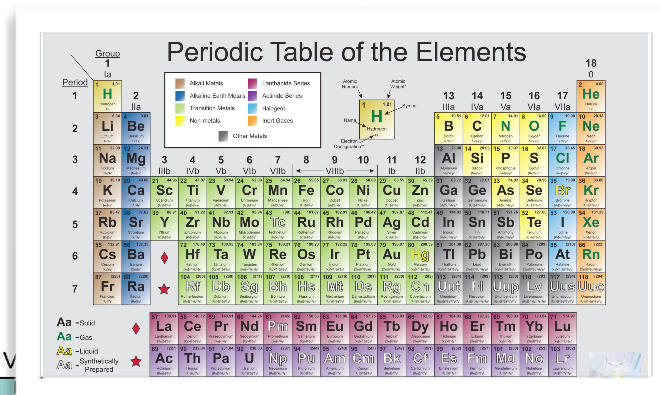
Period	1A[a] 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.94	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.96	43 **Tc** [98]	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** [208.98]	85 **At** [209.99]	86 **Rn** [222.02]
7	87 **Fr** [223.02]	88 **Ra** [226.03]	89 **Ac** [227.03]	104 **Rf** [261.11]	105 **Db** [262.11]	106 **Sg** [266.12]	107 **Bh** [264.12]	108 **Hs** [269.13]	109 **Mt** [268.14]	110 **Ds** [271]	111 **Rg** [272]	112 **Cn** [285]	113	114 **Fl** [289]	115	116 **Lv** [292]	117*	118

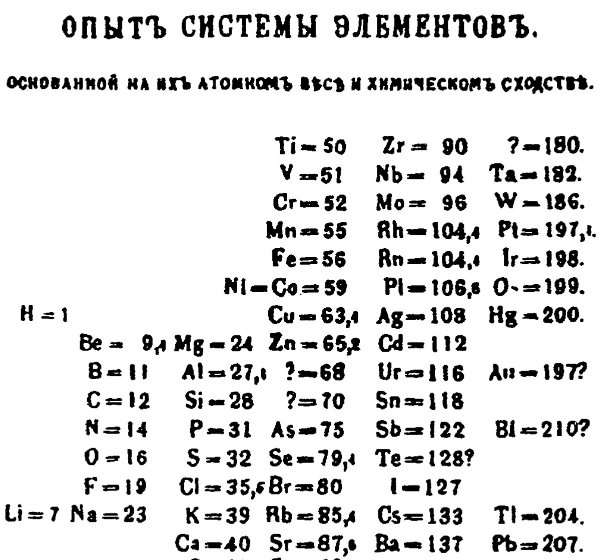
58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** [145]	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** [237.05]	94 **Pu** [244.06]	95 **Am** [243.06]	96 **Cm** [247.07]	97 **Bk** [247.07]	98 **Cf** [251.08]	99 **Es** [252.08]	100 **Fm** [257.10]	101 **Md** [258.10]	102 **No** [259.10]	103 **Lr** [262.11]

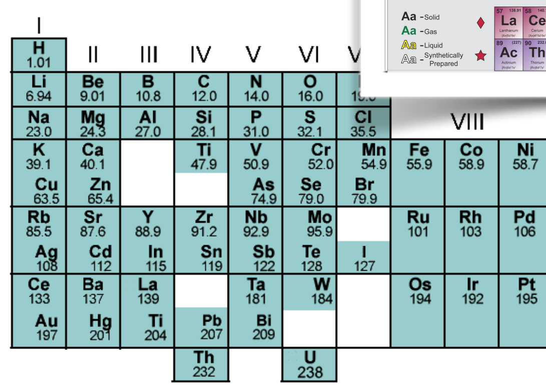
The single most costly…

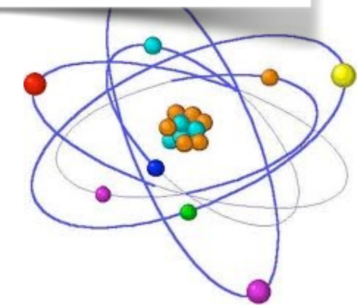
- Henry Moseley provided the last piece to the modern periodic table and an essential key to understanding the nuclear atom.
- When World War I broke out in Western Europe, Moseley left his research work at the University of Oxford behind to volunteer for the Royal Engineers of the British Army.
- Moseley was assigned to the force that invaded Gallipoli, Turkey, in April 1915, as a telecommunications officer.
- Moseley was shot and killed during the Battle of Gallipoli on 10 August 1915, at the age of 27.
  - Experts have speculated that Moseley could have been awarded the Nobel Prize in Physics in 1916, had he not been killed.
  - At 27 years old.
- Isaac Asimov called it ‘the single most costly death of the war’.

Henry Moseley 1887–1915









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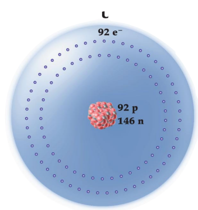

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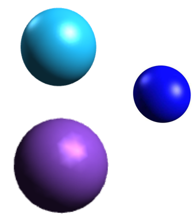

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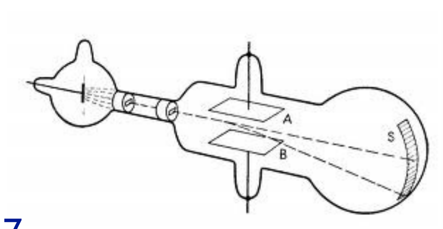
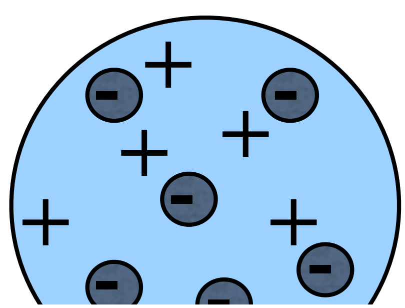
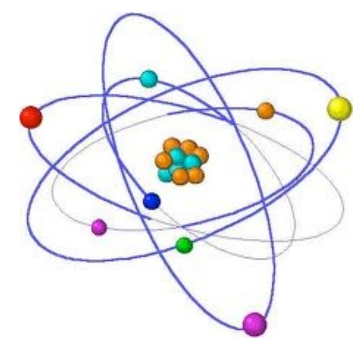
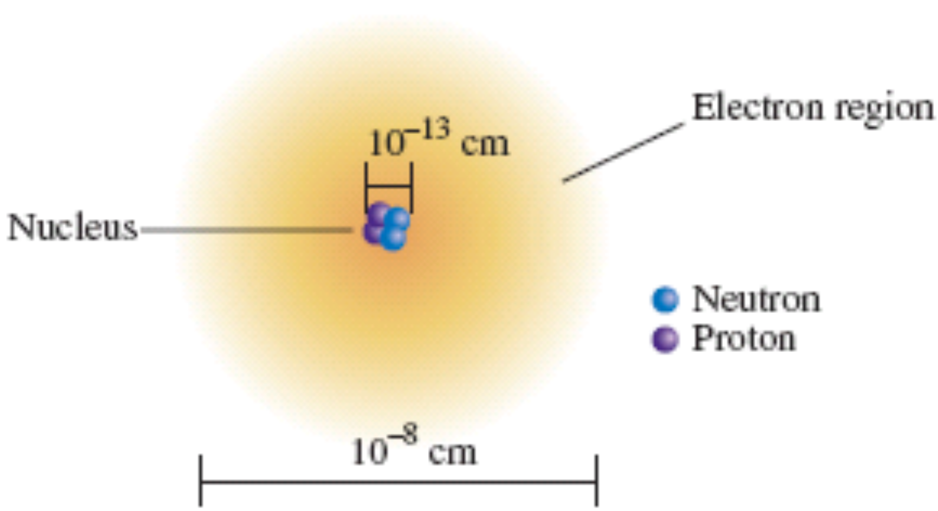


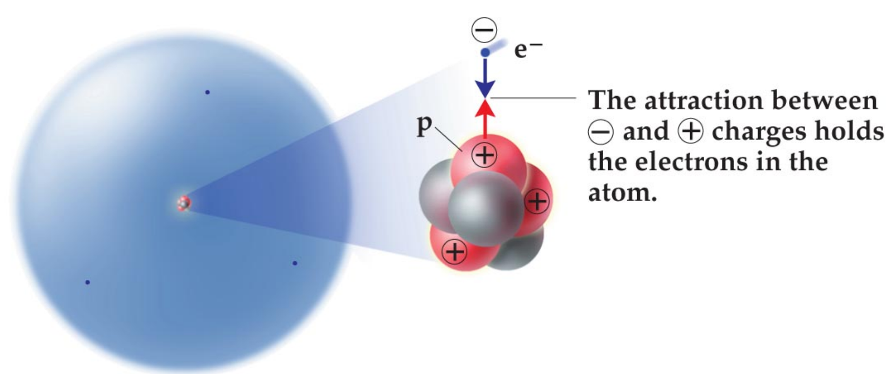




Pieces of the Atom

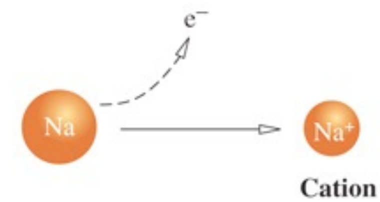
- Atoms are the smallest particle of an element that can enter into a chemical reaction.
- Protons and neutrons make up the dense, positive nucleus.
- Electrons occupy the empty space outside the nucleus.
- A neutral atom contains the same number of electrons and protons.



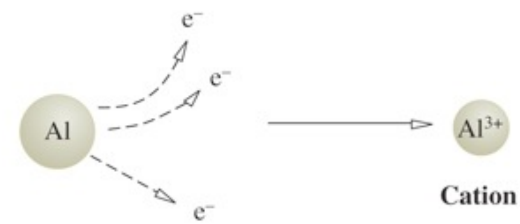


Ions

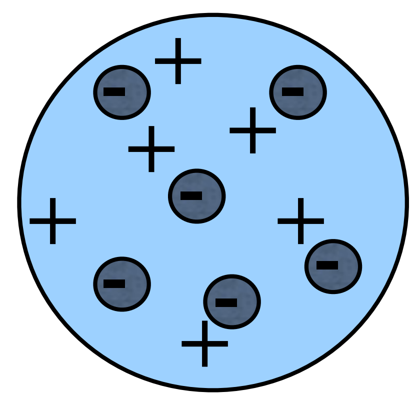
- JJ Thomson explained Michael Faraday's observations about some atoms being charged with his plumb pudding model (theory).

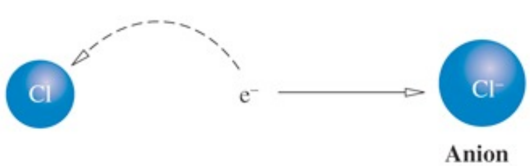


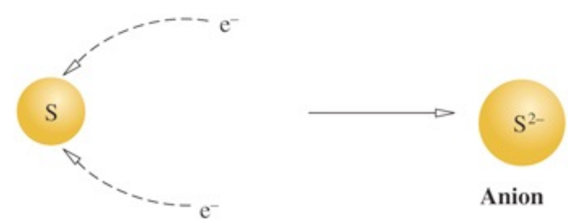
- Cations are formed by removing an electron from the atom.
  - Leaving more protons than protons and a net positive charge.
    - The difference between Al atom and Al^{3+} ion is the number of electrons.
    - The ion has ***very*** different properties than the atom.
      - Do not confuse them.



- Anions are formed by adding an electron to an atom.
  - Leaving more electrons than protons and a net negative charge.
    - The difference between S atom and S^{2-} ion is the number of electrons.
    - The ion has ***very*** different properties than the atom.
      - Do not confuse them.







Ch02

Atoms

- Wandering Atoms
  - Charge
- Subatomic Particles
  - Smaller than an Atom
    - Ions, Cathode Rays, Millikan's Oil Drop
  - The Electron
  - Atomic Theory 3.0 — Plum Pudding
- Radioactive Matter
- Rutherford—the Nuclear Age
  - Radiation, Gold Foil, the Nucleus
    - Protons & Neutrons
  - Atomic Theory 4.0 — Nuclear Atom
  - Moseley Law
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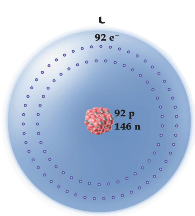

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  - Elements, proton count
  - Isotopes, mass
    (because they differ in neutron count)
    - Isotopic Notation
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  - Counting by weight
    - the AMU
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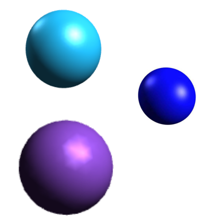
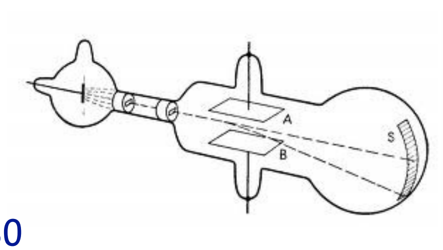
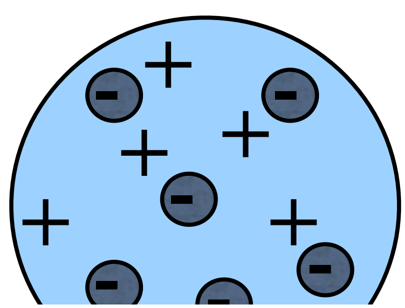


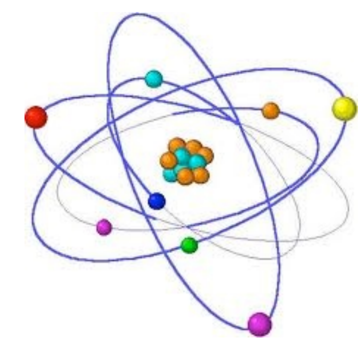
$^{A}_{Z}E$

$^{63}_{29}Cu$

$^{65}_{29}Cu$

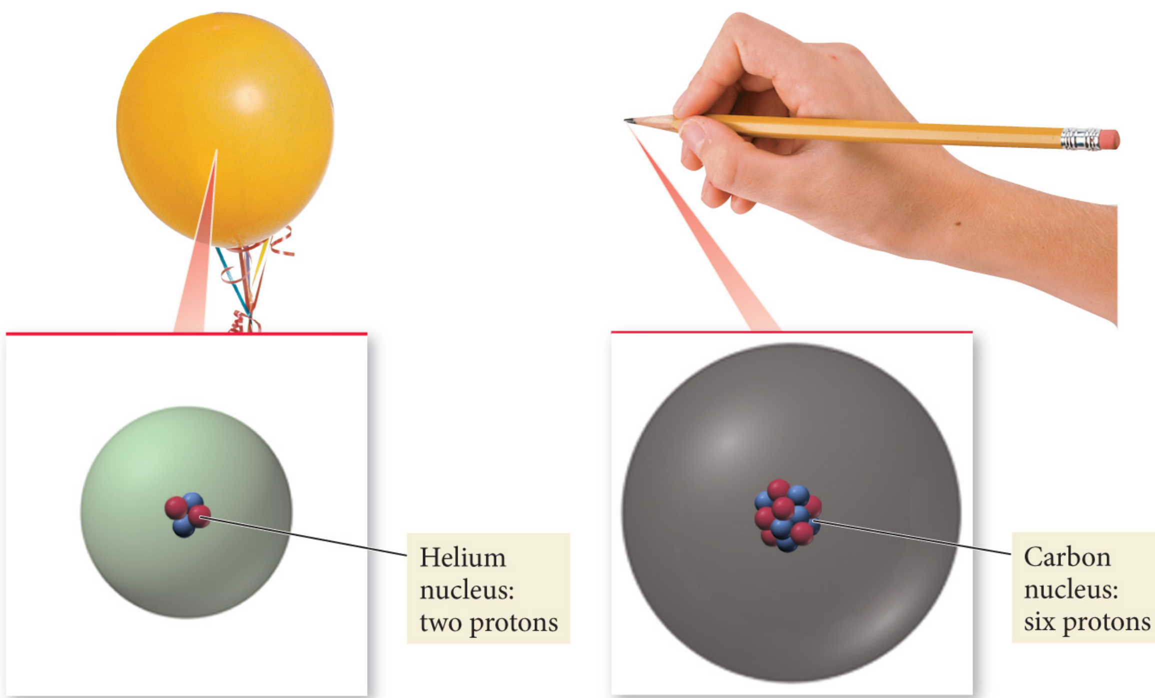






Elements differ in Protons

- If all atoms are made up of protons, neutrons, and electrons — what makes one element different from another?
- Elements differ by the number of protons.
- Carbon atoms have six protons. Helium atoms have two protons. Always.



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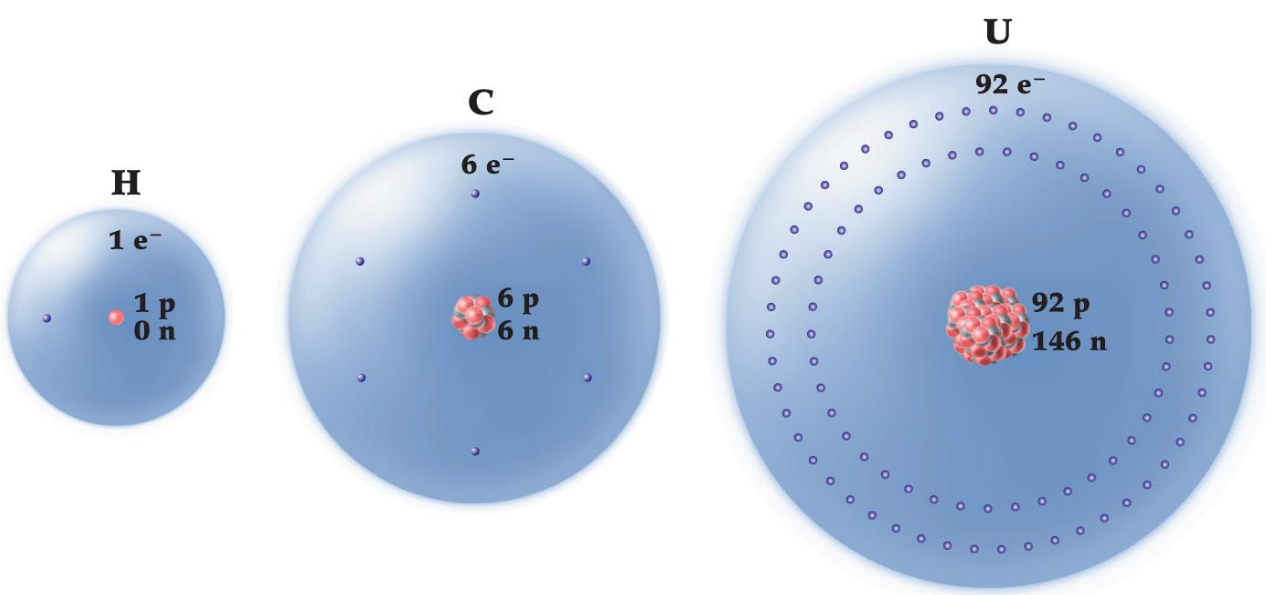
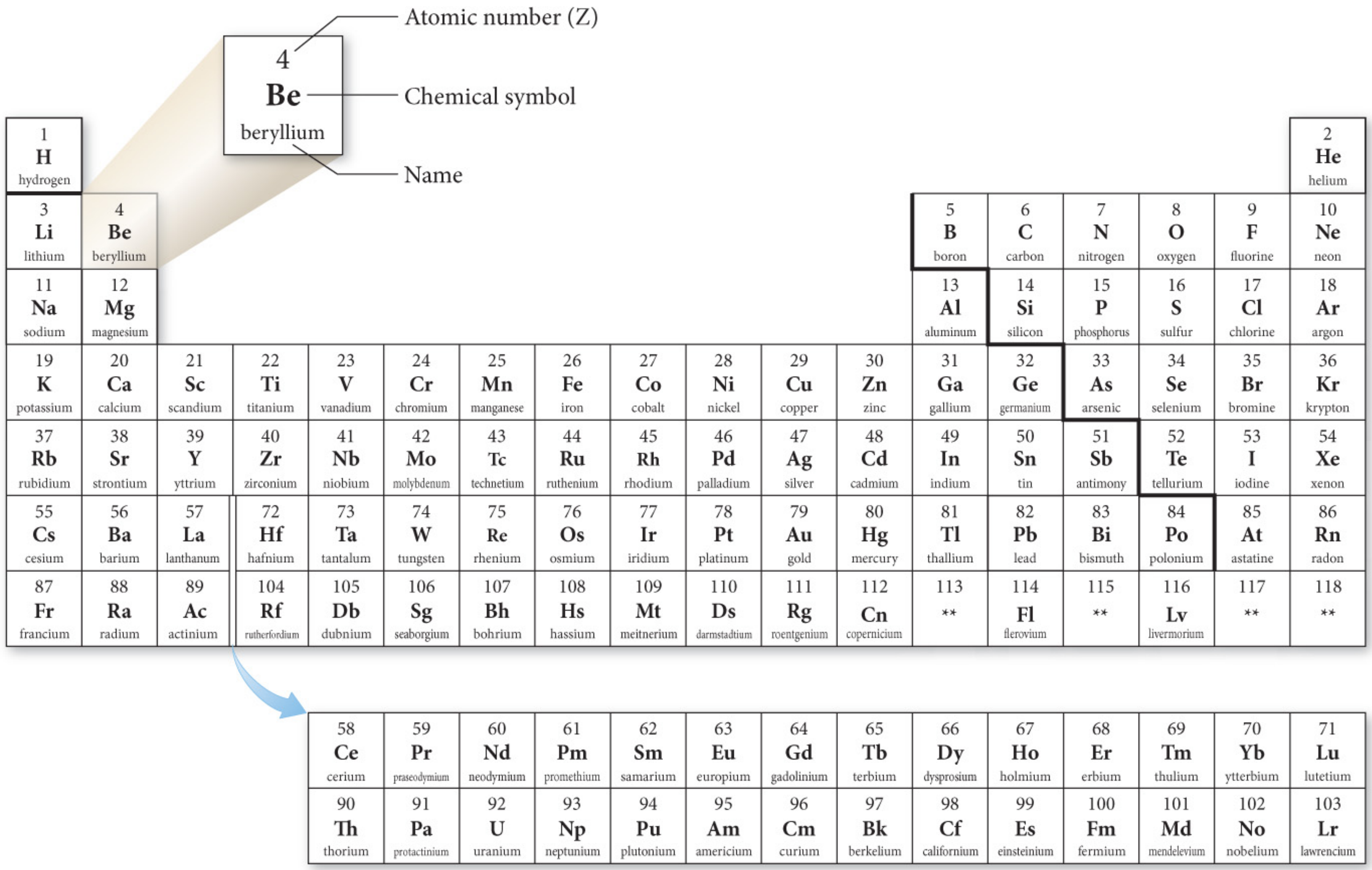


Elements differ in Protons

- The “serial number” in the periodic table is the atomic number.
- The atomic number equals the number of protons for that element.



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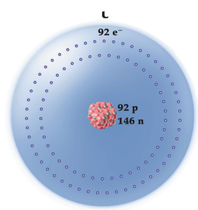

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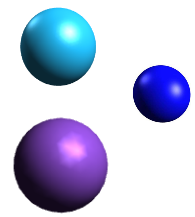

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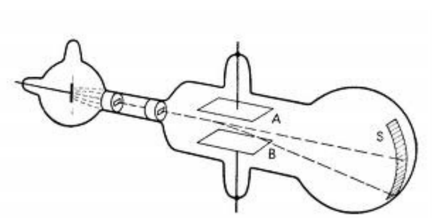
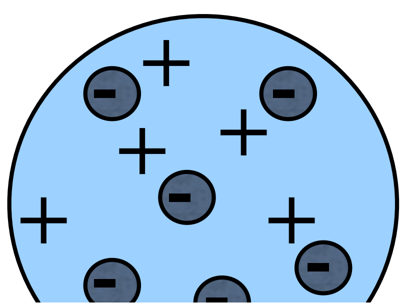
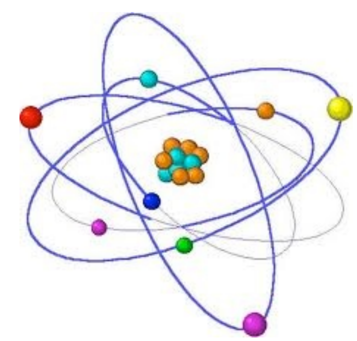
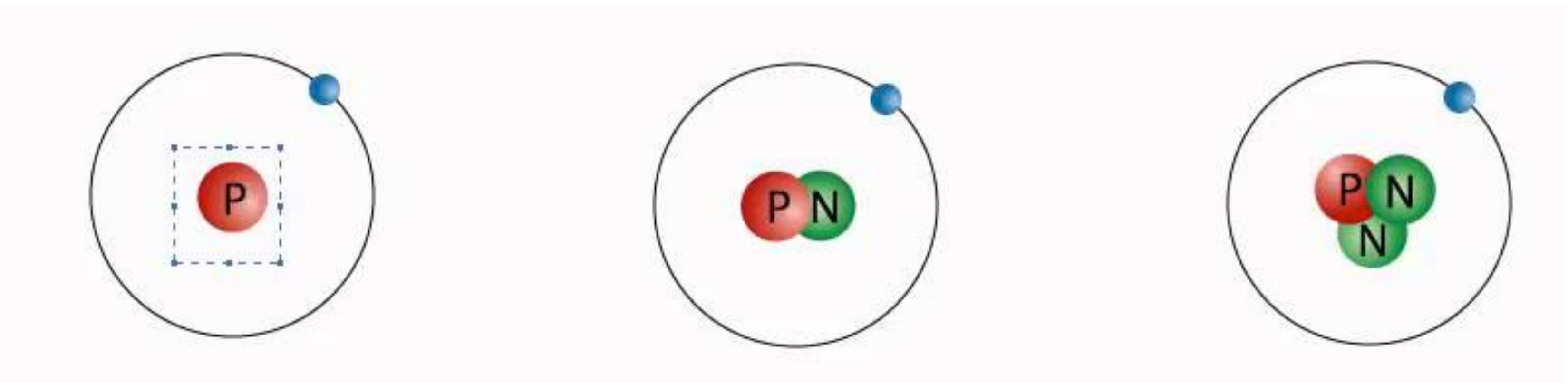






Isotopes differ in Mass

- All atoms of the same element, have the same number of protons.
- But may not have the same weight.
- Some hydrogen atoms weigh twice as much as other hydrogen atoms.
- The difference is in the number of neutrons.
- Atoms of the same element but different masses are called isotopes.



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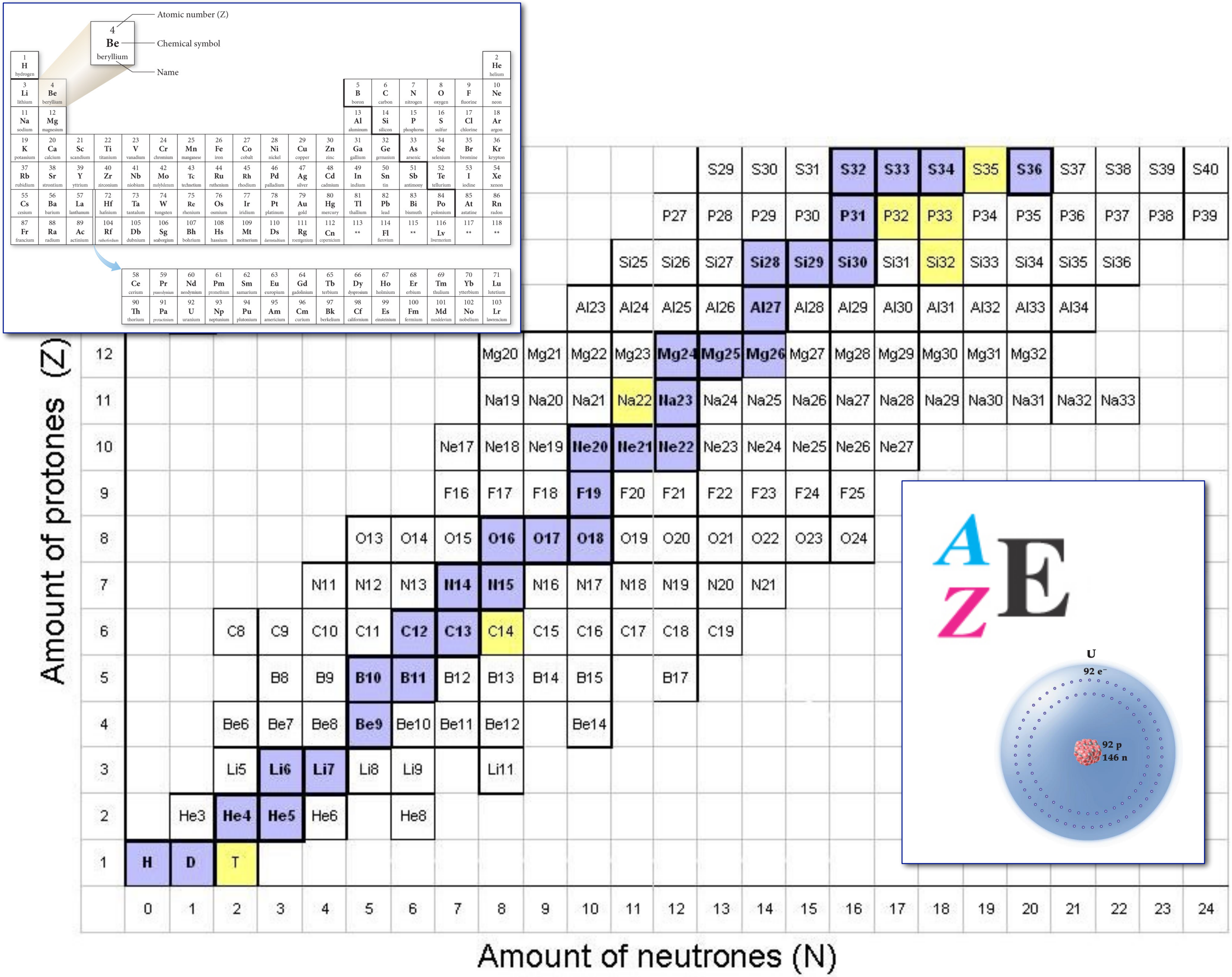
- Atoms of the same element but different masses are called isotopes.
- Isotopes are defined by their number of neutrons.
- We use isotopic notation to describe different isotopes.



Atomic number (Z)
Chemical symbol
Name
4 Be beryllium
Amount of protones (Z)
Amount of neutrones (N)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
1 2 3 4 5 6 7 8 9 10 11 12
H D T
He3 He4 He5 He6 He8
Li5 Li6 Li7 Li8 Li9 Li11
Be6 Be7 Be8 Be9 Be10 Be11 Be12 Be14
B8 B9 B10 B11 B12 B13 B14 B15 B17
C8 C9 C10 C11 C12 C13 C14 C15 C16 C17 C18 C19
N11 N12 N13 N14 N15 N16 N17 N18 N19 N20 N21
O13 O14 O15 O16 O17 O18 O19 O20 O21 O22 O23 O24
F16 F17 F18 F19 F20 F21 F22 F23 F24 F25
Ne17 Ne18 Ne19 Ne20 Ne21 Ne22 Ne23 Ne24 Ne25 Ne26 Ne27
Na19 Na20 Na21 Na22 Na23 Na24 Na25 Na26 Na27 Na28 Na29 Na30 Na31 Na32 Na33
Mg20 Mg21 Mg22 Mg23 Mg24 Mg25 Mg26 Mg27 Mg28 Mg29 Mg30 Mg31 Mg32
Al23 Al24 Al25 Al26 Al27 Al28 Al29 Al30 Al31 Al32 Al33 Al34
Si25 Si26 Si27 Si28 Si29 Si30 Si31 Si32 Si33 Si34 Si35 Si36
P27 P28 P29 P30 P31 P32 P33 P34 P35 P36 P37 P38 P39
S29 S30 S31 S32 S33 S34 S35 S36 S37 S38 S39 S40
A
Z
E
U
92 e⁻
92 p
146 n

Isotopes differ in Mass

$${}^{A}_{Z}E$$

- What would the symbol be for the Carbon-12 isotope?

6 protons + 6 neutrons

$${}^{12}_{6}C$$

6 protons

- What would the symbol be for the Carbon-14 isotope?

6 protons + 8 neutrons

$${}^{14}_{6}C$$

6 protons

Isotopes differ in Mass

$^{A}_{Z}E$

- Oxygen has three isotopes…
  - Oxygen-16
  - Oxygen-17
  - Oxygen-18

8 protons + 9 neutrons

$^{17}_{8}O$

8 protons

8 protons + 8 neutrons

$^{16}_{8}O$

8 protons

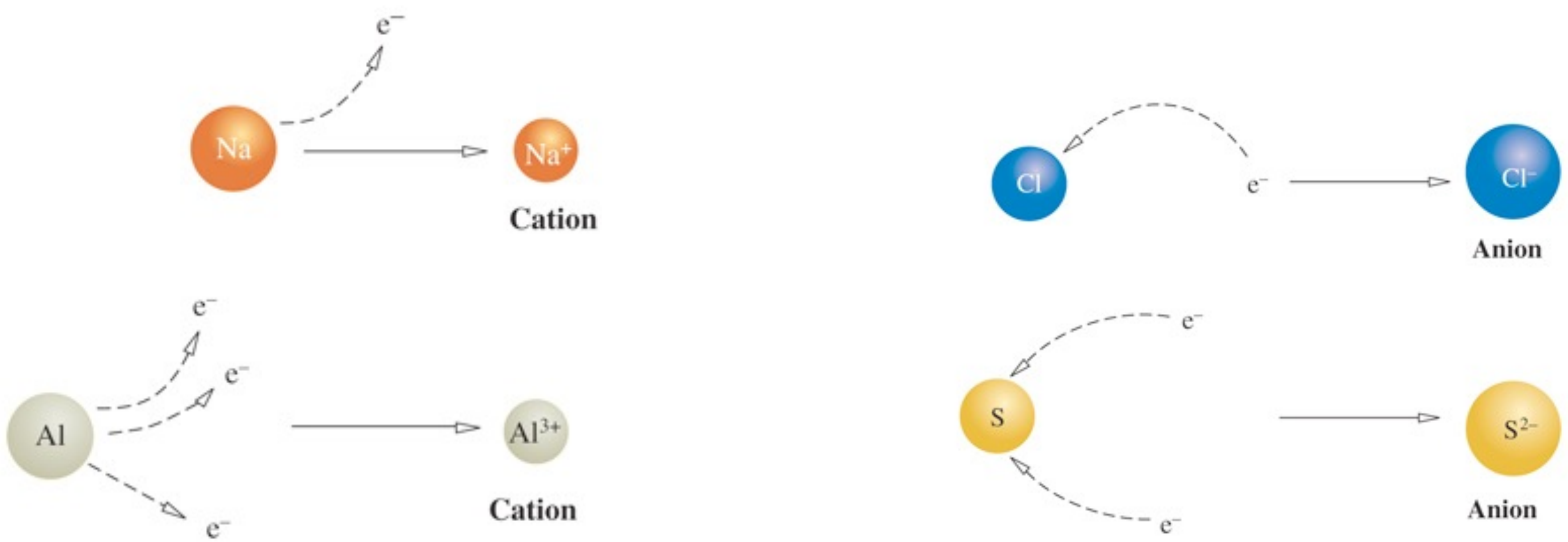
8 protons + 10 neutrons

$^{18}_{8}O$

8 protons

Ions differ in Electrons

- For a neutral atom, the number of protons equals the number of electrons.
- For a cation, there are less electrons than protons.
- For an anion, there are more electrons than protons.



Ions differ in Electrons

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$^{35}_{17}Cl$

17 protons,
17 electrons

$^{35}_{17}Cl^{-}$

17 protons,
18 electrons

Ions differ in Electrons

- For a neutral atom, the number of protons equals the number of electrons.
- For a cation, there are less electrons than protons.
- For an anion, there are more electrons than protons.

$$^{1}_{1}H$$

1 proton,
1 electron

$$^{1}_{1}H^{+}$$

1 proton,
0 electrons

Taking Atoms Apart

Symbol	Protons	Neutrons	Electrons	Mass
$^{44}_{11}Na$	11	33	11	44
$^{49}_{16}S$	16	33	16	49
$^{16}_{5}B$	5	11	5	16
$^{40}_{13}Al^{+3}$	13	27	10	40

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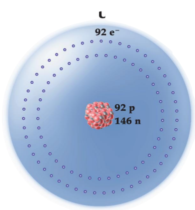

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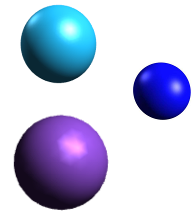

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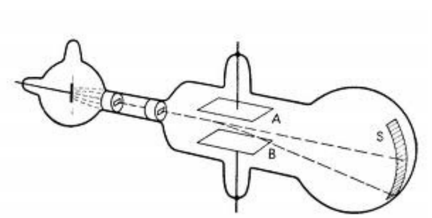
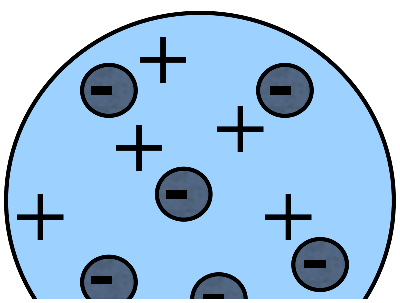
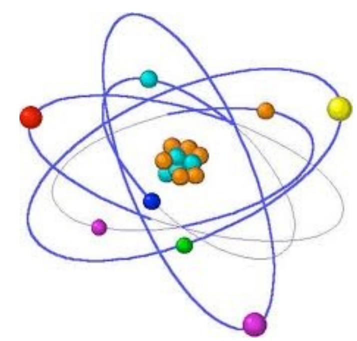
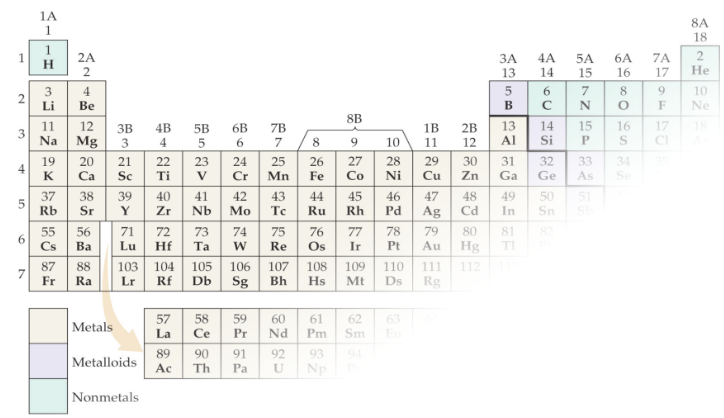






Counting by Weight

- A banker doesn't count pennies.
  - He know's how much a penny weighs. If you give him a bag of pennies he will weigh the bag, divide it by a pennies average weight and tell you the bags value.



$$508\,g \times \frac{1\ \text{Penny}}{2.50\,g} = 203.2\ \text{Pennies}$$

$$\boxed{203\ \text{Pennies}}$$

Counting by Weight

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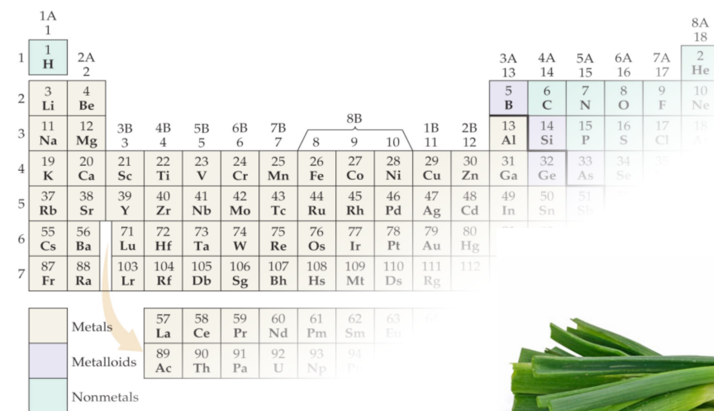
  - He know's how much a penny weighs. If you give him a bag of pennies he will weigh the bag, divide it by a pennies average weight and tell you the bags value.
- A banquet chef does the same.
  - If a recipe calls for 2 tomatoes per serving, he won't count out tomatoes to feed a thousand folks, he'll calculate the weight of 2,000 tomatoes and put baskets of them on the scale until he gets that weight.
  - But tomatoes don't have a single weight, like pennies do.
  - They come in different sizes.
  - So the chef needs to know the average weight of his tomatoes.



Weighted Averages

- How do you find the average mass of a tomato?
- If you have two tomatoes, you add their mass and divide by the number of tomatoes.

200 grams

100 grams

$$\frac{200g + 100g}{2} = 150g$$

$$\frac{200g + 200g + 100g + 100g + 100g + 100g + 100g + 100g + 100g + 100g}{10} = 120g$$

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- How do you find the average mass of a tomato?
- If you have two tomatoes, you add their mass and divide by the number of tomatoes.

200 grams

100 grams

$$\frac{200g + 100g}{2} = 150g$$

- If you have a lot of tomatoes, it might be easier to multiply the amount of tomatoes you have of each mass by that value rather than add them one at a time.
- The number of tomatoes at each mass over the total number of tomatoes is also the percent at each mass – if 8 of your 10 tomatoes is 100 grams, that's 80% of your tomatoes.

$$\frac{2 \times 200g + 8 \times 100g}{10}$$

$$= \frac{2}{10} \times 200g + \frac{8}{10} \times 100g$$

$$= 20\% \text{ of } 200g + 80\% \text{ of } 100g$$

$$= 0.20 \times 200g + 0.80 \times 100g$$

$$= 40g + 80g$$

$$= 120g$$

- If you have so many tomatoes you don't know the total number, you can take a sample of them and determine the percent that are 100 g and 200 g in your sample.
- As long as the sample is a good representation of the total, it produces the same average mass as if we added the mass of all the tomatoes and divided by the total.
- We weight the heavier value 80% because those tomatoes occur four times as often as the tomatoes we apply the 20% weighting factor to.
- We might not know how many tomatoes we have, but if we know 20% of them mass 200 g and 80% mass 100 g we know that if we pick up a random bucket of tomatoes the average mass for that bucket will be 120g each.

20% of 200g + 80% of 100g

$= 0.20 \times 200g + 0.80 \times 100g$

$= 40g + 80g$

$= 120g$

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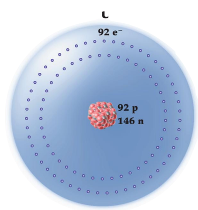

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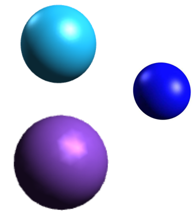

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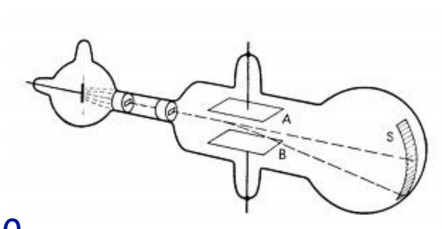

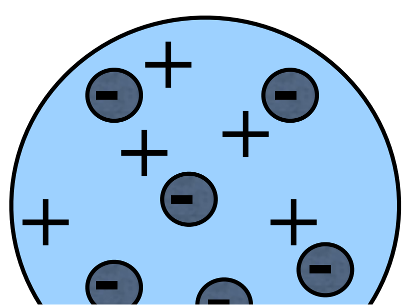

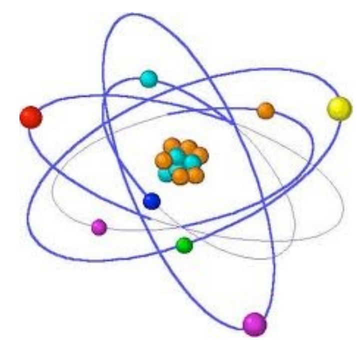

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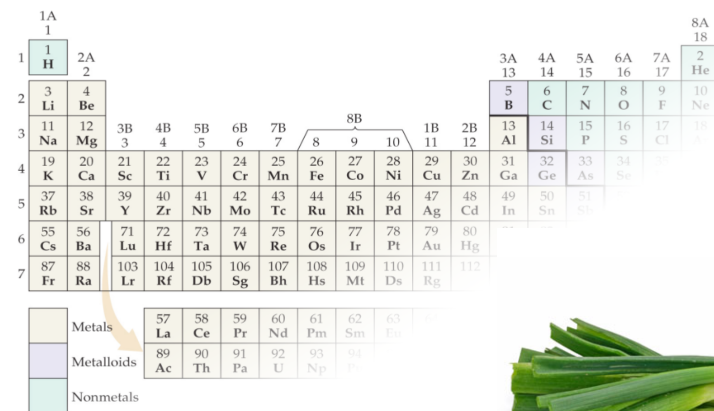
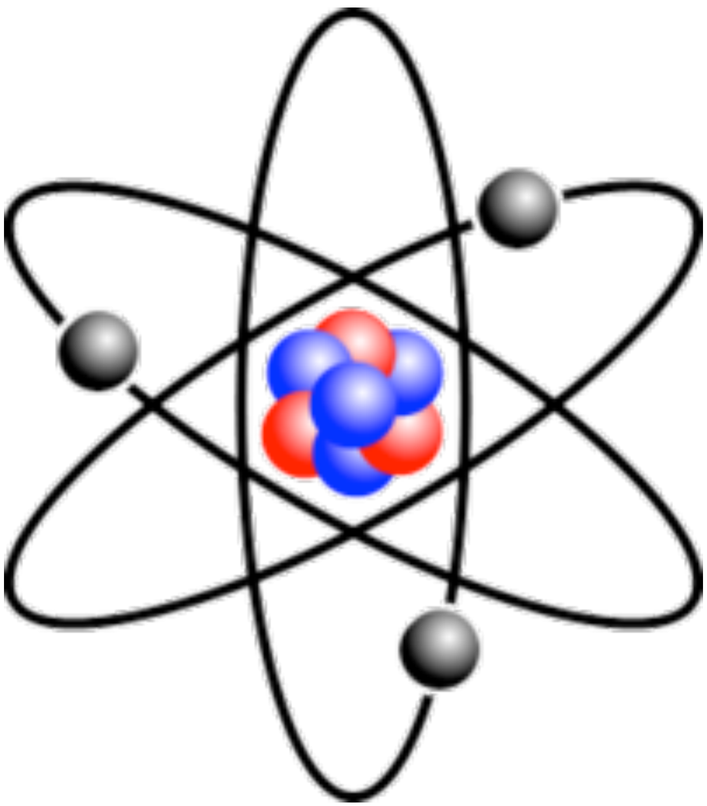
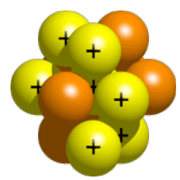
    - If a recipe calls for 2 scallions per serving, he won't count out scallions to feed a thousand folks, he'll calculate the weight of 2,000 scallions and put baskets of them on the scale until he gets that weight.
- Chemists are in the same boat.
    - Our recipe calls for 2 atoms of hydrogen and 1 of oxygen per serving, to make water. But we need 10^{23} servings to fill a thimble with water.
    - Just like a banker needs to know the weights of quarters and pennies, we need to know the weights of carbon atoms, nitrogen atoms, and hydrogen atoms. We need the weights of our elements.



The AMU





- The unit of mass for single atoms.
- Every flavor atom is made of neutrons & protons.
  - It's convenient when we're working on a molecular scale to have a unit of weight about the size of a neutron or proton.
  - We call that unit amu (atomic mass unit).
  - Most interesting molecules are made of carbon.
  - The most common isotope of carbon is made almost entirely of 6 protons and 6 neutrons.
  - An amu is defined as:

    exactly 1/12 the mass of Carbon-12
  - 1 amu is measured to be 1.6606 x 10^{-24} g.
  - ➡ (you don't need to memorize this)
- A chef weighing tomatoes doesn't use the weight of the largest tomato or the smallest. He uses the average weight of a tomato.
- Not all carbon atoms weigh the same, if we're weighing out carbon atoms we want to use average weight of a carbon atom.
- How do we get the average weight?

unit

$^{12}_{6}\mathrm{C}$

Ch02

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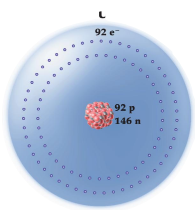

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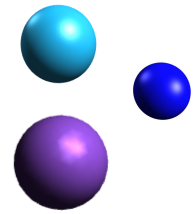
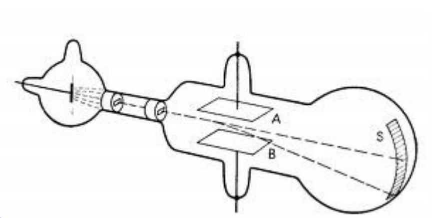
    - Natural Abundance
    - Atomic Mass
  - The Mole
    - Avogadro’s Number
    - Molar Mass

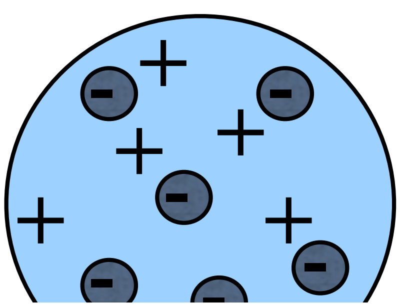


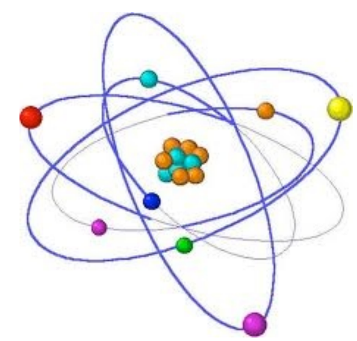
$^{A}_{Z}E$

$^{63}_{29}Cu$

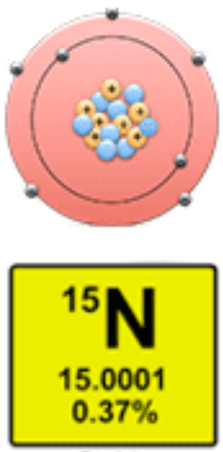
$^{65}_{29}Cu$

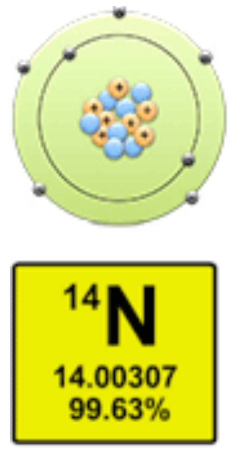


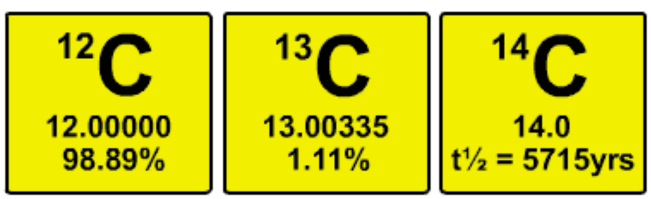




Natural Abundance



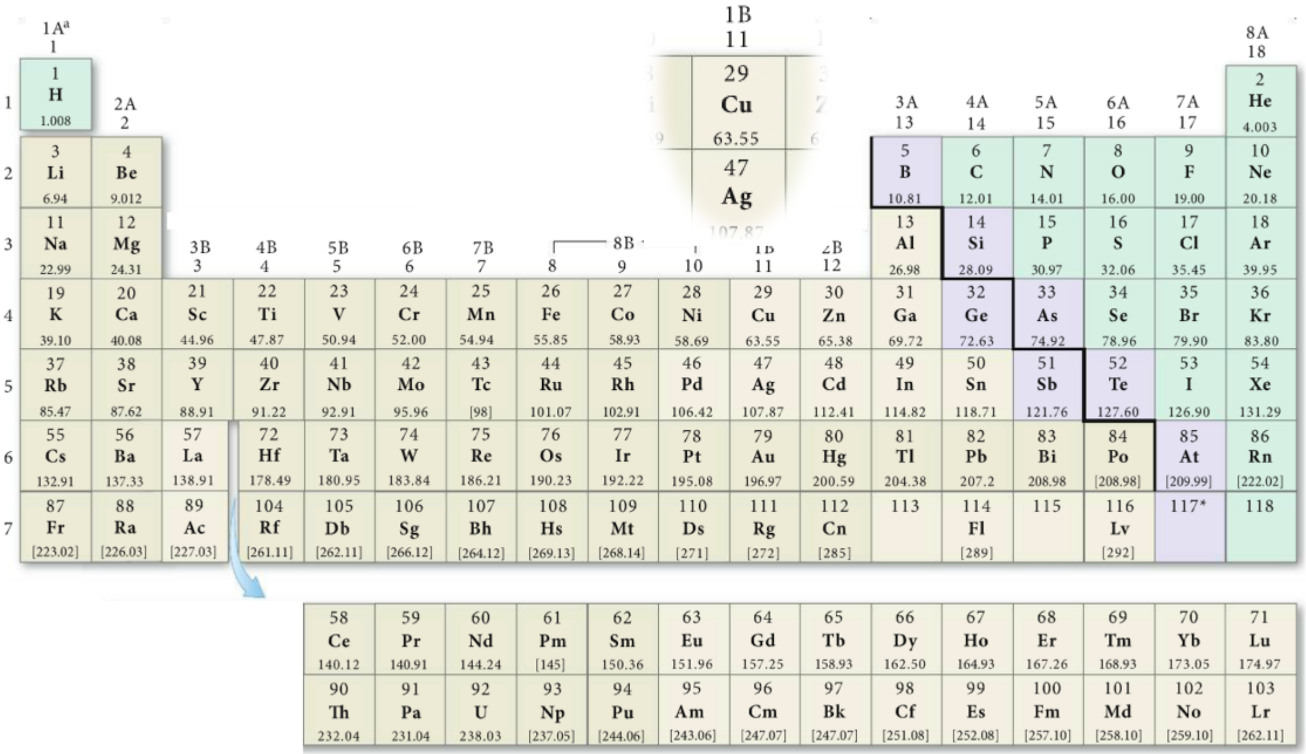


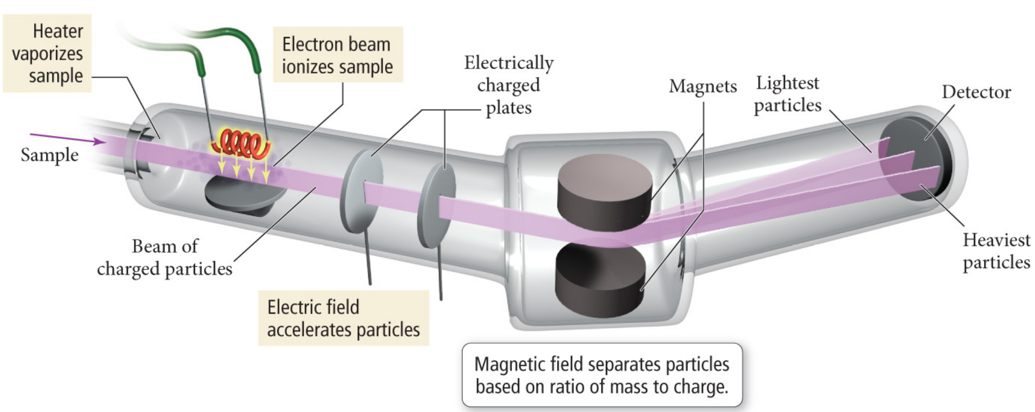


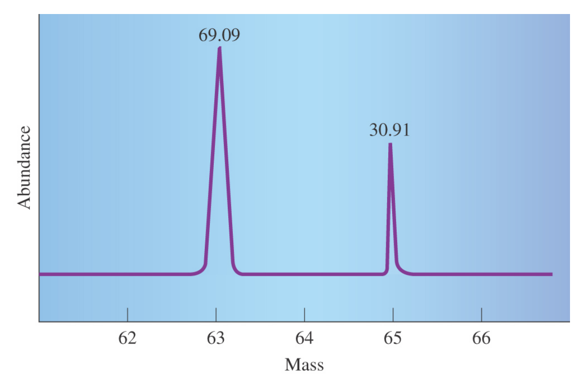
- The ratio of elements on the planet is mostly constant.
- Chemical reactions are selective of element (protons) and ions (electrons) but they don't really care about neutrons (isotopes).
- So natural processes don't discriminate between isotopes and therefore isotopes mixed naturally.
- That natural ratio of isotopes is now found in almost every source of any given element.

Average Atomic Mass

- The periodic table only reports one mass for each element, how does that work if each element has isotopes of different masses?
- The ratio of naturally occurring isotopes of each element is known.
- Every time we pour out a sample of copper, we know 69% of it's atoms are copper-63 and 31% are copper-65.
- Every time.
- So we don't care what the mass of each isotope is, just what the mass — on average — of a copper atom.
- The periodic table gives us an average atomic mass for that element.







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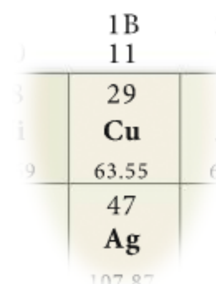
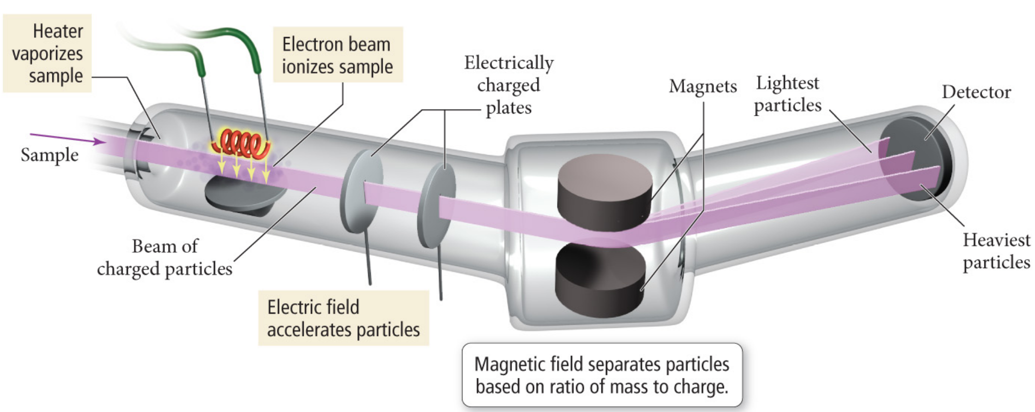
Isotope	Isotopic mass (amu)	Abundance (%)	Average atomic mass (amu)
$^{63}_{29}Cu$	62.9298	69.09	63.55
$^{65}_{29}Cu$	64.9278	30.91	

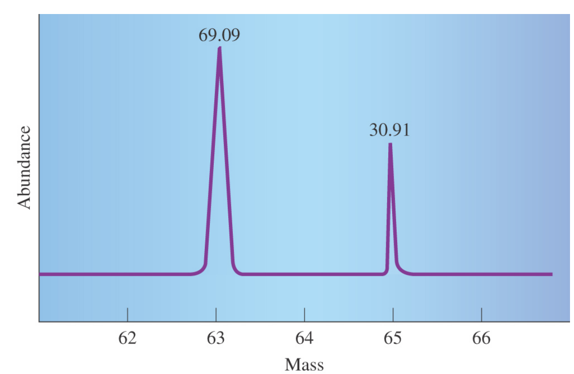
62.9298 amu × 0.6909 = 43.48 amu

64.9278 amu × 0.3091 = 20.07 amu

63.55 amu







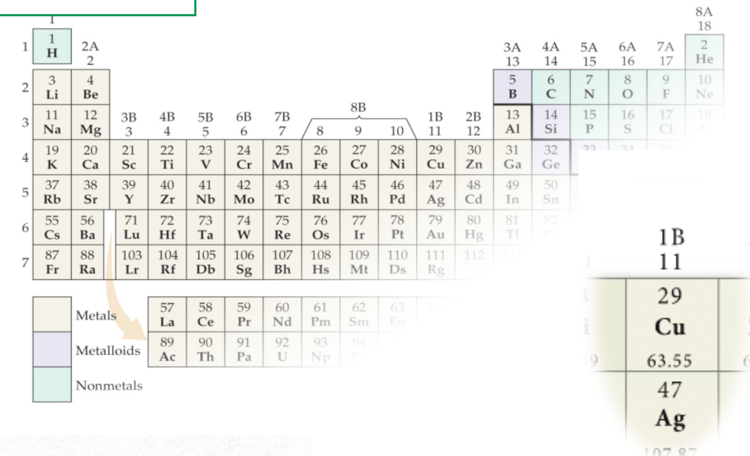
Average Atomic Mass

Important:
This is about 63½ protons. No copper atom has ever weighed this.
Protons don't come in ½'s. This is an **average** weight.

1 Cu = 63.55 amu

What's the average weight of one copper atom?

$$1\ \text{Cu} \times \frac{63.55\ \text{amu}}{1\ \text{Cu}} = 63.55\ \text{amu}$$



What's the weight of 17 copper atoms?

$$17\ \text{Cu} \cdot \frac{63.55\ \text{amu}}{1\ \text{Cu}} = 1{,}080.35\ \text{amu}$$

(counting # ∞ s.f.) 4 s.f. = 1,080 amu

1080. amu
or
1.080×10^3 amu

How many copper atoms in two pennies?

(a penny weighs about 3.0 grams, an amu = 1.6606×10^{-24} g)

penny → g → amu → atoms

$$2\ \text{penny} \cdot \frac{3.0\ \text{g}}{1\ \text{penny}} \cdot \frac{1\ \text{amu}}{1.6606 \times 10^{-24}\ \text{g}} \cdot \frac{1\ \text{Cu}}{63.55\ \text{amu}} = 5.68553 \times 10^{22}$$

(counting # ∞ s.f.) 2 s.f. 5 s.f. 4 s.f.

5.7×10^{22} copper atoms

Problems:
- **we need a ratio of atoms for our recipes (ie H_2O)**
- **in the lab we want to use grams**
- **we don't want to have to convert to amu every time we need to count atoms**
- **and x10^{24} is awkward number to work with anyway.**

Atoms

- Wandering Atoms
  - Charge
- Subatomic Particles
  - Smaller than an Atom
    - Ions, Cathode Rays, Millikan's Oil Drop
  - The Electron
  - Atomic Theory 3.0 — Plum Pudding
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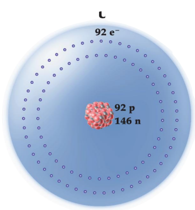

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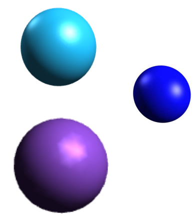

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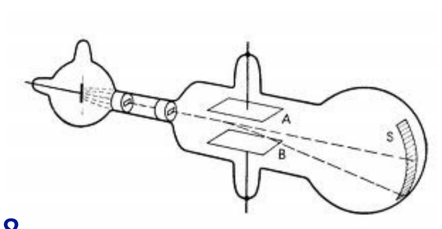
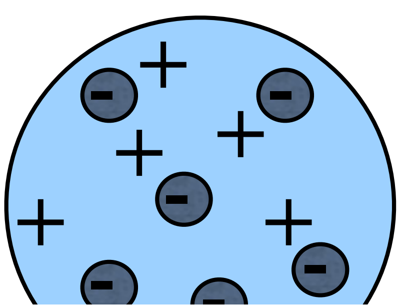
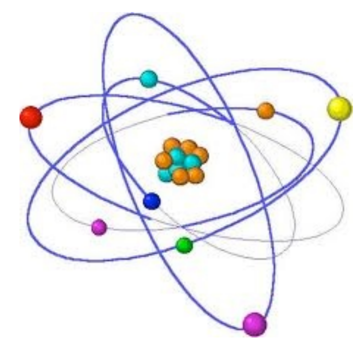






The Chemist's Dozen

- A recipe doesn't always list ingredients by single servings. Sometimes it uses dozens, score, or gross.
- When you're cooking for large groups, your recipe might call for 4 dozen eggs or 6 gross of dumplings.

  1 pair = 2 singles　　1 dozen = 12 singles

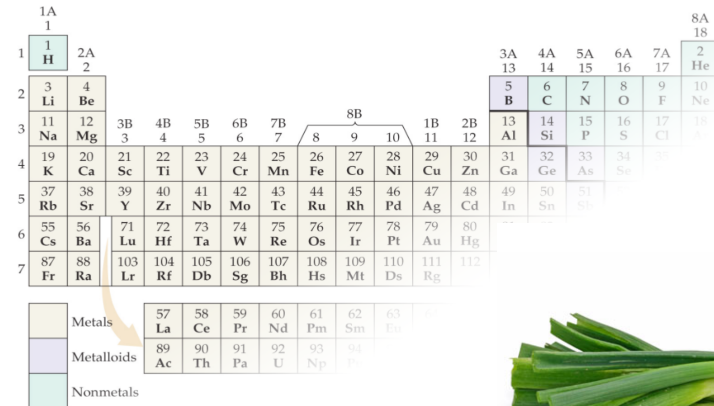
  1 score = 20 singles　　1 gross = 144 singles

  1 ream = 500 singles

- Working with dozens instead of singles let's a chef prepare on a scale 12x his design scale.
- We need a chemists dozen.
- We need to go from amu things (1 amu = 1.6606×10^{-24} g) to gram things (lab scale).
  - 1 gram ÷ 1 amu (in grams) = 6.022×10^{23}
  - 1 gram ÷ 1.661×10^{-24} grams = 6.022×10^{23}

the tool for going between molecular scale (amu) and lab scale (grams).

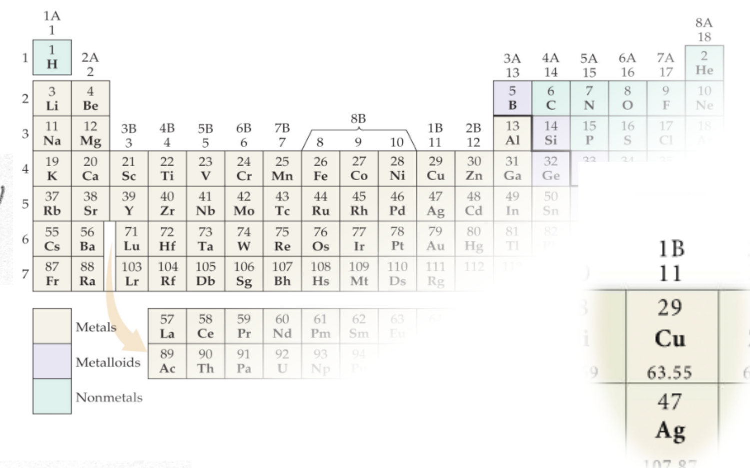
- We call 6.022×10^{23} singles a mole.
- It's the chemists dozen. We abbreviate mole as mol.
- A mol is a measurement, we will determine it to 4 sig figs and use it with 4 sig figs for most of this class.
- The number of singles in a mol is called Avogadro's Number.
- A mol is officially defined as the number of Carbon-12 atoms in 12 grams of pure Carbon-12 (you get the same number)



The Chemist's Dozen

1 mol = 6.022 x 10^{23} singles

How many atoms in exactly 1 mol Copper (Cu)?



exactly 1 mol Cu $\cdot \frac{6.022\times10^{23}\text{ atoms}}{1\text{ mol}} = \boxed{6.022\times10^{23}\text{ atoms Cu}}$

How many atoms in 2.53 mol Copper (Cu)?

2.53 mol Cu $\cdot \frac{6.022\times10^{23}\text{ atoms}}{1\text{ mol}} = 1.52357\times10^{24}$ atoms Cu

$\boxed{1.52\times10^{24}\text{ atoms Cu}}$

How many mol Cu in 30.5 grams Cu?

g → amu → atoms → mol   There's an easier way!

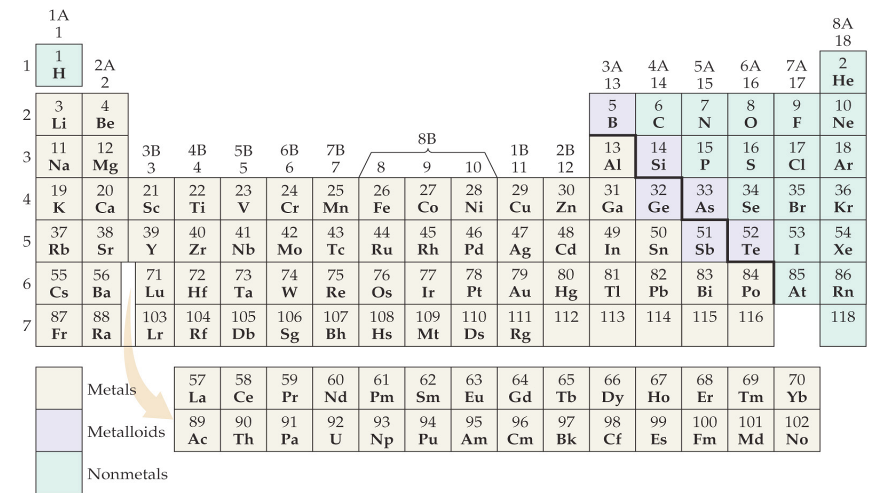
How many Cu atoms in 30.5 grams Cu?

Atomic Weights / Molar Weights

- Weights are listed in the periodic table without units.
- The weight listed is the average mass of one atom of each element, in amu.
- $1 \text{ gram} \div 1.6606 \times 10^{-24} \text{ grams} = 6.022 \times 10^{23}$

  $1 \text{ gram} \div 1 \text{ amu} = 1 \text{ mol}$

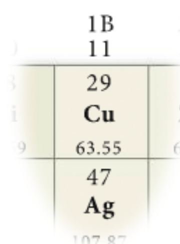
  $1 \text{ gram} = 1 \text{ mol} \times 1 \text{ amu}$



- That means:

  1 mol of *anything* will weigh in grams,
  what a single of that *anything* weighs in amu.

- If a cat weighs X amu, a mol of cats weighs X grams.
- That means each weight in the periodic table is:
  - the weight of 1 atom of that element, in amu
  - the weight of 1 mol of that element, in grams
- Reading from the periodic table...
  - a hydrogen atom (H) weighs 1.008 amu
  - a mol of hydrogen atoms (H) weigh 1.008 g
  - a copper atom (Cu) weighs 63.55 amu
  - a mol of copper atoms (Cu) weighs 63.55 g



1 H = 1.008 amu

1 mol H = 1.008 g

1 Cu = 63.55 amu

1 mol Cu = 63.55 g

Atoms

- Wandering Atoms
  - Charge
- Subatomic Particles
  - Smaller than an Atom
    - Ions, Cathode Rays, Millikan’s Oil Drop
  - The Electron
  - Atomic Theory 3.0 — Plum Pudding
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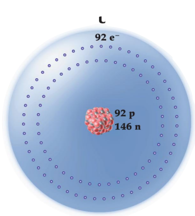

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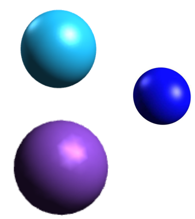

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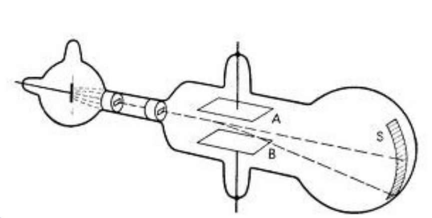
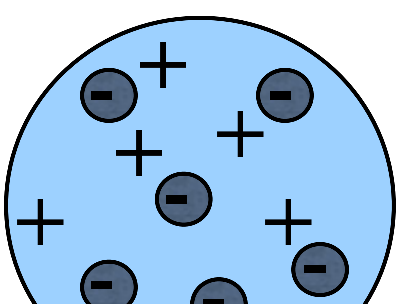
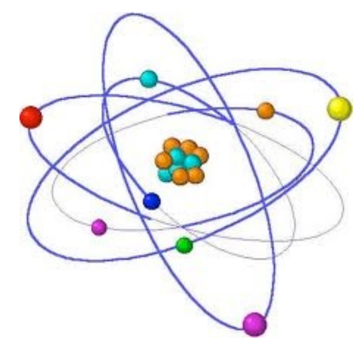
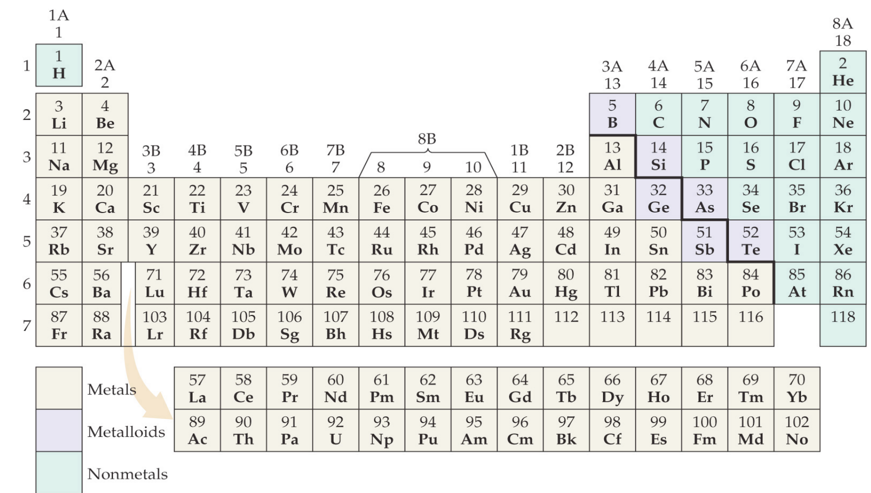






New Conversion Factors

You are responsible for these conversion factors, a periodic table will be provided.

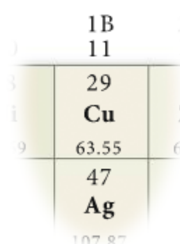


Avogadro's Number

1 mol = 6.022 x10^{23} singles

Atomic Mass

1 copper atom = 63.55 amu



Molar Mass

1 mol copper atoms = 63.55 grams

Mapping it Out

- Let's map it out.
- Places we go between:
  - molecular scale: atoms, amu
  - molar scale: mol, grams (and more are coming…)
- What gets us there (conversion factors)
  - Avogadro's Number
  - Molar Weight (aka Molar Mass)
  - Atomic Weight (aka Atomic Mass)
- Some Possible Conversions
  - How do we go from grams to atoms?
    - g ➞ mol ➞ atoms
      - molar mass; Avogadro's number
  - How do we go from atoms to mol?
    - atoms ➞ mol
      - Avogadro's Number
  - How do we go from atoms to grams?
    - atoms ➞ mol ➞ grams
      - Avogadro's Number; molar mass
  - How do we go from grams to atoms?
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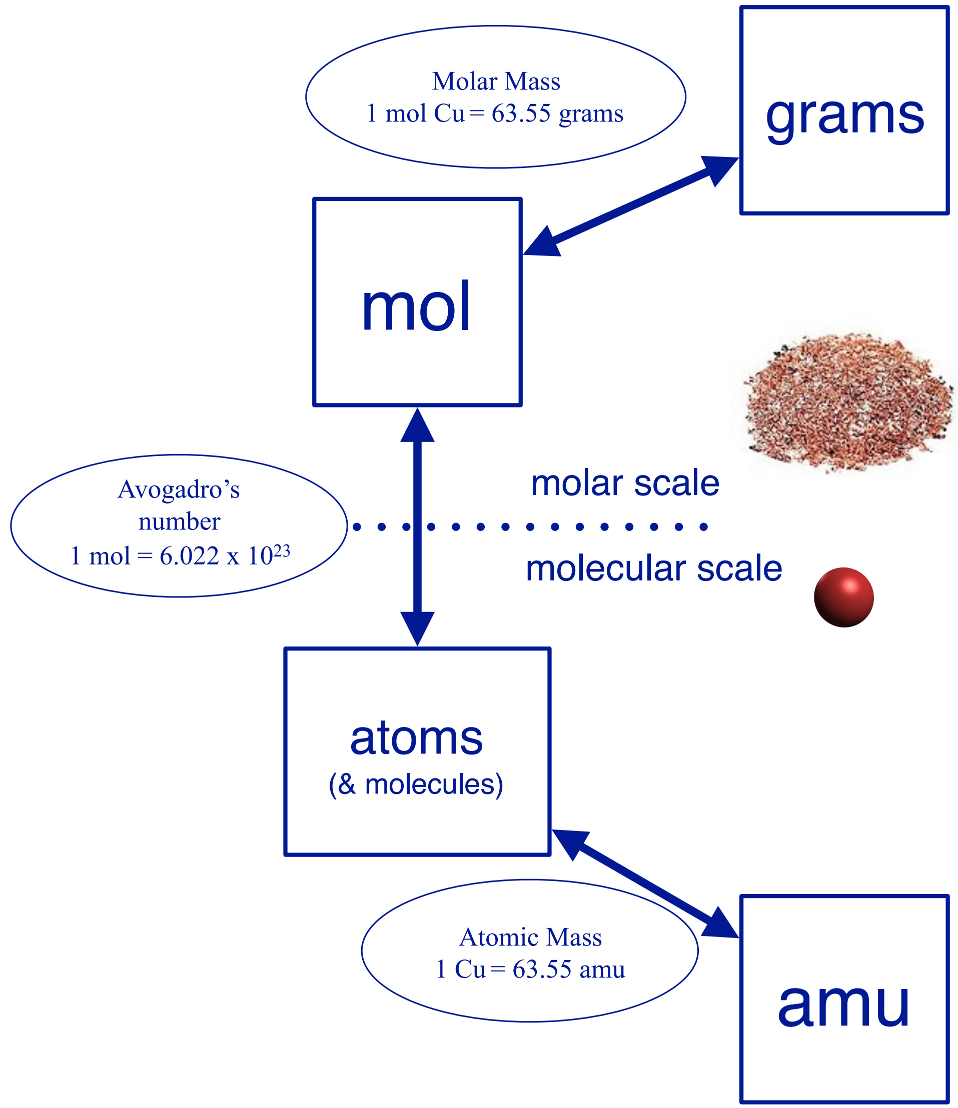

Counting by Weight

1 mol = 6.022×10^{23} singles

How many atoms in exactly 1 mol Copper (Cu)?

exactly 1 mol Cu $\cdot \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = \boxed{6.022 \times 10^{23} \text{ atoms Cu}}$

1 Cu = 63.55 amu

1 mol Cu = 63.55 g

How many atoms in 2.53 mol Copper (Cu)?

$2.53 \text{ mol Cu} \cdot \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = 1.52357 \times 10^{24} \text{ atoms Cu}$

$\boxed{1.52 \times 10^{24} \text{ atoms Cu}}$

How many mol Cu in 30.5 grams Cu?

g → mol

$30.5 \text{ g Cu} \cdot \frac{1 \text{ mol}}{63.55 \text{ g}} = 4.79937 \times 10^{-1} \text{ mol Cu}$

3 sd, 4 sd

$\boxed{0.480 \text{ mol Cu}}$

How many Cu atoms in 30.5 grams Cu?

g → mol → atoms

$30.5 \text{ g Cu} \cdot \frac{1 \text{ mol}}{63.55 \text{ g}} \cdot \frac{6.022 \times 10^{23} \text{ atoms}}{1 \text{ mol}} = 2.8901809 \times 10^{23} \text{ atoms}$

3 sd, 4 sd, 4 sd

$\boxed{2.89 \times 10^{23} \text{ atoms Cu}}$

How many atoms?

A gold ring weighs 1.24 grams. How many atoms of gold are in it?

g → mol → atoms

199.97 g/mol

$6.022 \times 10^{23} \frac{\text{single atoms}}{\text{mol atoms}}$

$$1 \text{ ring} \cdot \frac{1.24 \text{ g}}{1 \text{ ring}} \times \frac{1 \text{ mol}}{199.97 \text{ g}} \times \frac{6.022 \times 10^{23}}{1 \text{ mol}}$$

$$= 3.73 \times 10^{21} \text{ atoms}$$

How many grams?

An experiment calls for 4.3 mols of Calcium atoms, how many grams of pure calcium should you weigh out?

mols → g

Ca 40.08 g/mol

$4.3 \text{ mol Ca} \cdot \frac{40.08 \text{ g}}{1 \text{ mol}} = 172.344 \text{ g}$

170 g Ca

Weight of 4 atoms?

A phosphorus molecule is composed of 4 atoms of phosphorus. What is it's weight in AMUs?

atoms ⟶ amu

P $30.97 \frac{amu}{atom}$

$$4 \text{ atoms P} \cdot \frac{30.97 \text{ amu}}{1 \text{ atom}} = 123.88 \text{ amu}$$

123.9 amu

Atoms

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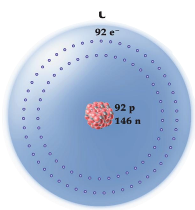

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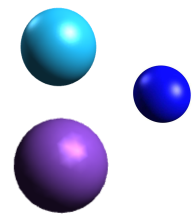

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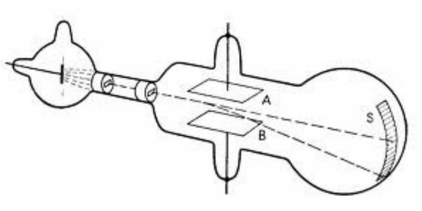
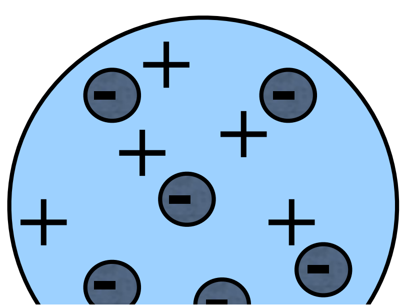
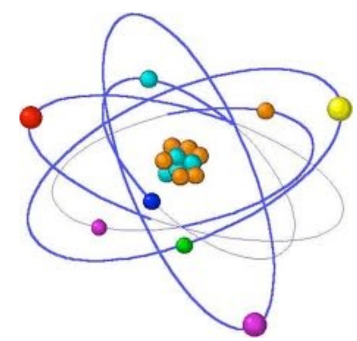
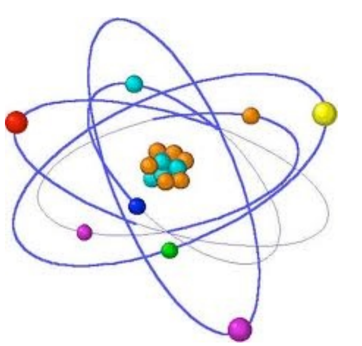






Questions?



1. What is the weight of 23 copper atoms?
2. How many single atoms in 2.3 moles?
3. What is the weight of 2.3 moles of copper atoms?
4. How many moles of copper atoms in 6.2 grams?
5. How many single copper atoms in 6.2000 grams of copper?