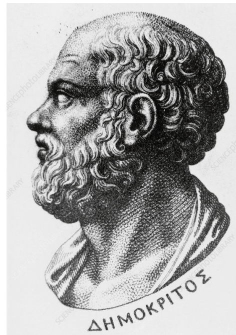
From Matter to Atoms

Democritus Theory of Matter

Democritus: Fifth Century BC (*460 – 370BC*)

If matter is divided into the smallest possible pieces you will eventually reach the smallest division of matter - "*Atomos*" – The atom



The Basic Elements

Prior to Democritus philosophers believed everything was made of Fire, Earth, Wind, Water, and Ether

1

From Matter to Atoms

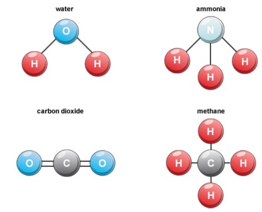
Preliminary Laws of Matter

Law of Conservation of Matter
Matter is neither created or destroyed just rearranged in new ways

Law of Conservation of Mass
The physical mass of matter is constant

Law of Definite Composition (*Proust's Law*)
All combinations of atoms contain the same ratio (*by mass*) of all atoms that make up the matter

Compounds and Molecules
All combination of atoms are formed from existing atoms in definite proportions
Water is always 1 oxygen and 2 hydrogen [H_2O]



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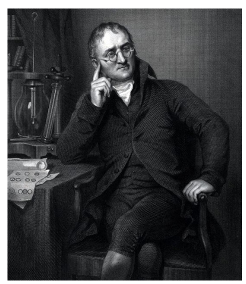
From Matter to Atoms

Dalton's Four Principles of the Atom

Matter and the atom is defined based on the basic principles of matter. His principles were:

First Principle of Atoms
All Matter is Made of Indivisible Atoms

Second Principle of Atoms
All Atoms of the same type have the same properties, including mass (*elements*)



John Dalton
English Chemist
1766 – 1844AD

3

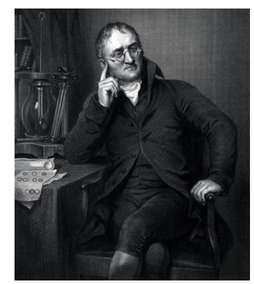
From Matter to Atoms

Dalton's Four Principles of the Atom

Dalton used the scientific method in this principles and was the first to write down the basic ideas in his principles of matter

Third Principle of Atoms
Compounds and Molecules are combinations of two or atoms combined together

Fourth Principle of Atoms
A *Chemical Reaction* occurs when atoms are rearranged forming new atom combinations



John Dalton
English Chemist
1766 – 1844AD

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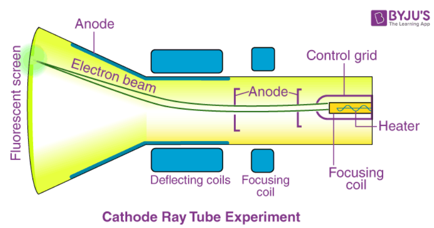
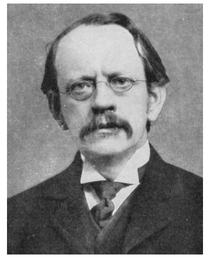
Subatomic Particles
Thomson's Cathode Ray Experiments
Thomson worked with Cathode "Canal" Rays in a vacuum to determine the energy and charge of e^-





Joseph John Thomson
English Chemist
1856 - 1940AD

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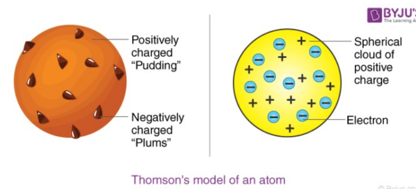
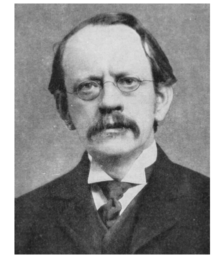
Subatomic Particles
Thomson's Plum Pudding Model
Thomson's discovery of the electron (e^-) lead to the *plum pudding model,* e^- in an atom surrounded by a positive *matrix*





Joseph John Thomson
English Chemist
1856 - 1940AD

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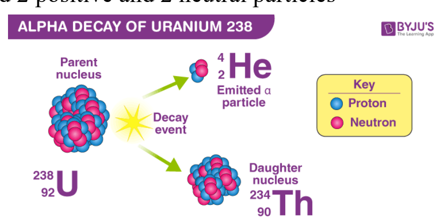
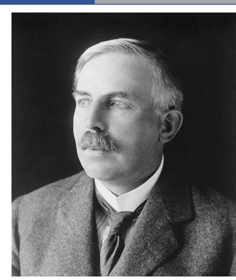
Subatomic Particles
Radiation and Alpha Particles
Rutherford separated nuclear radiation into three types of radiation. Alpha Decay (α), the weakest had 2 positive and 2 neutral particles





Earnest Rutherford
English Chemist
1871 - 1931AD

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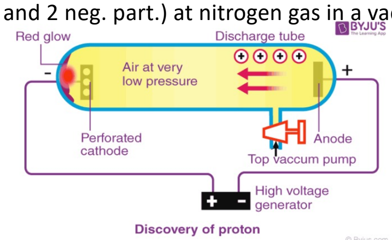
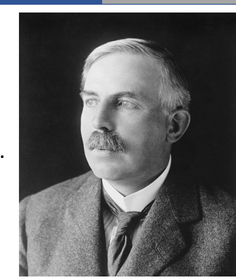
Subatomic Particles
Rutherford's Nitrogen Experiment
Rutherford accelerated *shot* alpha particles (2 pos. and 2 neg. part.) at nitrogen gas in a vacuum.



The resulting particles were positive protons (p^+)



Earnest Rutherford
New Zealand Chemist
1871 - 1931AD

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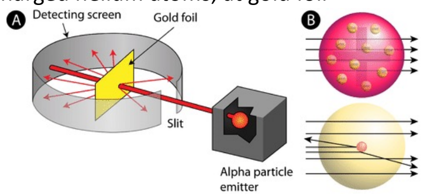
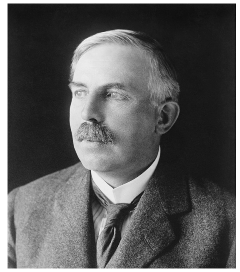
Subatomic Particles
Rutherford's Gold Foil Experiment

Rutherford accelerated *shot* alpha particles, charged helium atoms, at gold foil



The alpha particles showed the atom to be basically empty except for a nucleus in the center



Earnest Rutherford
New Zealand Chemist
1871 - 1931AD

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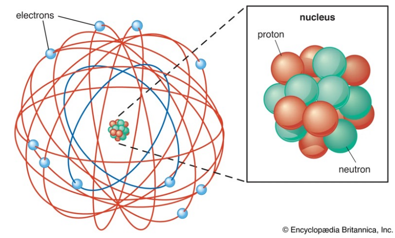
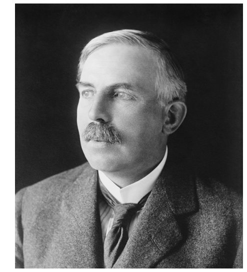
Subatomic Particles
Rutherford's Atomic Model

Strong positive center to the atom (*nucleus*) surrounded by negatively charged electrons (e^-)





Earnest Rutherford
New Zealand Chemist
1871 - 1931AD

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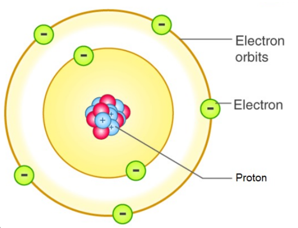
Subatomic Particles
Bohr's Atomic Model

e^- travel in orbits around the center of the atom

Atomic Orbits
Pathways around nucleus e^- travel in to maintain distance between other e^- and keep e^- and p^+ from colliding (*nucleus*)



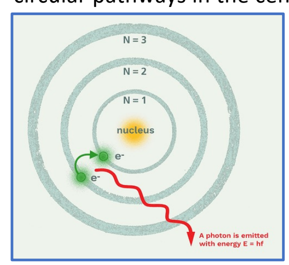
Bohr atomic model of a Nitrogen atom

Neil Bohr
Polish Chemist
1885 - 1962AD

11

Energy and the Bohr Model of the Atom

Bohr's Model of the atom shows the pathways that electrons travel in the atom. Bohr's model also shows that the *inner electrons* also travel in circular pathways in the center of the atom (*the orbitals*)



Electrons exist in areas called *energy levels* within the atom.

Energy added to the atom disrupts the placement of the electrons. When energy is added to the atom the electron *jumps* to a higher level. When the electron loses the extra energy *light* energy is produced.

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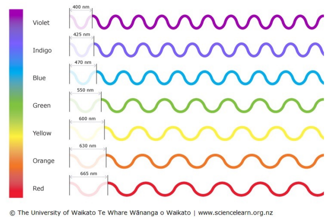
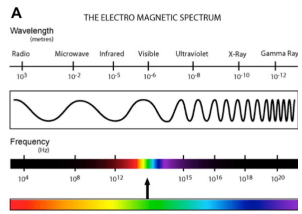
Energy and Color of Light

Light travels in wave patterns. The length of the waves determines the type of light. For visible light, the wavelength determines the color.



Visible light is based on wavelength
Red = Longest, Blue = Shortest



Different light sources are based on wavelength and energy

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Subatomic Particles

Inner and Valence Electrons (e^-)

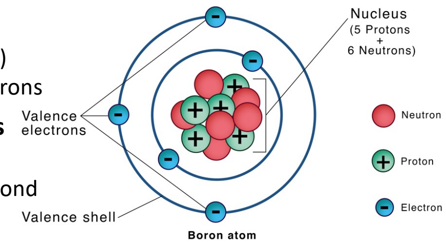
Electrons contain different roles within the atom

Inner (*Shell*) Electrons

Provide repulsive force (- to -) helping protect valence electrons

Valence (*Outer*) Electrons

Electrons that communicate (*transferred or shared*) and bond (*connect*) with other atoms



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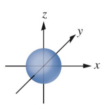
Subatomic Particles

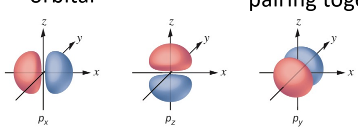
Atomic Orbitals and Electron Filling

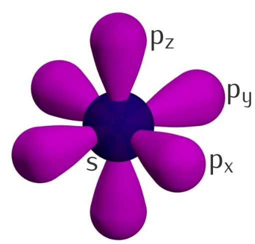
Orbitals are predicted electron locations around the atom to minimize electron repulsion in the orbitals.

0, 1 or 2 e^- allowed per orbital



Electrons always fill one per suborbital before pairing together





Overall Orbital Set

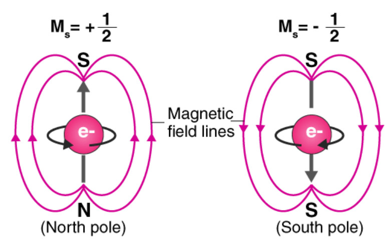
8 electrons fit within 4 orbitals in the s, p_x, p_y, p_z orbital set

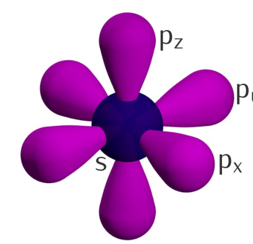
15

Subatomic Particles

Atomic Orbital Electron Spin

Within an orbital electrons spin in opposite directions (+1/2 and -1/2) to min. replusion





Overall Orbital Set

8 electrons fit within 4 orbitals in the s, p_x, p_y, p_z orbital set

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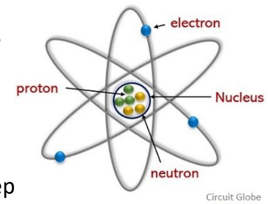
Role of Subatomic Particles

The modern atomic model contains protons, electrons, and neutrons *(+, -, and neutral)*

Protons
In nucleus (*center of atom*), identifies atom, keep electrons within the outer portion of the atom

Electrons
Atomic communication, connection to other atoms, balancing protons in the atom

Neutrons
Barrier between protons/electrons, sheilding



Basic Structure of the Atom

Includes electrons (e^-), protons (p+), and neutrons (n^o)

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Elements

The *atomic number* (Z, # protons, p^+) can be used to identify the type of element being studied on the periodic table

- Atomic number — 26
- Chemical symbol — Fe
- Element name — **Iron**
- Atomic mass — **55.847**

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Isotopes

Atoms can commonly have more than one ratio of protons and neutrons that are stable. The equations below will help calculate the number of each subatomic particle in an isotope of an element

Atomic Number = # Protons (p^+) [*Type of Atom*]

 # Protons (p^+) = # Electrons (e^-) [*Atoms Neutral*]

Mass Number = # Protons + # Neutrons [*Isotope Mass*]

 # Neutrons (n^o) = Mass Number - Atomic Number

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Average Atomic Mass

The average of the atomic masses of all isotopes that make up a particular form of matter.

- Sodium — Element Name
- 11 — Atomic Number
- Na — Element Symbol
- 22.990 — Average Atomic Mass

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Atomic Isotope Notation

Writing atomic isotopes

B ⟵ Mass #
Protons + Neutrons

X

A ⟵ Atomic #
Protons

Element – B
Atomic # Mass #

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Compare Mass Number and Atomic Mass

Mass Number

The number of subatomic particles that make up the mass of an atom ($p^+ + n^o$, count)

Example
Sodium – 23 ($11p^+ + 12n^o$)
Mass Number = 11 + 12 = 23

Atomic Mass

The mass of the subatomic particles that contribute mass to an atom ($p^+ + n^o$, amu)

Example
Sodium – 23 ($11p^+ + 12n^o$)
Atomic Mass = 11amu + 12amu
= 23amu

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Classifying Elements

Döbereiner's Elemental Triads

Elements repeat properties in groups of three based on mass. The mass of the middle element is the average of the mass of the first and third element.

Set I		Set II		Set-III	
Element	Atomic mass	Element	Atomic mass	Element	Atomic mass
Calcium	40	Lithium	7	Chlorine	35.5
Strontium	87.5	Sodium	23	Bromine	80
Barium	137	Potassium	39	Iodine	127
Average of the atomic masses of calcium and barium $= \frac{40+137}{2} = 88.5$		Average of the atomic masses of lithium and potassium $= \frac{7+39}{2} = 23$		Average of the atomic masses of chlorine and iodine $= \frac{35.5+127}{2} = 81.2$	
Atomic mass of strontium = 87.5		Atomic mass of sodium = 23		Atomic mass of bromine = 80	

Johann Döbereiner
German Chemist
1780 – 1840AD

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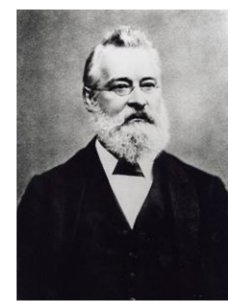
Classifying Elements

Newland's Law of Octaves

Table 4.2 Newland's table of octaves (oct- eight)

NO.	NO.	NO.	NO.	NO.	NO.	NO.	NO.
H1	F8	Cl 15	Co&Ni 22	Br 29	Pd 36	I 42	Pt & Ir 50
Li 2	Na 9	K 16	Cu 23	Rb 30	Ag 37	Cs 44	Os 51
G 3	Mg 10	Ca 17	Zn 24	Sr 31	Cd 38	Ba & V45	Hg 52
BO 4	Al 11	Cr 19	Y 25	Ce & La33	U40	Ta 46	Ti 53
C 5	Si 12	Ti 18	In 26	Zr 32	Sn 39	W 47	Pb 54
N 6	P 13	Mn 20	As 27	Di&Mo 34	Sb 41	Nb 48	Bi 55
O7	S 14	Fe 21	Se 28	Ro&Ru 35	To 43	Au 49	Th 56

Elements repeat properties when arranged in rows (*periods*) of 8 elements (*the octave*)



John Newlands
British Chemist
1837 – 1898AD

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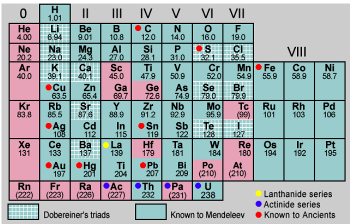
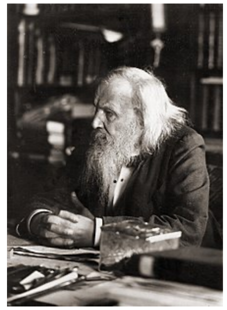
Classifying Elements
Mendeleev's Periodic Table





Dmitri Mendeleev
Russian Chemist
1834 – 1907AD

Elements repeat properties when arranged by atomic mass. (*rows and periods*)

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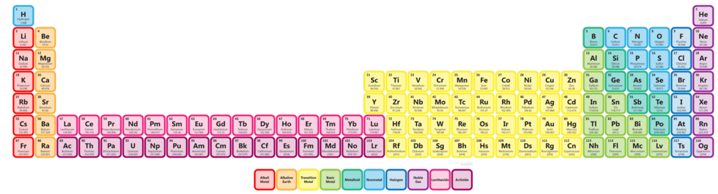
Classifying Elements
Modern Periodic Table

With the discovery of the subatomic particles (e$^-$, p$^+$, and n^o), and the nucleus, the modern periodic table was arranged by atomic number.



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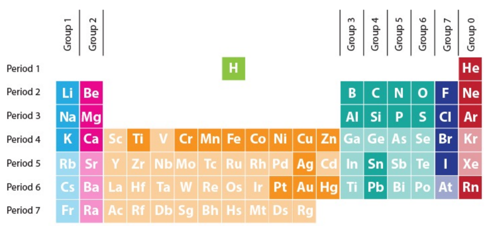
Modern Periodic Table
Groups and Periods

Elements are arranged into groups (*up and down*), and periods (*left to right*) based on atomic number.



The periodic table is arranged into 8 groups and 7 periods.

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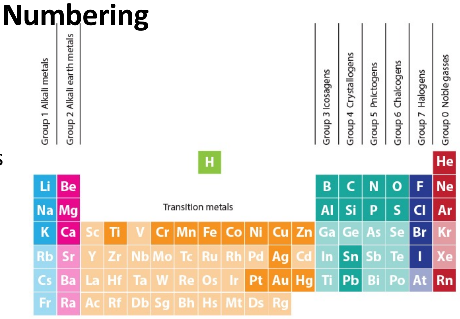
Modern Periodic Table
Groups Naming and Numbering

Groups are numbered in two ways (*modern + trad*)

1 (1A) – Alkali Metals
2 (2A) – Alkali Earth Metals
13 (3A) – Earth Metals
15 (5A) – Pnictogens
16 (6A) – Chalcogens
17 (7A) – Halogens
18 (8A) – Noble Gases



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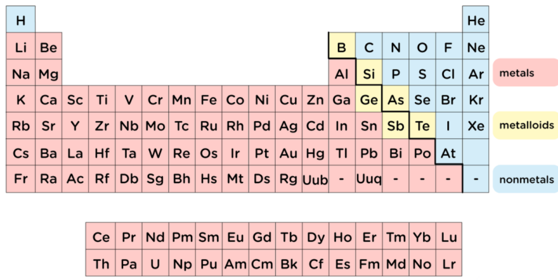
Modern Periodic Table

Metals, Non-Metals, and Metalloids

Main groups on the table are shown here (*metals, metalloids, & non-metals*) based on how elements react together



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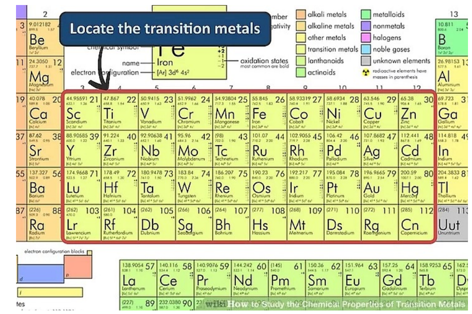
Modern Periodic Table

Transitional Metals

3 – 12, 1B – 10B

Metals in the center of the table that react and behave different from other metals in groups 1A (1) and 2A (2). Metals in 3A (13), and 4A (14) have properties like transition metals.



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Subatomic Particles

Counting Valence Electrons (e^-) [*Representative Groups*]

Valence Electrons are based on group on the table

Group	Name	Val e^-	Group		Val e^-
1A (1)	Alkali Metals	1	5A (15)	Pnictogens	5
2A (2)	Alkali Earth Metals	2	6A (16)	Chalcogens	6
3A (13)	Earth Metals	3	7A (17)	Halogens	7
4A (14)	Carbon Group	4	8A (18)	Noble Gases	8

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Subatomic Particles

Counting Valence Electrons (e^-) [*Transition Metals*]

Valence Electrons are based on group on the table

Transition Metals can have 1 – 7 valence electrons (*base 2*)

Group	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)	1B (11)	2B (12)
Element	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
Possible Valence electron	3	3 4	2 3 4 5	2 3 4 6	2 3 4 5 7	2 3 6	2 3	2 3	1 2 3	2

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Subatomic Particles

Ion Charge

Charge of an ion is based on the group on the periodic table

Cation (+ ion): Ions formed due to gaining electrons (*metals*)
Anion (- ion): Ions formed due to losing electrons (*non-metals*)

Group	Val e^-	Charge	Group	Val e^-	Charge	Group	Val e^-	Charge
1A (1)	1	1+	**3A (13)**	3	3+	**6A (16)**	6	2-
2A (2)	2	2+	**4A (14)**	4	4+ / 4-	**7A (17)**	7	1-
1B – 10B (3 – 12)	2 (Varies)	Varies	**5A (15)**	5	3-	**8A (18)**	8	No Charge

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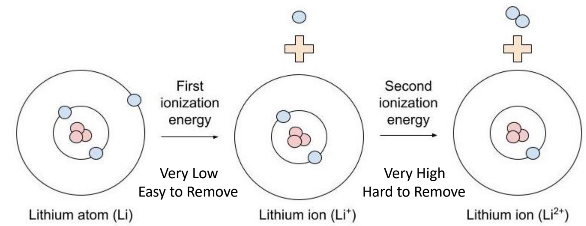
Formation of Ions

Ionization Energy

Energy required to remove an electron from atom to form an ion



Neutral Atom — Li^{1+} (0 val e^-) — Li^{2+} (-1 val e^-)

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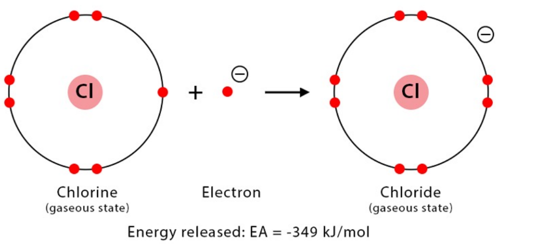
Formation of Ions

Electron Affinity

Energy lost (*ideal*) or gained when an atom gains an electron



Chloride Anion (-1 anion) — Chlorine Atom (Neutral)

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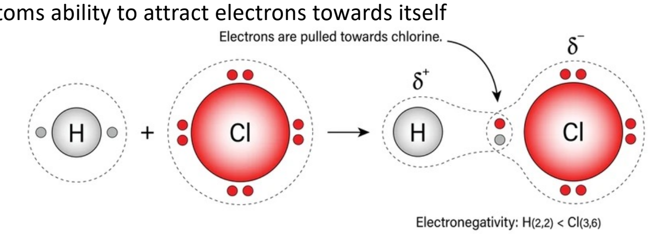
Formation of Ions

Electronegativity

Atoms ability to attract electrons towards itself



Metals/Hydrogen – Low Electroneg. Non-Metals – High Electroneg.

Higher Electronegativity = More pull on electrons towards itself in bond

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Formation of Ions

Comparing Ionization Energy and Electron Affinity

Energy required to remove an electron from atom to form an ion

Element Type	Ionization Energy	Electron Affinity
Metals (0 – 4 Valence Electrons)	Low IE (*easy to lose e^-*) Atoms want to lose e^-	Low EA (*Low desire to gain e^-*) Atoms don't want e^-
Non-Metals (5 – 8 Valence Electrons)	High IE (*hard to lose e^-*) Atoms don't want to lose e^-	High EA (*High desire to gain e^-*) Atoms want to gain e^-

In general: Atoms always want to lose heat (*q*), - to become more stable

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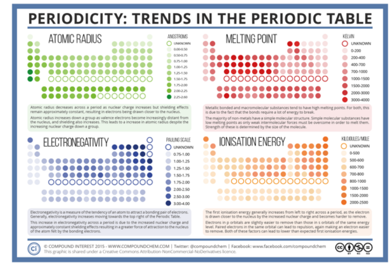
Periodic Trends

All properties of atoms can be compared to each other based on position of atom / ion on the periodic table.

Common Periodic Trends

Atomic Radius
Ion Radius
Ionization Energy
Electron Affinity
Electronegativity
Metallic / Non-Metallic Character
Melting Point / Freezing Point



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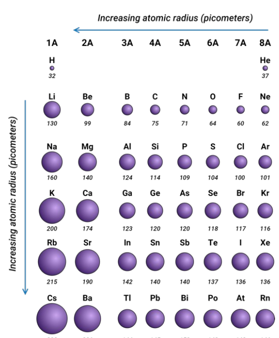
Periodic Trends – Atom Size



Group Trend (*top to bottom*)

Atoms get **larger** from **top to bottom** *due to more inner electrons farther from nucleus*

Period Trend (*left to right*)

Atoms get **slightly smaller** from left to right *due to more protons pulling on the same outer valance electrons.*

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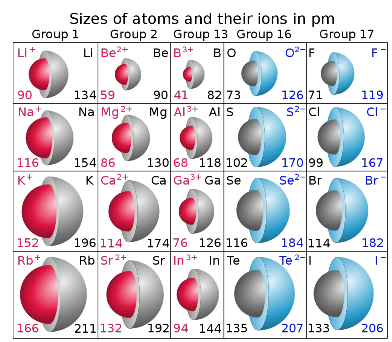
Periodic Trends - Ion Size



Neutral Atom/Cation (*+ ion*)

Cations are always **smaller than the neutral atom**

Cations are smaller due to losing valance electrons

Neutral Atom/Anion (*- ion*)

Anions are always **larger than** the **neutral atom**

Anions are larger due to increased shielding of added inner electrons in ion

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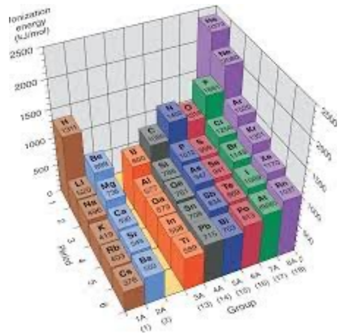
Periodic Trends – Ionization Energy



<u>Group Trend (*top to bottom*)</u>
Ionization Energy goes **slightly down** from top to bottom.
Larger atoms have more e^- shielding / e^- removal easier.

<u>Period Trend (*left to right*)</u>
Ionization Energy goes **up** across the table.
Non-metals do not want to lose electrons requiring more energy to lose electrons.

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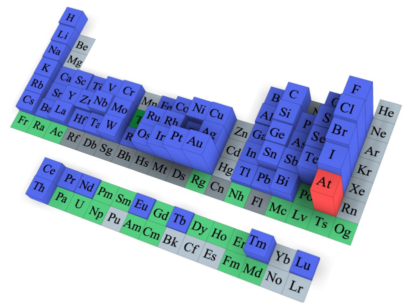
Periodic Trends – Electron Affinity



<u>Group Trend (*top to bottom*)</u>
Electron Affinity goes **slightly down** from top to bottom.
Larger atoms are slightly more stable, have lower e^- desire

<u>Period Trend (*left to right*)</u>
Electron Affinity goes **up** across the table.
Non-metals want to gain electrons increasing desire to obtain electrons

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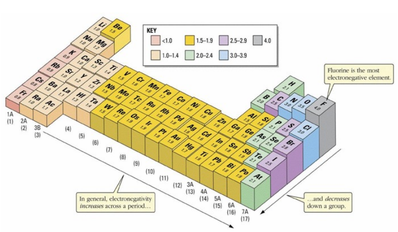
Periodic Trends – Electronegativity



<u>Group Trend (*top to bottom*)</u>
Electronegativity goes **slightly down** from top to bottom.
Larger atoms are less likely to share electrons.

<u>Period Trend (*left to right*)</u>
Elecronegativity goes **up** across the table.
The closer an atom is to 8 val. e^- the more it is likely to share electrons to get an octet of e^-

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Atomic Stability – Z-Ratio (n^o:p^+ Ratio)

The Stability of an isotope of an atom is based on the relationship between protons (p^+) and neutrons (n^o) in an atom. Atoms with too many or too new n^o will become unstable.

Z-Ratio

Ratio between the protons (p^+) and neutrons (n^o) in the atom.

$$\text{Z-Ratio} = \frac{\#n^o\ (neutrons)}{\#p^+\ (protons)}$$

Most stable isotopes of elements have the following ratios:

Small (1 – 20): 1.0 – 1.2 Large (55 – 82): 1.4 – 1.5
Medium (1 – 54): 1.2 – 1.3 No Stable Isotopes Above 82

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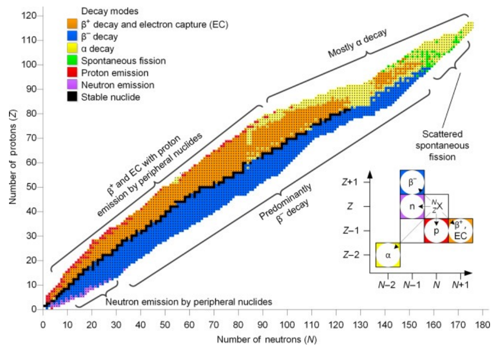
Z-Ratio (n^o:p^+ ratio) Graph



Nuclear Isotope Ratio Diagram

The chart shown to the left show the potential isotopes of a radioactive atom's isotopes. The colors indicate the type of decay process that occurs to make atom stable.

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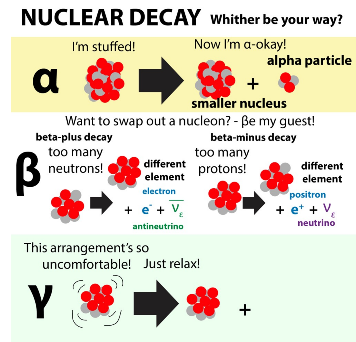
Nuclear Decay Processes



Nuclear Decay

Unstable Isotopes are isotopes that have a z-ratio outside the stable range for the element.

Most common nuclear decay processes include:

Alpha Decay – Atom too large
Beta Decay (+) – Too many n^o
Beta Decay (-) – Too many p^+

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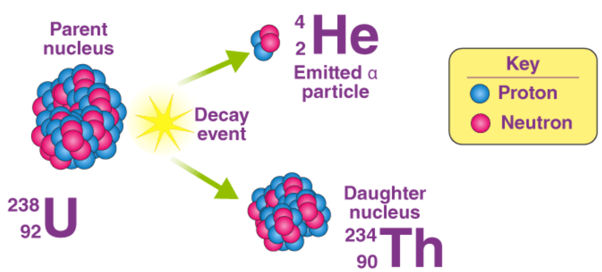
Alpha Nuclear Decay

Breakdown of a large unstable atomic isotope by removing 2 protons and 2 neutrons ($2p^+ + 2n^o$) producing an alpha particle and a smaller isotope



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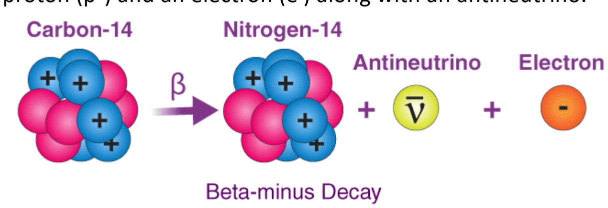
Beta (-) Nuclear Decay

An atom with too many neutrons (n^o) will transmute the extra neutron into a proton (p^+) and an electron (e^-) along with an antineutrino.



Carbon-14 is an important isotope that is used for radioactive dating of older carbon samples. (*The ratio of C-12 and C-14 gives the approx. age*)

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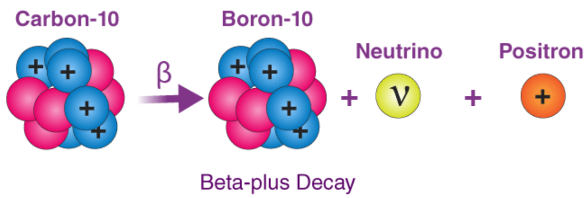
Beta (+) Nuclear Decay

An atom with too few neutrons (n^o) will transmute the extra proton into a neutron (n^o) and a positron (e^+) (+ electron) and a neutrino.



Unstable Carbon-10 has too new neutrons ($4n^o$) and decays into the larger Boron-10 isotope which is the main stable isotope.

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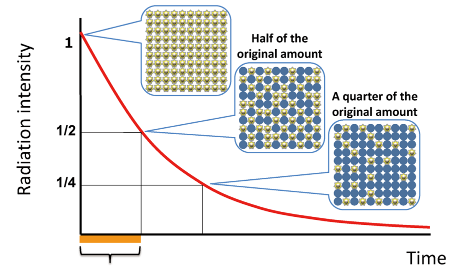
Nuclear Decay Rate

Based on the stability each isotope of an atom has a chance to decay every moment of time.



Each isotope will decay over time, the rate starting fast (*more particles can decay*) then slowing down (*less particles to decay*) over time as the sample decays

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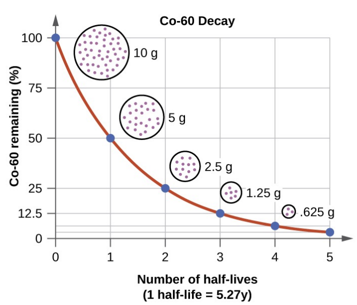
Nuclear Half Life

The time for particles to decay is based on the stability of particles



The **Half-Life** of a particle is the time it takes for half (50%) of the particles to decay from the original isotope state.

More Stable = Longer Half Life
Less Stable = Shorter Half Life

Nuclear Decay is an *inverse function* with a negative slope

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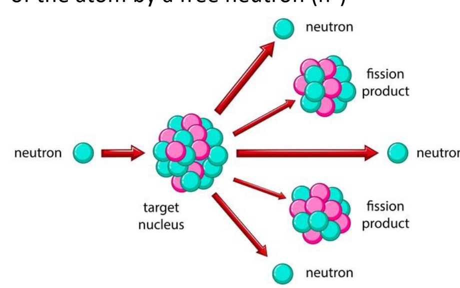
Fission

Fission in the process where a *fissionable* atom is split by the interaction of the atom by a free neutron (n^o)



Fissionable Isotopes

Uranium-235 (*uncommon*) and Plutonium-239 can undergo fission.

Uranium-238 (*common*) can be converted to U-239 when hit by neutrons, then converted to Pu-239

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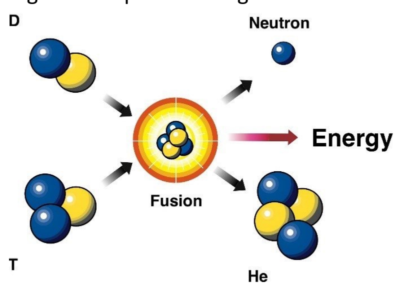
Fusion

Fission in the process where a *small isotopes* combine under pressure together to produce larger atoms with lots of energy



Production of Elements

Elements can be *transmuted* to other elements through the process of fusion.

Man-Made elements heaver than Uranium (U) can be formed through fusion with protons and neutrons

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