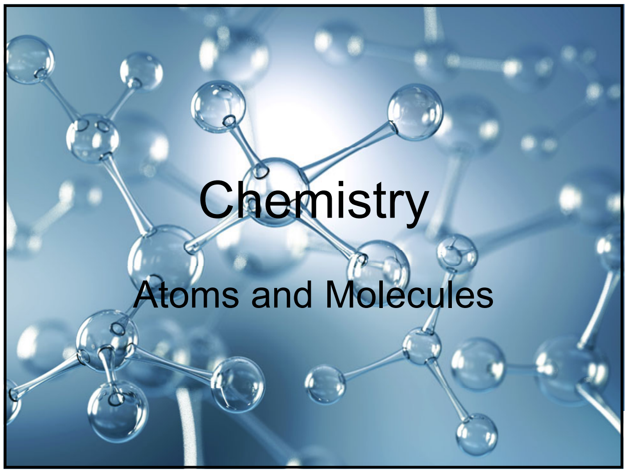
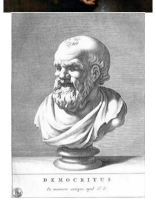


Chemistry

Atoms and Molecules

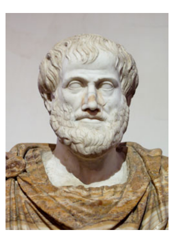
Early Ideas

- Leucippus and Democritus (Greek), c. 5th Century BCE
  - All matter was composed of small, finite particles called *atomos*
    - Moving particles that differed in size and shape and could join together



Leucippus – Didier Descouens (CC BY-SA 4.0)
Democritus – unknown (Public Domain)

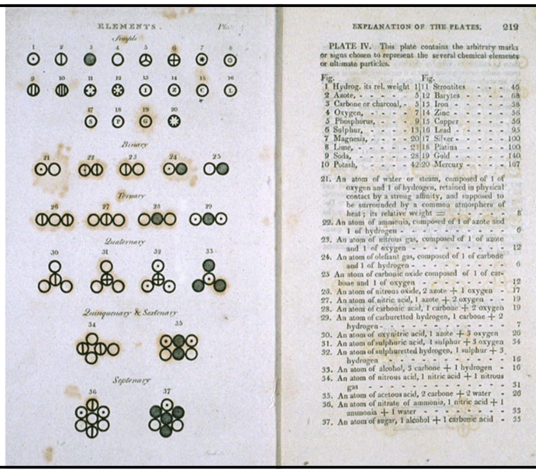
- Aristotle (Greek), 384-322 BCE
  - Matter is composed of four "elements"
    - Fire, air, earth, water



Aristotle – Ludovisi Collection (Public Domain)

- John Dalton (English), 1807
  - Revolutionized Chemistry with his atomic theory

Dalton – Charles Turner, Library of Congress Print and Photograph Division, digital ID: cph.3b12511, Public Domain



ELEMENTS.

Simple

Binary

Ternary

Quaternary

Quinquenary & Sextenary

Septenary

EXPLANATION OF THE PLATES. 219

PLATE IV. This plate contains the arbitrary marks or signs chosen to represent the several chemical elements or ultimate particles.

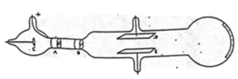
Fig.			Fig.		
1	Hydrog. its rel. weight	1	11	Strontites	46
2	Azote,	5	12	Barytes	68
3	Carbone or charcoal,	5	13	Iron	38
4	Oxygen,	7	14	Zinc	56
5	Phosphorus,	9	15	Copper	56
6	Sulphur,	13	16	Lead	95
7	Magnesia,	20	17	Silver	100
8	Lime,	24	18	Platina	100
9	Soda,	28	19	Gold	140
10	Potash,	42	20	Mercury	167

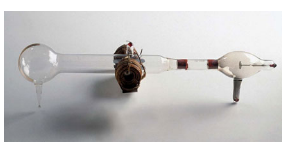
21. An atom of water or steam, composed of 1 of oxygen and 1 of hydrogen, retained in physical contact by a strong affinity, and supposed to be surrounded by a common atmosphere of heat; its relative weight = - - - - - 8
22. An atom of ammonia, composed of 1 of azote and 1 of hydrogen - - - - - 6
23. An atom of nitrous gas, composed of 1 of azote and 1 of oxygen - - - - - 12
24. An atom of olefiant gas, composed of 1 of carbone and 1 of hydrogen - - - - - 6
25 An atom of carbonic oxide composed of 1 of carbone and 1 of oxygen - - - - - 12
26. An atom of nitrous oxide, 2 azote + 1 oxygen - 17
27. An atom of nitric acid, 1 azote + 2 oxygen - - 19
28. An atom of carbonic acid, 1 carbone + 2 oxygen 19
29. An atom of carburetted hydrogen, 1 carbone + 2 hydrogen - - - - - 7
30. An atom of oxynitric acid, 1 azote + 3 oxygen 26
31. An atom of sulphuric acid, 1 sulphur + 3 oxygen 34
32. An atom of sulphuretted hydrogen, 1 sulphur + 3 hydrogen - - - - - 16
33. An atom of alcohol, 3 carbone + 1 hydrogen - 16
34. An atom of nitrous acid, 1 nitric acid + 1 nitrous gas - - - - - 31
35. An atom of acetous acid, 2 carbone + 2 water - 26
36. An atom of nitrate of ammonia, 1 nitric acid + 1 ammonia + 1 water - - - - - 33
37. An atom of sugar, 1 alcohol + 1 carbonic acid - 35

John Dalton. A New System of Chemical Philosophy. 1808. (Public Domain)

Evolution of Atomic Theory

- J. J. Thomson (British), 1897
  - Discovered the electron





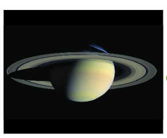
J. J. Thomson – unknown (Public Domain)
Sketch of Cathode Ray Tube – J. J. Thomson (Public Domain)
J. J. Thomson's cathode ray tube – Cavendish Laboratory, Cambridge, Science Museum, London. (CC BY-NC-SA 4.0)

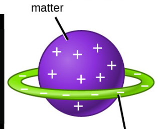
- Robert A. Millikan (American), 1913
  - Experimentally determined the charge on an electron

Robert A. Millikan – unknown (Mondadori Publishers) (Public Domain)
Original oil-drop apparatus – unknown (Public Domain)

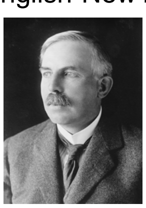
- In 1904, Thomson proposed the “plum pudding” model of the atom. (Based on the new evidence)
  - A positively charged mass with an equal amount of negatively charged electrons embedded in it.

- Hantaro Nagaoka (Japanese), 1903
  - postulated a Saturn-like atom
    - Positively charged sphere surrounded by a halo of electrons

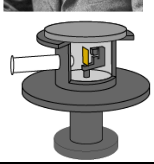




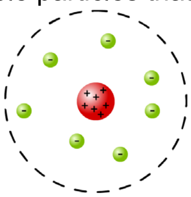
- Ernest Rutherford (English-New Zealand), Hans Geiger (German), Ernest Marsden (English-New Zealand), 1909



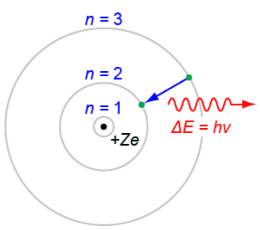
- Showed that atoms are mostly empty space.



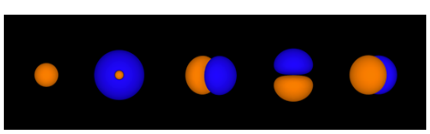
- From this result, Rutherford proposed that an atom had a very small positively charged nucleus, in which most of the mass is concentrated, surrounded by negatively charged electrons.
- Rutherford also discovered that the positive core was multiple particles that he called protons.



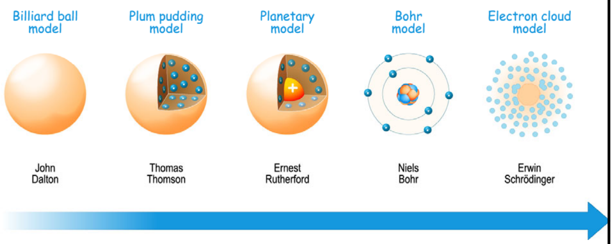
- Niels Bohr (Danish), 1913
  - Built on Rutherford's model and proposed that the electrons were in specific orbits around the nucleus



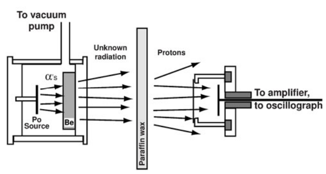
- Werner Heisenberg (German) and Erwin Schrödinger (Austrian), 1926
  - First introduced the modern understanding of atoms that electrons are not in orbits but rather in regions that were called orbitals



Timeline of atomic models



- James Chadwick (British), 1932
  - Discovered the neutron



These results, and others I have obtained in the course of the work, are very difficult to explain on the assumption that the radiation from beryllium is a quantum radiation, if energy and momentum are to be conserved in the collisions. The difficulties disappear, however, if it be assumed that the radiation consists of particles of mass 1 and charge 0, or neutrons. (Chadwick, J. Nature. Feb 27, 1932. p 312)

Atomic Structure & Symbolism

- Atoms have a very small nucleus composed of positively charged protons and uncharged (neutral) neutrons surrounded by a much larger space containing negatively charged electrons.
  - The diameter of an atom is on the order of 10^{-10} m, whereas the diameter of the nucleus is roughly 10^{-15} m (about 100,000 times smaller).

- If the nucleus were the size of a blueberry, then the atom would be the size of a football field.

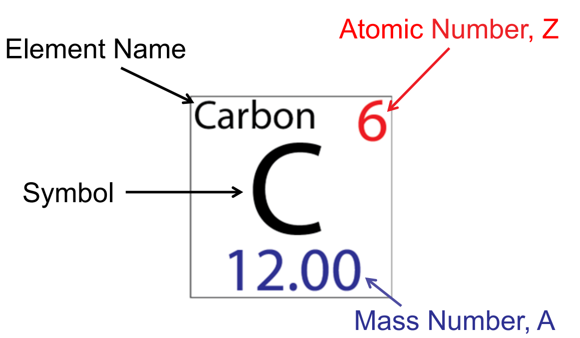
Football field, Stadium High School, Tacoma, WA – Curtis Cronn (CC BY-NC-ND 2.0)
Blueberries – Bill Young (CC BY-NC-ND 2.0)

- Protons, neutrons, and electrons have very small masses and charges.
  - A proton has a mass of $1.67 \times 10^{-27}\text{kg}$ and a charge of $1.6 \times 10^{-19}\text{C}$.
- Special units are used to describe these very small values.
  - Atomic mass units (amu)
  - Fundamental unit of charge (e)
    - The proton has a mass of 1 amu and a charge of +1 e.

- Properties of subatomic particles

Particle	Symbol	Charge (e)	Mass (amu)
proton	p^+	$+1$	1
neutron	n^0	0	1
electron	e^-	-1	$\frac{1}{2000}$

- The number of protons in the nucleus of an atom is the **atomic number (Z)**
- The number of protons plus neutrons in the atom is the **mass number (A)**
- The number of neutrons is the mass number minus the atomic number
- The number of electrons in an atom is equal to the number of protons (atomic number)



Note: Mass number should be rounded to nearest whole number

For example

- Fluorine
  - Atomic Number, Z= 9
  - Mass Number, A= 19

Number of protons = 9
Number of neutrons = 10
Number of electrons = 9

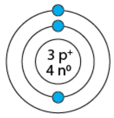
Electron Energy Levels

- Electrons occupy specific energy levels or shells
- A specific number of electrons occupy each shell as follows:
  - 1st shell (K): 2 electrons
  - 2nd shell (L): 8 electrons
  - 3rd shell (M): 18 electrons

- Electrons fill orbit shells in a consistent order.
- Under standard conditions, atoms fill the inner shells (closer to the nucleus) first, often resulting in a variable number of electrons in the outermost shell.
- Electrons follow the **octet rule**
  - An atom is more stable energetically when it has 8 electrons in its most outer or valence shell.

Bohr Diagrams

- Bohr diagrams show electrons orbiting the nucleus of an atom somewhat like planets orbit around the sun.
- In the Bohr model, electrons are pictured as traveling in circles at different shells, depending on which element you have.

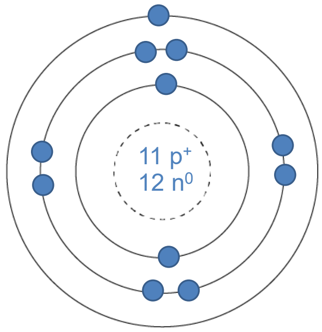


Bohr diagram for Lithium – David Libby (Public Domain)

Example

Sodium

11
Na
Sodium
22.9897693



Atomic number, Z=11
Mass number, A=23

Protons = 11
Neutrons = 12
Electrons = 11

1 shell (K) = 2
2 shell (L) = 8
3 shell (M) = 1

Chemical Symbols

- A chemical symbol is an abbreviation that we use to indicate an element or an atom of an element.
  - Some symbols are derived from the common name of the element.
  - Some symbols are abbreviations of the name in other languages.
  - If there are two (or more letters) only the first letter is capitalized.

Element	Symbol	Element	Symbol
Aluminum	Al	Iron	Fe (ferrum)
Calcium	Ca	Lead	Pb (plumbum)
Carbon	C	Sodium	Na (natrium)
Chlorine	Cl	Potassium	K (kalium)
Oxygen	O	Gold	Au (aurum)
Helium	He	Silver	Ag (argentum)
Hydrogen	H	Tin	Sn (stannum)
Iodine	I		

Chemical Formulas

- A chemical formula is a representation of a compound that uses chemical symbols to indicate the types of atoms followed by subscripts to show the number of each atom in the compound.

H_2SO_4

H_2SO_4

2 Hydrogen — 1 Sulfur — 4 Oxygen

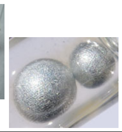
$Mg(OH)_2$

1 Magnesium — 2 Oxygen — 2 Hydrogen

The Periodic Table

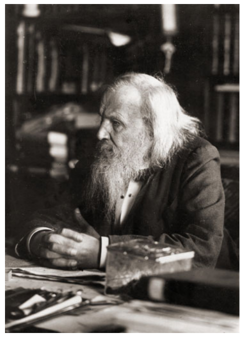
- As early chemists worked to purify ores and discovered more elements, they realized that various elements had similar chemical properties.
  - For example, lithium (Li), sodium (Na), and potassium (K) are all shiny and conduct electricity well





Lithium – Tomihahndorf (Public Domain)
Sodium – Dnn87 (CC BY-SA 3.0)
Potassium – unknown (Wikipedia Commons) (CC BY 1.0)

- Dmitri Mendeleev (Russian), 1869
  - Recognized that there was a periodic relationship among the elements
  - Published a table with the elements arranged according to increasing atomic mass



Dmitri Mendeleev – unknown (Public Domain)

Reihen	Gruppo I. — R^2O	Gruppo II. — RO	Gruppo III. — R^2O^3	Gruppo IV. RH^4 RO^2	Gruppo V. RH^3 R^2O^5	Gruppo VI. RH^2 RO^3	Gruppo VII. RH R^2O^7	Gruppo VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Mendeleev's periodic table – Dmitri Mendeleev (Public Domain)

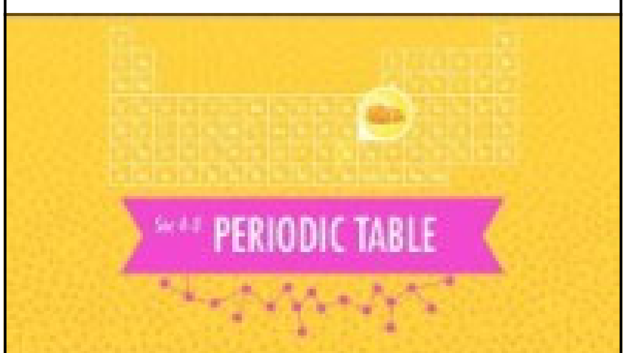
- Lothar Meyer (German), 1870
  - Independently created a table of the elements
  - His table did not go as far as Mendeleev's
    - Mendeleev used his table to predict the existence of elements with similar properties to the elements that were already known.

Lothar Meyer – Wilhelm Hornung (Public Domain)

- By the 20th century, it became apparent that the periodic relationship involved atomic numbers rather than atomic mass.
- A modern periodic table arranges the elements in increasing order of their atomic numbers and groups atoms with similar properties in the same vertical column.
- The elements are arranged in 7 rows called **periods** and 18 columns called **groups**.

- Each period represents one electron energy shell.
  - All elements in period 2 have two shells
  - All elements in period 3 have three shells
- In general, all the elements in each group have the same number of valence electrons (electrons in outermost shell).
  - All elements in group 1 have 1 valence electron.
  - All elements in group 2 have 2 valence electrons.

The Periodic Table: Crash Course Chemistry #4



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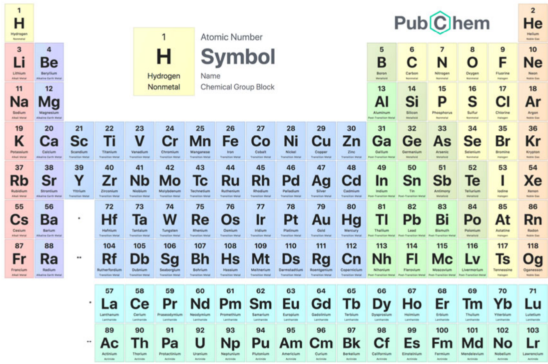
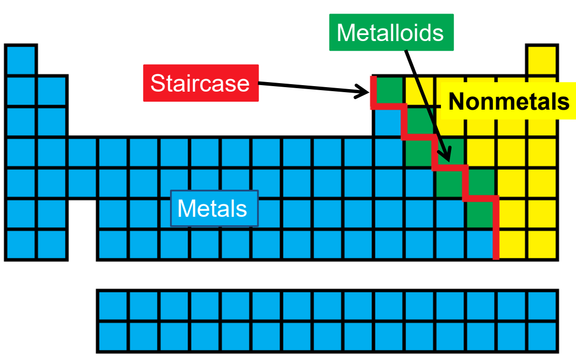
PERIODIC TABLE OF ELEMENTS



- The table is divided into two large categories
  - Metals
  - Nonmetals
- These categories are separated by a “staircase”
  - Metals are on the left
  - Nonmetals are on the right
- A number of elements along the staircase have properties of both metals and nonmetals
  - Metalloids



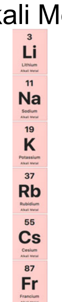
Properties of Metals and Nonmetals

Metals
- Shiny
- Malleable
- Ductile
- Good conductors of heat and electricity

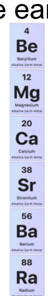
Nonmetals
- Dull
- Brittle
- Poor conductors of heat and electricity

Group Names

- Group 1
- Alkali Metals



- Group 2
- Alkaline earth metals



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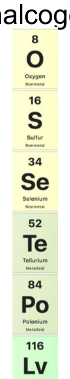
- Group 16
- Chalcogens



- Group 17
- Halogens

- Group 18
- Noble Gases

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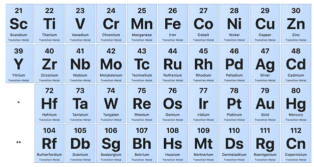
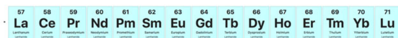
- Transition metals

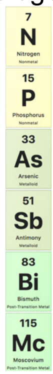


- Inner transition metals
  - Lanthanides



  - Actinides

- Group 15
- Pnictogens



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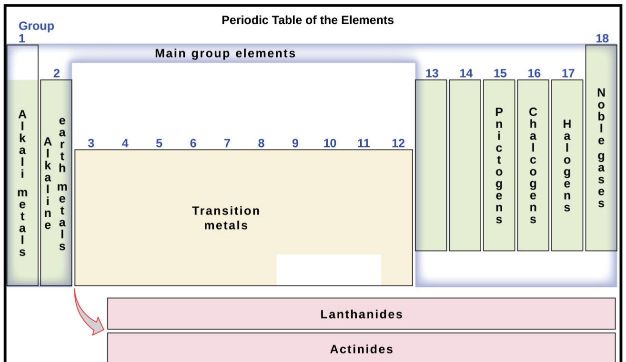
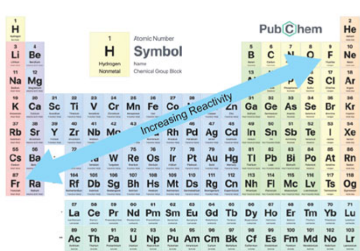


Credit: Flowers, Paul, et al. "The Periodic Table." Chemistry 2e. OpenStax, Houston, TX. 2019.
https://openstax.org/books/chemistry-2e/pages/2-5-the-periodic-table
(CC BY 4.0)

Chemical Reactivity

- The design of the periodic table also provides insight into the chemical reactivity of the elements.



- Metals
  - Decreases as you go left to right
    - More valence electrons to get rid of
  - Increases as you go down the group
    - The atom gets bigger, so it is easier to lose electrons
- Nonmetals
  - Increases as you go left to right
    - Electronegativity (ability to attract electrons) increases
  - Decreases as you go down the group
    - Electronegativity decreases as the atom gets bigger

https://youtu.be/kqe9tEcZkno