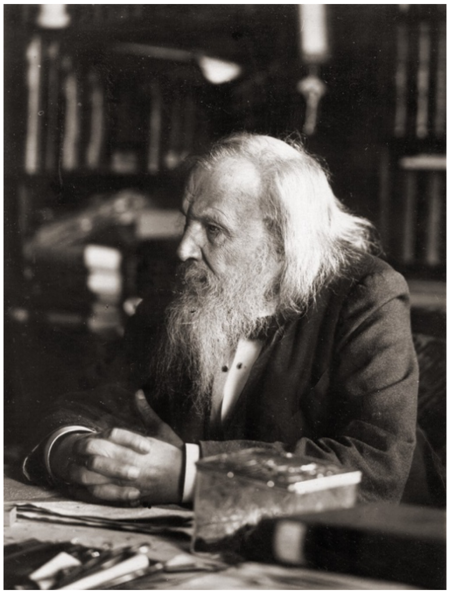
01C_Chemical Bonds: The Periodic Table

Topics:

•The Periodic Table



8 February 1834 – 2 February 1907

In 1863, there were 56 known elements.

After becoming a teacher in 1867, Mendeleev wrote Principles of Chemistry, which became the definitive textbook of its time. It was published in two volumes between 1868 and 1870, and Mendeleev wrote it as he was preparing a textbook for his course. This is when he made his most important discovery. As he attempted to classify the elements according to their chemical properties, he noticed patterns that led him to postulate his periodic table; he claimed to have envisioned the complete arrangement of the elements in a dream. https://en.wikipedia.org/wiki/Dmitri_Mendeleev

•The electronic nature of bonding among atoms (the electron orbitals)

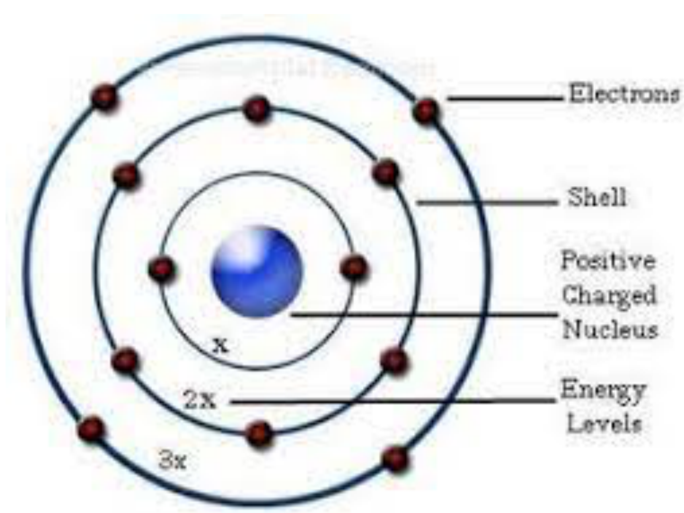
•Metallic Bonds

•Ionic and Covalent Bonds

•Electronegativity: ionic and covalent bonding

•The special case of Carbon

The Periodic Table



In 1913, Niels Bohr proposed a theory for the hydrogen atom, based on quantum theory that some physical quantities only take discrete values. ... Bohr's model explained why atoms only emit light of fixed wavelengths, and later incorporated the theories on light quanta**.**

The quantized orbitals in atoms gave a rational explanation for the eight-column classification of the periodic table.

The orbitals are quantized as 1, 2, 3 etc.

Each orbital may contain only 2, 8, 18 electrons ($2n^2$) and so on.

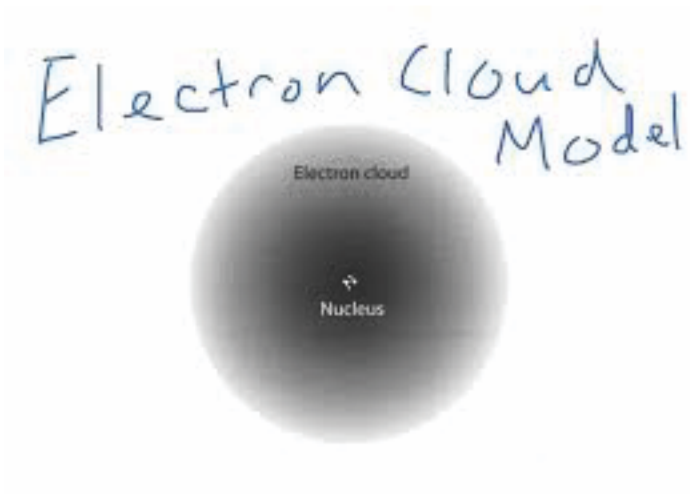
The energy of a collection of atoms is lowest if the shells are complete. So if an atom has 7 electrons; it will bond to other atoms if by borrowing or sharing it can fill its orbital with 8 electrons. Hence the eight columns of the periodic table. When progressing to the third orbital, the middle of the periodic table expands to accommodate then ten extra atoms.

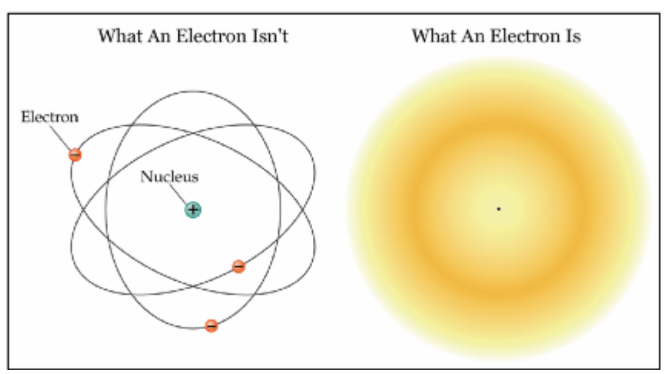
Explore the chemical elements through this periodic table

Group	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 H 1.008 Hydrogen																		2 He 4.0026 Helium
2	3 Li 6.94 Lithium	4 Be 9.0122 Beryllium												5 B 10.81 Boron	6 C 12.011 Carbon	7 N 14.007 Nitrogen	8 O 15.999 Oxygen	9 F 18.998 Fluorine	10 Ne 20.180 Neon
3	11 Na 22.990 Sodium	12 Mg 24.305 Magnesium												13 Al 26.982 Aluminium	14 Si 28.085 Silicon	15 P 30.974 Phosphorus	16 S 32.06 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.948 Argon
4	19 K 39.098 Potassium	20 Ca 40.078 Calcium		21 Sc 44.956 Scandium	22 Ti 47.867 Titanium	23 V 50.942 Vanadium	24 Cr 51.996 Chromium	25 Mn 54.938 Manganese	26 Fe 55.845 Iron	27 Co 58.933 Cobalt	28 Ni 58.693 Nickel	29 Cu 63.546 Copper	30 Zn 65.38 Zinc	31 Ga 69.723 Gallium	32 Ge 72.630 Germanium	33 As 74.922 Arsenic	34 Se 78.971 Selenium	35 Br 79.904 Bromine	36 Kr 83.798 Krypton
5	37 Rb 85.468 Rubidium	38 Sr 87.62 Strontium		39 Y 88.906 Yttrium	40 Zr 91.224 Zirconium	41 Nb 92.906 Niobium	42 Mo 95.95 Molybdenum	43 Tc 96.906 Technetium	44 Ru 101.07 Ruthenium	45 Rh 102.91 Rhodium	46 Pd 106.42 Palladium	47 Ag 107.87 Silver	48 Cd 112.41 Cadmium	49 In 114.82 Indium	50 Sn 118.71 Tin	51 Sb 121.76 Antimony	52 Te 127.60 Tellurium	53 I 126.90 Iodine	54 Xe 131.29 Xenon
6	55 Cs 132.91 Caesium	56 Ba 137.33 Barium	*	71 Lu 174.97 Lutetium	72 Hf 178.49 Hafnium	73 Ta 180.95 Tantalum	74 W 183.84 Tungsten	75 Re 186.21 Rhenium	76 Os 190.23 Osmium	77 Ir 192.22 Iridium	78 Pt 195.08 Platinum	79 Au 196.97 Gold	80 Hg 200.59 Mercury	81 Tl 204.38 Thallium	82 Pb 207.2 Lead	83 Bi 208.98 Bismuth	84 Po 208.98 Polonium	85 At 209.99 Astatine	86 Rn 222.02 Radon
7	87 Fr 223.02 Francium	88 Ra 226.03 Radium	**	103 Lr 262.11 Lawrencium	104 Rf 267.12 Rutherfordium	105 Db 270.13 Dubnium	106 Sg 269.13 Seaborgium	107 Bh 270.13 Bohrium	108 Hs 269.13 Hassium	109 Mt 278.16 Meitnerium	110 Ds 281.17 Darmstadtium	111 Rg 281.17 Roentgenium	112 Cn 285.18 Copernicium	113 Nh 286.18 Nihonium	114 Fl 289.19 Flerovium	115 Mc 289.20 Moscovium	116 Lv 293.20 Livermorium	117 Ts 293.21 Tennessine	118 Og 294.21 Oganesson
*Lanthanoids			*	57 La 138.91 Lanthanum	58 Ce 140.12 Cerium	59 Pr 140.91 Praseodymium	60 Nd 144.24 Neodymium	61 Pm 144.91 Promethium	62 Sm 150.36 Samarium	63 Eu 151.96 Europium	64 Gd 157.25 Gadolinium	65 Tb 158.93 Terbium	66 Dy 162.50 Dysprosium	67 Ho 164.93 Holmium	68 Er 167.26 Erbium	69 Tm 168.93 Thulium	70 Yb 173.05 Ytterbium		
**Actinoids			**	89 Ac 227.03 Actinium	90 Th 232.04 Thorium	91 Pa 231.04 Protactinium	92 U 238.03 Uranium	93 Np 237.05 Neptunium	94 Pu 244.06 Plutonium	95 Am 243.06 Americium	96 Cm 247.07 Curium	97 Bk 247.07 Berkelium	98 Cf 251.08 Californium	99 Es 252.08 Einsteinium	100 Fm 257.10 Fermium	101 Md 258.10 Mendelevium	102 No 259.10 Nobelium		

The standard form of the periodic table shown here includes periods (shown horizontally) and groups (shown vertically). The properties of elements in groups are similar in some respects to each other.

The electronic nature of bonding among atoms (the electron orbitals)





The distribution of electrons around the nucleus is not strictly in a discreet orbit, but rather distributed in space around the discreet orbit as calculated in the Bohr model.

Metallic, Ionic and Covalent Bonds

What is the electronic structure of these bonds?

Metallic bonding:

Atoms part with the extra electrons in the outermost shell to create a common "sea of electrons", and thus a bond among the atoms.

Why? because it is easier for the atom to part with one or two electrons, than to borrow many more electrons to complete its shell.

Metallic bonding is not localized. It is spread out among several neighboring atoms.

In general atoms want to pack together as closely as possible to maximize the "energy of formation", the energy of formation is the exothermic energy if a bunch of atoms are brought together from the vapor state to the solid state.

Ionic Bonding:

Electrons transfer from the atoms on the left-hand side, to those on the right hand side of the periodic table, thereby creating complete shells for both atoms. For example consider $Na^{+}Cl^{-}$. The chlorine has a greater affinity for electrons -it is more electronegative than sodium.

Ideally, ionic bonding is non-directional. The properties of NaCl can be approximately analyzed by consider sodium and chlorine atoms as point charges (positive and negative) and studying the bonding energy as an electrostatics problem.

Covalent Bonding:

Electrons are shared among neighboring atoms. Carbon is a classical example.

The bonding is highly directional. The sharing of electrons is enabled by the electron "cloud" being like a lobe from the nucleus. For example a carbon atom can have four lobes that forms diamond, or it may have three lobes which forms graphene.

These are strong bonds, as well as multiplicity of bonding increases the energy of formation.

Mixed Ionic and Covalent Bonding:

Such mixed bonds can occur only among two different atoms, each with a different degree of electron-affinity.

Linus Pauling developed a electronegativity scale that describes the electron affinity of elements. The table is given on the right hand side. Note that the element at the bottom left corner is the most electropositive and the element at the top right is the most electronegative element.

						H										
						2.1										
Li	Be	B											C	N	O	F
1.0	1.5	2.0											2.5	3.0	3.5	4.0
Na	Mg	Al											Si	P	S	Cl
0.9	1.2	1.5											1.8	2.1	2.5	3.0
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br
0.8	1.0	1.3	1.5	1.6	1.6	1.5	1.8	1.9	1.9	1.9	1.6	1.6	1.8	2.0	2.4	2.8
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I
0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.2	2.2	2.2	1.9	1.7	1.7	1.8	1.9	2.1	2.5
Cs	Ba	La-Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At
0.7	0.9	1.0-1.2	1.3	1.5	17	1.9	2.2	2.2	2.2	2.4	1.9	1.8	1.9	1.9	2.0	2.2
Fr	Ra	Ac	Th	Pa	U	Np-No										
0.7	0.9	1.1	1.3	1.4	1.4	1.4-1.3										

The difference between the electron affinity of two elements determines the extent of mixed bonding, or in other words, the ionic character of a bond expressed as a fraction of the total bond strength. The so called "ionic character" between any two atoms, A and B is given by,

$$I_C = 1 - \exp\left[1 - \frac{(\chi_A - \chi_B)^2}{4}\right]$$

Note that the result depends only on the magnitude of the difference between the electronegativities (since it is written as the square of the difference. The following table gives the magnitude of the ionic character according to the above equation.

$x_A - x_B$	Amount of ionic Character (%)	$x_A - x_B$	Amount of ionic Character (%)
0.2	1	1.8	55
.4	4	2.0	63
.6	9	2.2	70
.8	15	2.4	76
1.0	22	2.6	82
1.2	30	2.8	86
1.4	39	3.0	89
1.6	47	3.2	92