JBSP Mandal's
Art & Science College,
~~Department Of Chemistry~~
Topic : Chemical Bonding

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Chemical compounds - covalent (molecular) and ionic

Chemical formulas

- elemental analysis, empirical formulas
- Molar masses with empirical formulas --> chemical formula

Expressing chemical equations

Stoichiometric calculations

Limiting Reactant : determines amount of product formed

Theoretical yields vs actual yields

Chemical Bonding

A chemical bond results from strong electrostatic interactions between two atoms.

The nature of the atoms determines the kind of bond.

COVALENT bonds result from a strong interaction between NEUTRAL atoms

Each atom donates an electron resulting in a pair of electrons that are SHARED between the two atoms

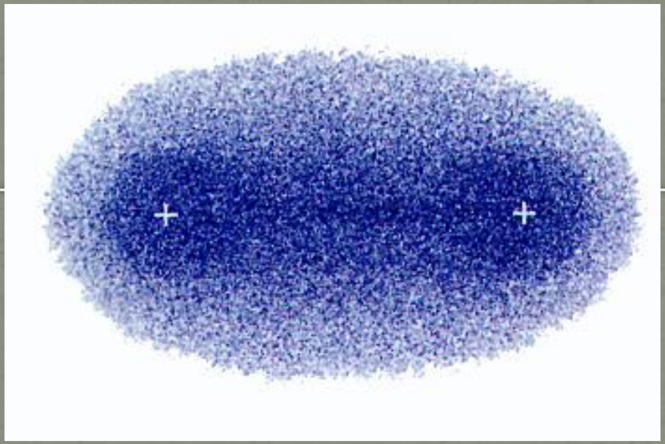
For example, consider a hydrogen molecule, H_2. When the two hydrogen, H, atoms are far apart from each other they do not feel any interaction.

As they come closer each “feels” the presence of the other.

The electron on each H atom occupies a volume that covers both H atoms and a COVALENT bond is formed.

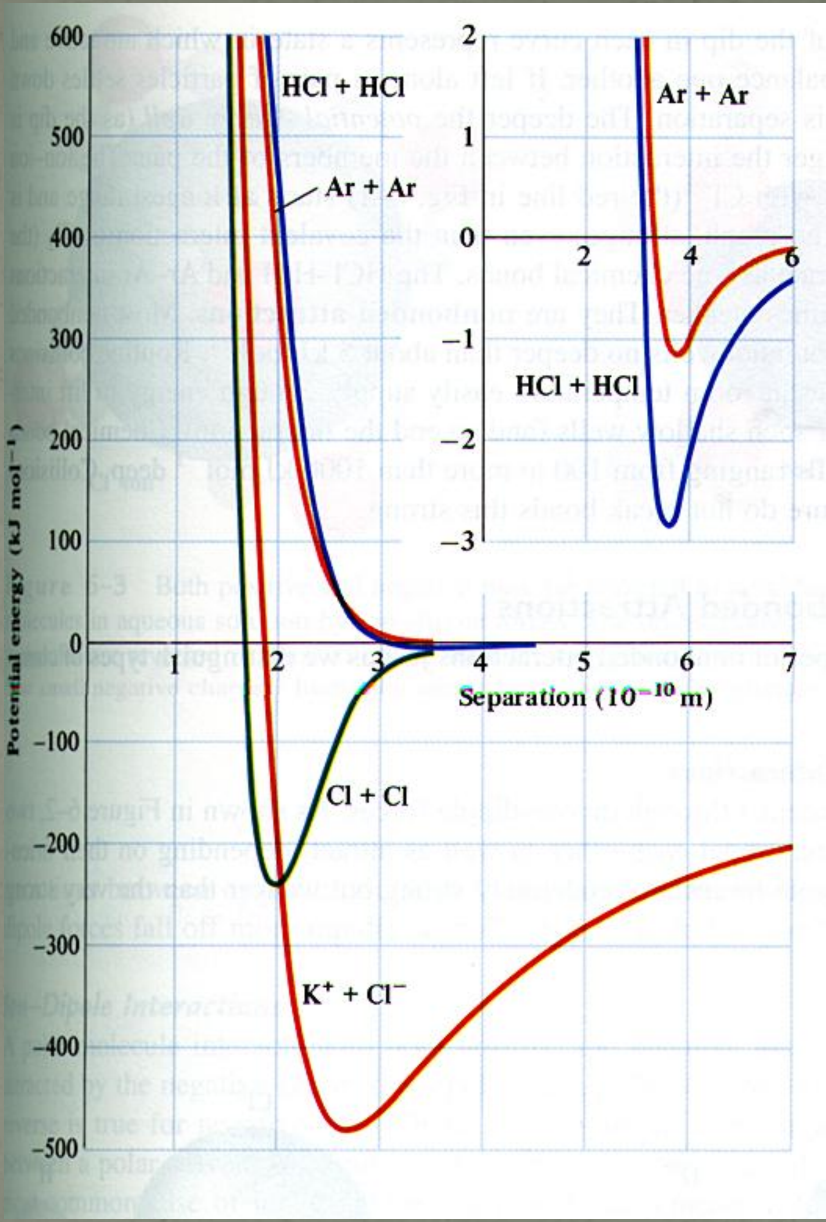
Once the bond has been formed, the two electrons are shared by BOTH H atoms.

An electron density plot for the H_2 molecule shows that the shared electrons occupy a volume equally distributed over BOTH H atoms.



Electron Density for the H_2 molecule

Potential energy (kJ/mol)



Separation (Å)

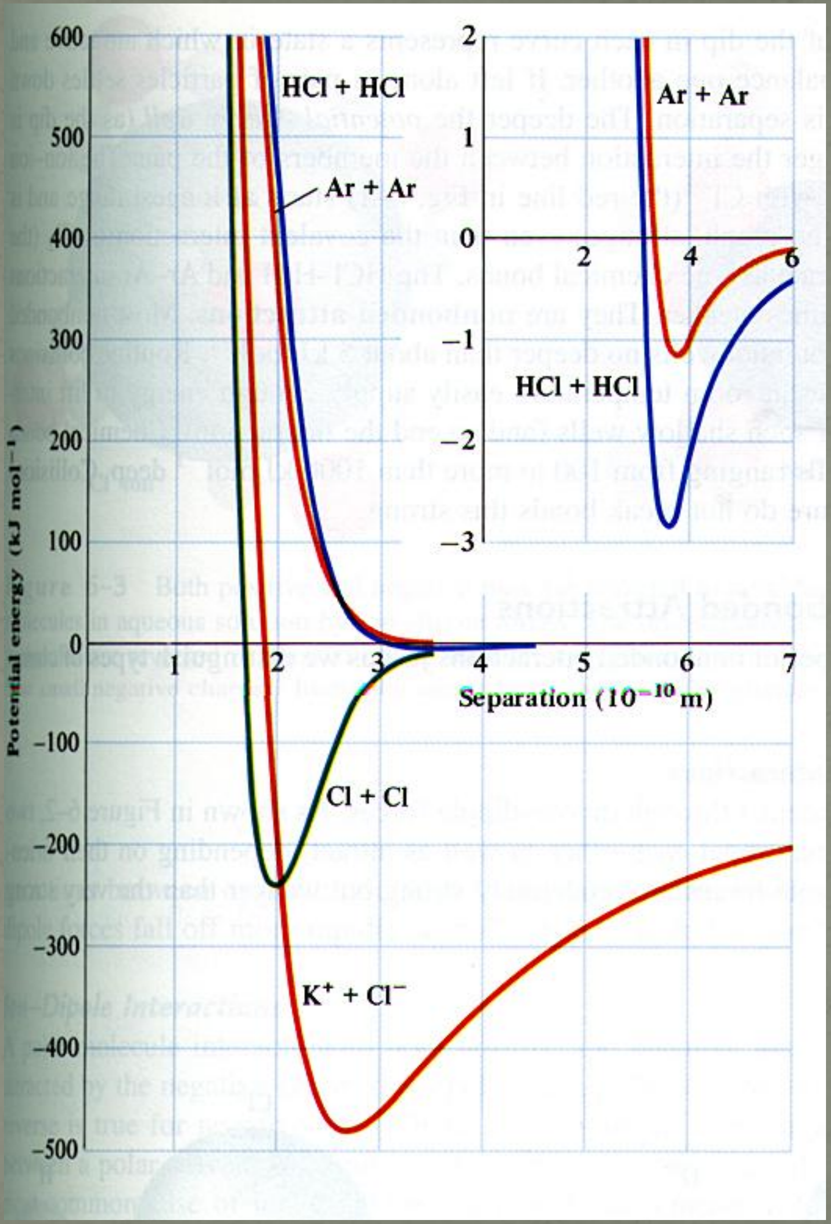
It is also possible that, as two atoms come closer, one electron is transferred to the other atom.

The atom that gives up an electron acquires a +1 charge and the other atom, which accepts the electron acquires a –1 charge.

The two atoms are attracted to each other through Coulombic interactions – opposite charges attract – resulting in an IONIC bond.

Animation

Potential energy (kJ/mol)



Separation (Å)

What factors determine if an atom forms a covalent or ionic bond with another atom?

The number of electrons in an atom, particularly the number of the electrons furthest away from the nucleus determines the atom's reactivity and hence its tendency to form covalent or ionic bonds.

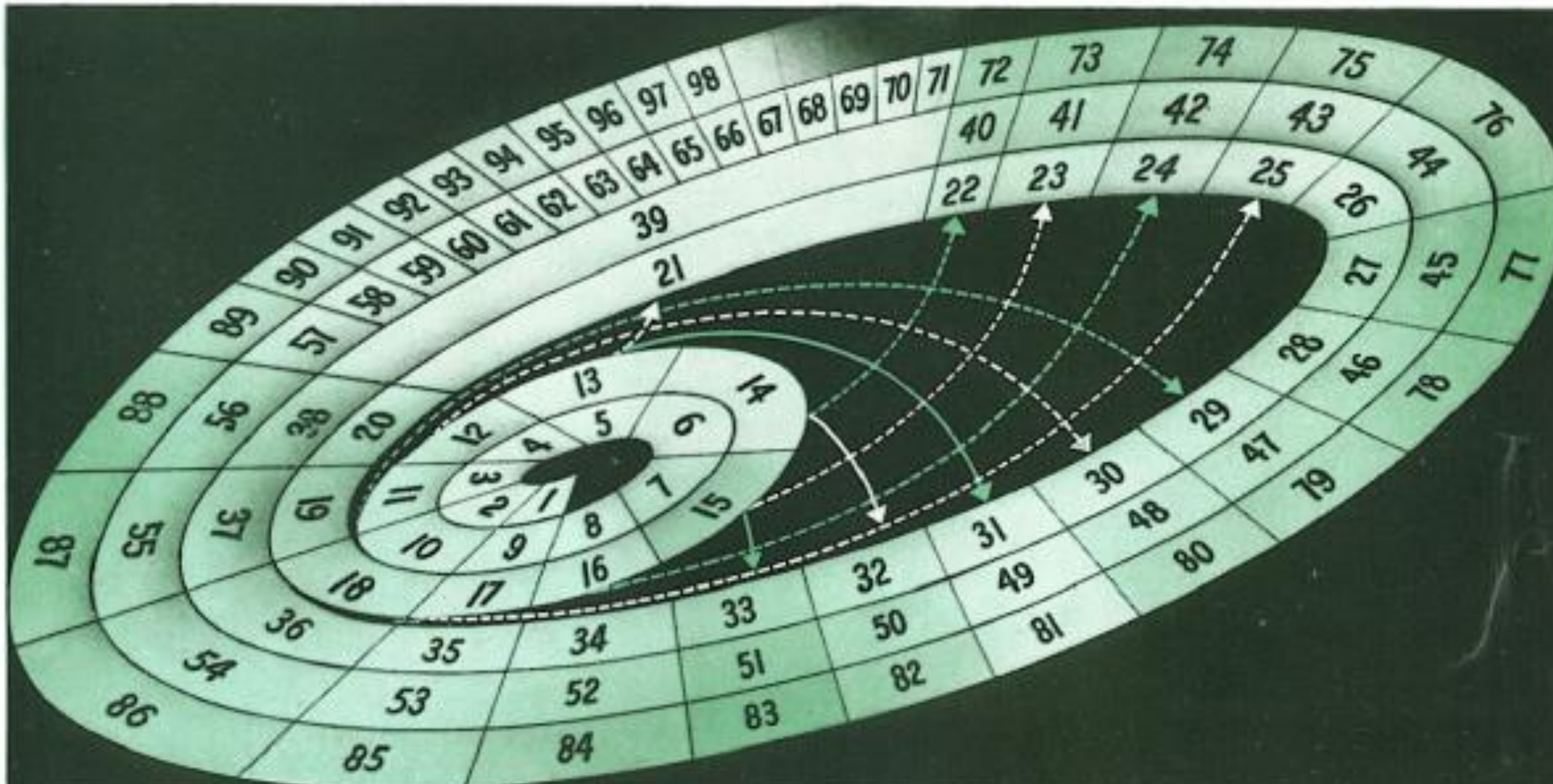
These outermost electrons are the one's that are more likely to "feel" the presence of other atoms and hence the one's involved in bonding i.e. in reactions.

Chemistry of an element depends almost entirely on the number of electrons, and hence its atomic number.

THE PERIODIC TABLE

By the late 1800's it was realized that elements could be grouped by similar chemical properties and that the chemical and physical properties of elements are periodic functions of their atomic numbers – PERIODIC LAW.

The arrangements of the elements in order of increasing atomic number, with elements having similar properties placed in a vertical column, is called the PERIODIC TABLE.



1 HYDROGEN
2 HELIUM
3 LITHIUM
4 BERYLLIUM
5 BORON
6 CARBON
7 NITROGEN
8 OXYGEN
9 FLUORINE
10 NEON
11 SODIUM
12 MAGNESIUM
13 ALUMINIUM
14 SILICON
15 PHOSPHORUS
16 SULPHUR
17 CHLORINE
18 ARGON
19 POTASSIUM
20 CALCIUM
21 SCANDIUM
22 TITANIUM
23 VANADIUM
24 CHROMIUM
25 MANGANESE
26 IRON
27 COBALT
28 NICKEL
29 COPPER
30 ZINC
31 GALLIUM
32 GERMANIUM
33 ARSENIC
34 SELENIUM
35 BROMINE
36 KRYPTON
37 RUBIDIUM
38 STRONTIUM
39 YTTRIUM
40 ZIRCONIUM
41 COLUMBIUM
42 MOLYBDENUM
43 TECHNETIUM
44 RUTHENIUM
45 RHODIUM
46 PALLADIUM
47 SILVER
48 CADMIUM
49 INDIUM
50 TIN
51 ANTIMONY
52 TELLURIUM
53 IODINE
54 XENON
55 CAESIUM
56 BARIUM
57 LANTHANUM
58 CERIUM
59 PRASEODYMIUM
60 NEODYMIUM
61 PROMETHEUM
62 SAMARIUM
63 EUROPIUM
64 GADOLINIUM
65 TERBIUM
66 DYSPROSIUM
67 HOLMIUM
68 ERBIUM
69 THULIUM
70 YTTERBIUM
71 LUTECIUM
72 HAFNIUM
73 TANTALUM
74 TUNGSTEN
75 RHENIUM
76 OSMIUM
77 IRIDIUM
78 PLATINUM
79 GOLD
80 MERCURY
81 THALLIUM
82 LEAD
83 BISMUTH
84 POLONIUM
85 ASTATINE
86 RADON
87 FRANCIUM
88 RADIUM
89 ACTINIUM
90 THORIUM
91 PROTACTINIUM
92 URANIUM
93 NEPTUNIUM
94 PLUTONIUM
95 AMERICIUM
96 CURIUM
97 BERKELIUM
98 CALIFORNIUM

Elements beyond this number have not yet been made.

The Elements arranged in the order of their mass on The Periodic Table

Periodic Table of the Elements

- Alkali Metals
- Alkaline earth Metals
- Transition metals
- Lanthanide series
- Actinide series
- Other Metals
- Nonmetals
- Noble gases

- C Solid
- Br Liquid
- H Gas
- Tc Synthetic

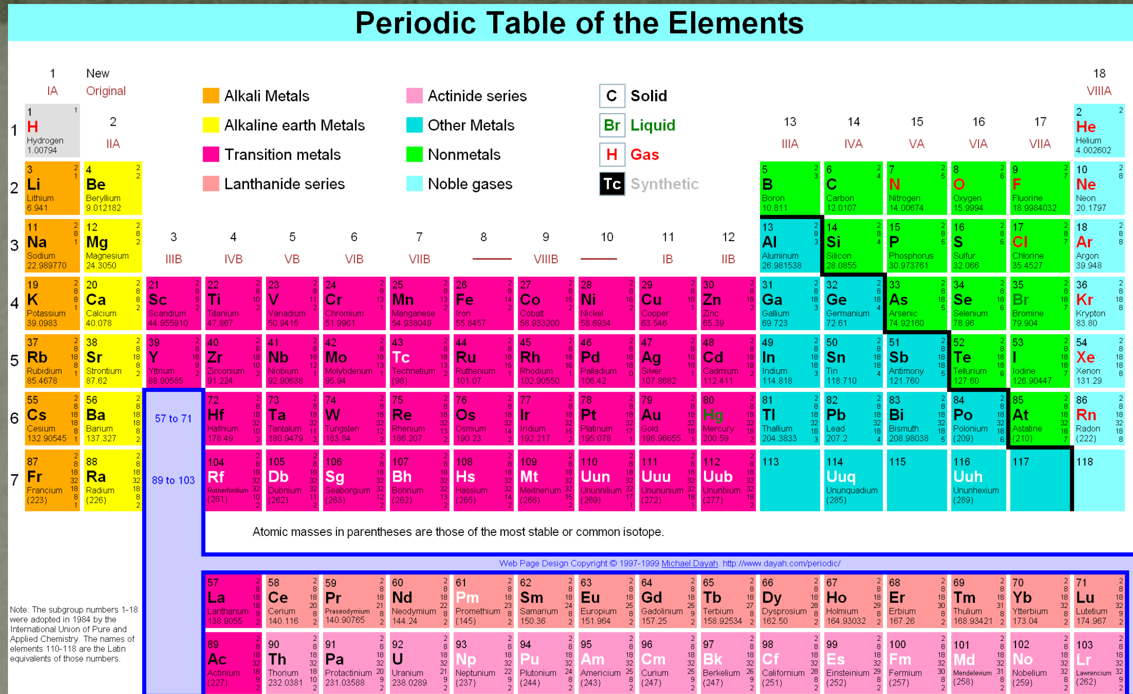
New / Original

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H Hydrogen 1.00794 (1)																	2 He Helium 4.002602 (2)
2	3 Li Lithium 6.941 (2 1)	4 Be Beryllium 9.012182 (2 2)											5 B Boron 10.811 (2 3)	6 C Carbon 12.0107 (2 4)	7 N Nitrogen 14.00674 (2 5)	8 O Oxygen 15.9994 (2 6)	9 F Fluorine 18.9984032 (2 7)	10 Ne Neon 20.1797 (2 8)
3	11 Na Sodium 22.989770 (2 8 1)	12 Mg Magnesium 24.3050 (2 8 2)											13 Al Aluminum 26.981538 (2 8 3)	14 Si Silicon 28.0855 (2 8 4)	15 P Phosphorus 30.973761 (2 8 5)	16 S Sulfur 32.066 (2 8 6)	17 Cl Chlorine 35.4527 (2 8 7)	18 Ar Argon 39.948 (2 8 8)
4	19 K Potassium 39.0983 (2 8 8 1)	20 Ca Calcium 40.078 (2 8 8 2)	21 Sc Scandium 44.955910 (2 8 9 2)	22 Ti Titanium 47.867 (2 8 10 2)	23 V Vanadium 50.9415 (2 8 11 2)	24 Cr Chromium 51.9961 (2 8 13 1)	25 Mn Manganese 54.938049 (2 8 13 2)	26 Fe Iron 55.8457 (2 8 14 2)	27 Co Cobalt 58.933200 (2 8 15 2)	28 Ni Nickel 58.6934 (2 8 16 2)	29 Cu Copper 63.546 (2 8 18 1)	30 Zn Zinc 65.39 (2 8 18 2)	31 Ga Gallium 69.723 (2 8 18 3)	32 Ge Germanium 72.61 (2 8 18 4)	33 As Arsenic 74.92160 (2 8 18 5)	34 Se Selenium 78.96 (2 8 18 6)	35 Br Bromine 79.904 (2 8 18 7)	36 Kr Krypton 83.80 (2 8 18 8)
5	37 Rb Rubidium 85.4678 (2 8 18 8 1)	38 Sr Strontium 87.62 (2 8 18 8 2)	39 Y Yttrium 88.90585 (2 8 18 9 2)	40 Zr Zirconium 91.224 (2 8 18 10 2)	41 Nb Niobium 92.90638 (2 8 18 12 1)	42 Mo Molybdenum 95.94 (2 8 18 13 1)	43 Tc Technetium (98) (2 8 18 13 2)	44 Ru Ruthenium 101.07 (2 8 18 15 1)	45 Rh Rhodium 102.90550 (2 8 18 16 1)	46 Pd Palladium 106.42 (2 8 18 18 0)	47 Ag Silver 107.8682 (2 8 18 18 1)	48 Cd Cadmium 112.411 (2 8 18 18 2)	49 In Indium 114.818 (2 8 18 18 3)	50 Sn Tin 118.710 (2 8 18 18 4)	51 Sb Antimony 121.760 (2 8 18 18 5)	52 Te Tellurium 127.60 (2 8 18 18 6)	53 I Iodine 126.90447 (2 8 18 18 7)	54 Xe Xenon 131.29 (2 8 18 18 8)
6	55 Cs Cesium 132.90545 (2 8 18 18 8 1)	56 Ba Barium 137.327 (2 8 18 18 8 2)	57 to 71	72 Hf Hafnium 178.49 (2 8 18 32 10 2)	73 Ta Tantalum 180.9479 (2 8 18 32 11 2)	74 W Tungsten 183.84 (2 8 18 32 12 2)	75 Re Rhenium 186.207 (2 8 18 32 13 2)	76 Os Osmium 190.23 (2 8 18 32 14 2)	77 Ir Iridium 192.217 (2 8 18 32 15 2)	78 Pt Platinum 195.078 (2 8 18 32 17 1)	79 Au Gold 196.96655 (2 8 18 32 18 1)	80 Hg Mercury 200.59 (2 8 18 32 18 2)	81 Tl Thallium 204.3833 (2 8 18 32 18 3)	82 Pb Lead 207.2 (2 8 18 32 18 4)	83 Bi Bismuth 208.98038 (2 8 18 32 18 5)	84 Po Polonium (209) (2 8 18 32 18 6)	85 At Astatine (210) (2 8 18 32 18 7)	86 Rn Radon (222) (2 8 18 32 18 8)
7	87 Fr Francium (223) (2 8 18 32 18 8 1)	88 Ra Radium (226) (2 8 18 32 18 8 2)	89 to 103	104 Rf Rutherfordium (261) (2 8 18 32 32 10 2)	105 Db Dubnium (262) (2 8 18 32 32 11 2)	106 Sg Seaborgium (263) (2 8 18 32 32 12 2)	107 Bh Bohrium (262) (2 8 18 32 32 13 2)	108 Hs Hassium (265) (2 8 18 32 32 14 2)	109 Mt Meitnerium (266) (2 8 18 32 32 15 2)	110 Uun Ununnilium (269) (2 8 18 32 32 17 1)	111 Uuu Unununium (272) (2 8 18 32 32 18 1)	112 Uub Ununbium (277) (2 8 18 32 32 18 2)	113	114 Uuq Ununquadium (285)	115	116 Uuh Ununhexium (289)	117	118

Atomic masses in parentheses are those of the most stable or common isotope.

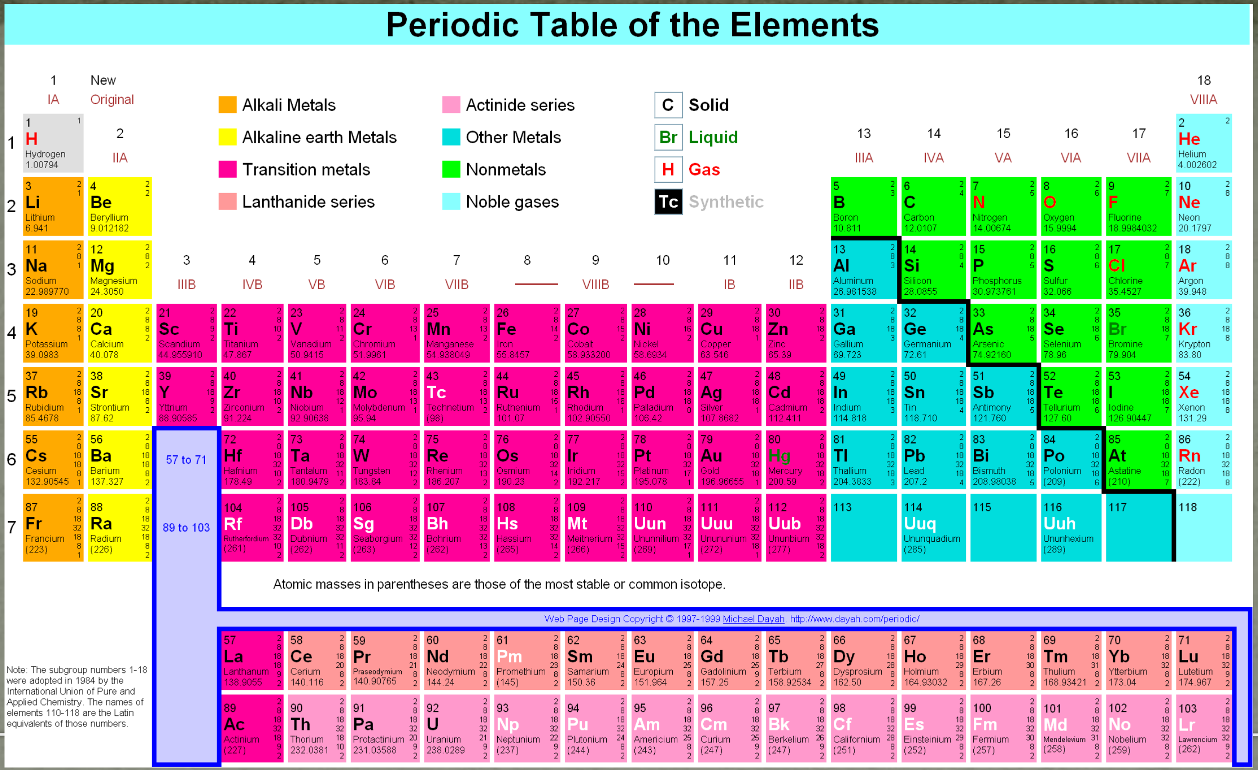
57 La Lanthanum 138.9055 (2 8 18 18 9 2)	58 Ce Cerium 140.116 (2 8 18 20 8 2)	59 Pr Praseodymium 140.90765 (2 8 18 21 8 2)	60 Nd Neodymium 144.24 (2 8 18 22 8 2)	61 Pm Promethium (145) (2 8 18 23 8 2)	62 Sm Samarium 150.36 (2 8 18 24 8 2)	63 Eu Europium 151.964 (2 8 18 25 8 2)	64 Gd Gadolinium 157.25 (2 8 18 25 9 2)	65 Tb Terbium 158.92534 (2 8 18 27 8 2)	66 Dy Dysprosium 162.50 (2 8 18 28 8 2)	67 Ho Holmium 164.93032 (2 8 18 29 8 2)	68 Er Erbium 167.26 (2 8 18 30 8 2)	69 Tm Thulium 168.93421 (2 8 18 31 8 2)	70 Yb Ytterbium 173.04 (2 8 18 32 8 2)	71 Lu Lutetium 174.967 (2 8 18 32 9 2)
89 Ac Actinium (227) (2 8 18 32 18 9 2)	90 Th Thorium 232.0381 (2 8 18 32 18 10 2)	91 Pa Protactinium 231.03588 (2 8 18 32 20 9 2)	92 U Uranium 238.0289 (2 8 18 32 21 9 2)	93 Np Neptunium (237) (2 8 18 32 22 9 2)	94 Pu Plutonium (244) (2 8 18 32 24 8 2)	95 Am Americium (243) (2 8 18 32 25 8 2)	96 Cm Curium (247) (2 8 18 32 25 9 2)	97 Bk Berkelium (247) (2 8 18 32 27 8 2)	98 Cf Californium (251) (2 8 18 32 28 8 2)	99 Es Einsteinium (252) (2 8 18 32 29 8 2)	100 Fm Fermium (257) (2 8 18 32 30 8 2)	101 Md Mendelevium (258) (2 8 18 32 31 8 2)	102 No Nobelium (259) (2 8 18 32 32 8 2)	103 Lr Lawrencium (262) (2 8 18 32 32 9 2)

Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 110-118 are the Latin equivalents of those numbers.



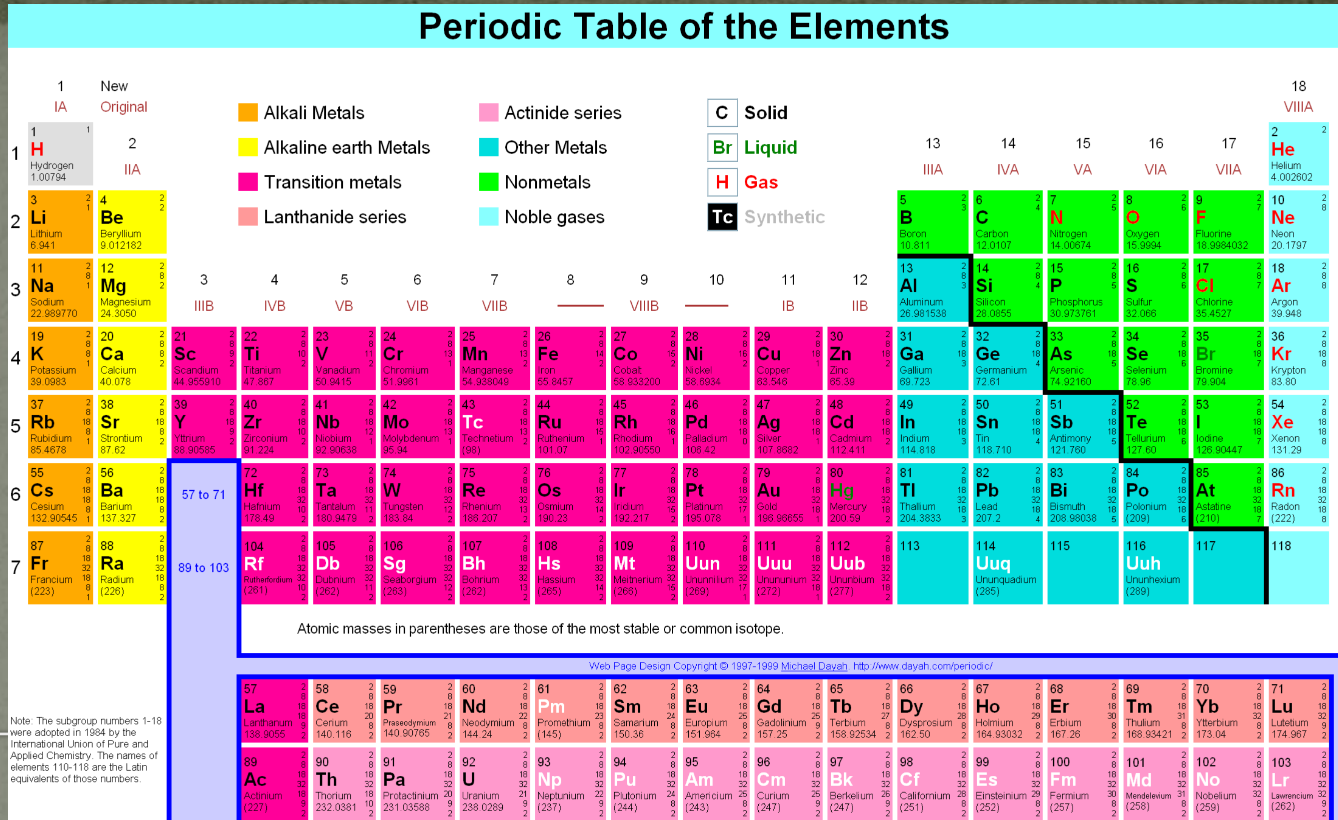
Columns are called GROUPS (FAMILIES) and rows are called PERIODS.

Elements in a group have similar chemical and physical properties.



The total number of electrons within a group is different, increasing in number down a group

However, the number of electrons furthest away from the nucleus, called the OUTER or VALENCE electrons is the same for all elements in a group.

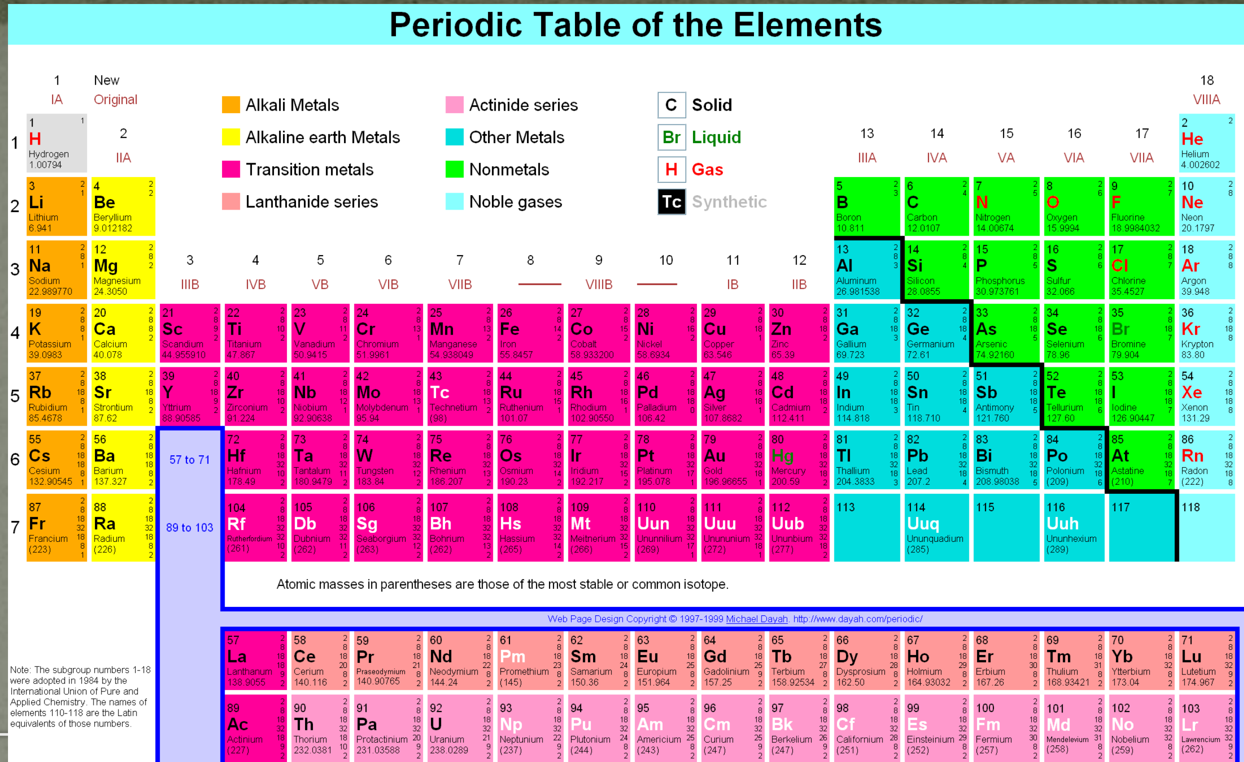


Groups are referred to by names, which often derive from their properties

I – Alkali metals; II – Alkaline Earth metals

VII – Halogens; VIII – Noble gases

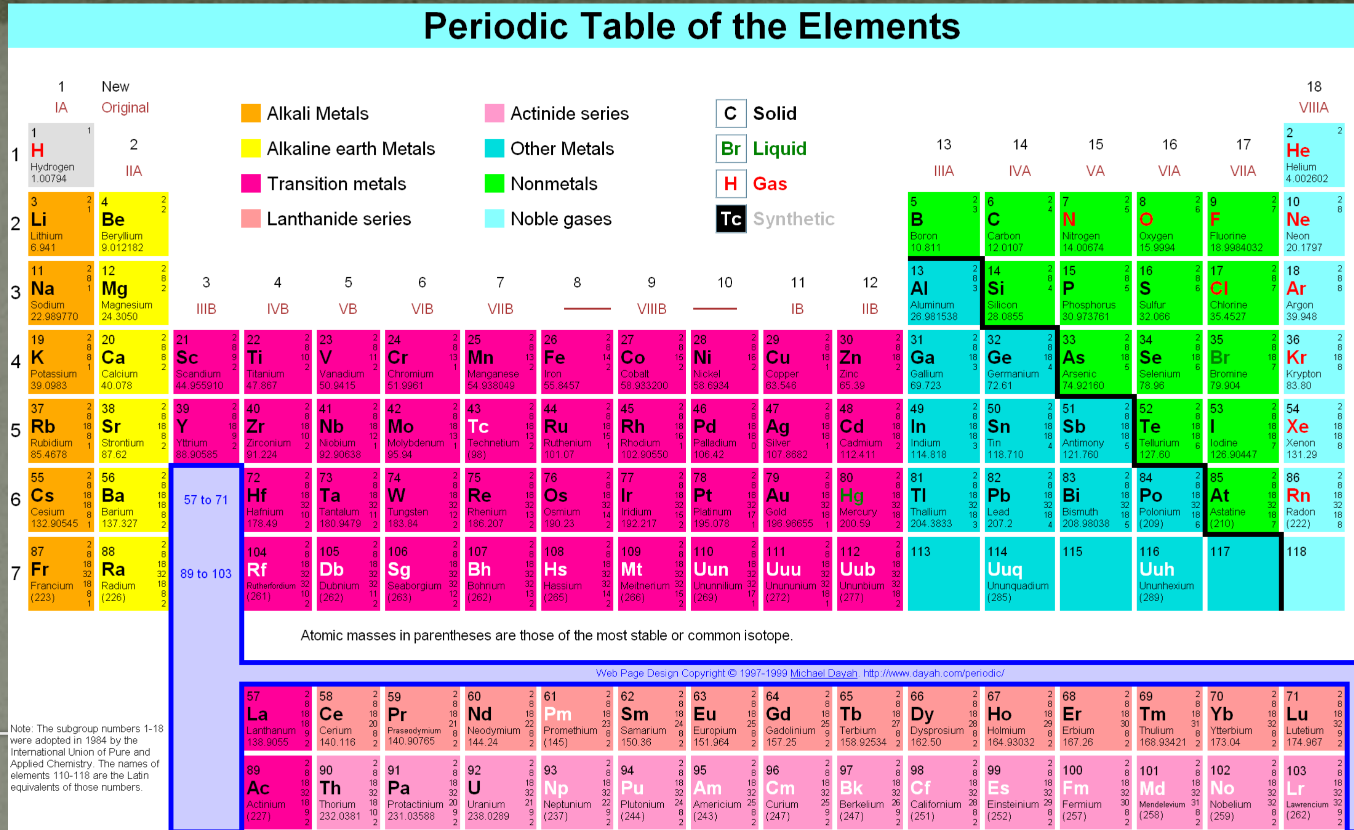
The elements in the middle block are called TRANSITION ELEMENTS



Elements in the A group are diverse; metals and non-metals, solids and gases at room temperature.

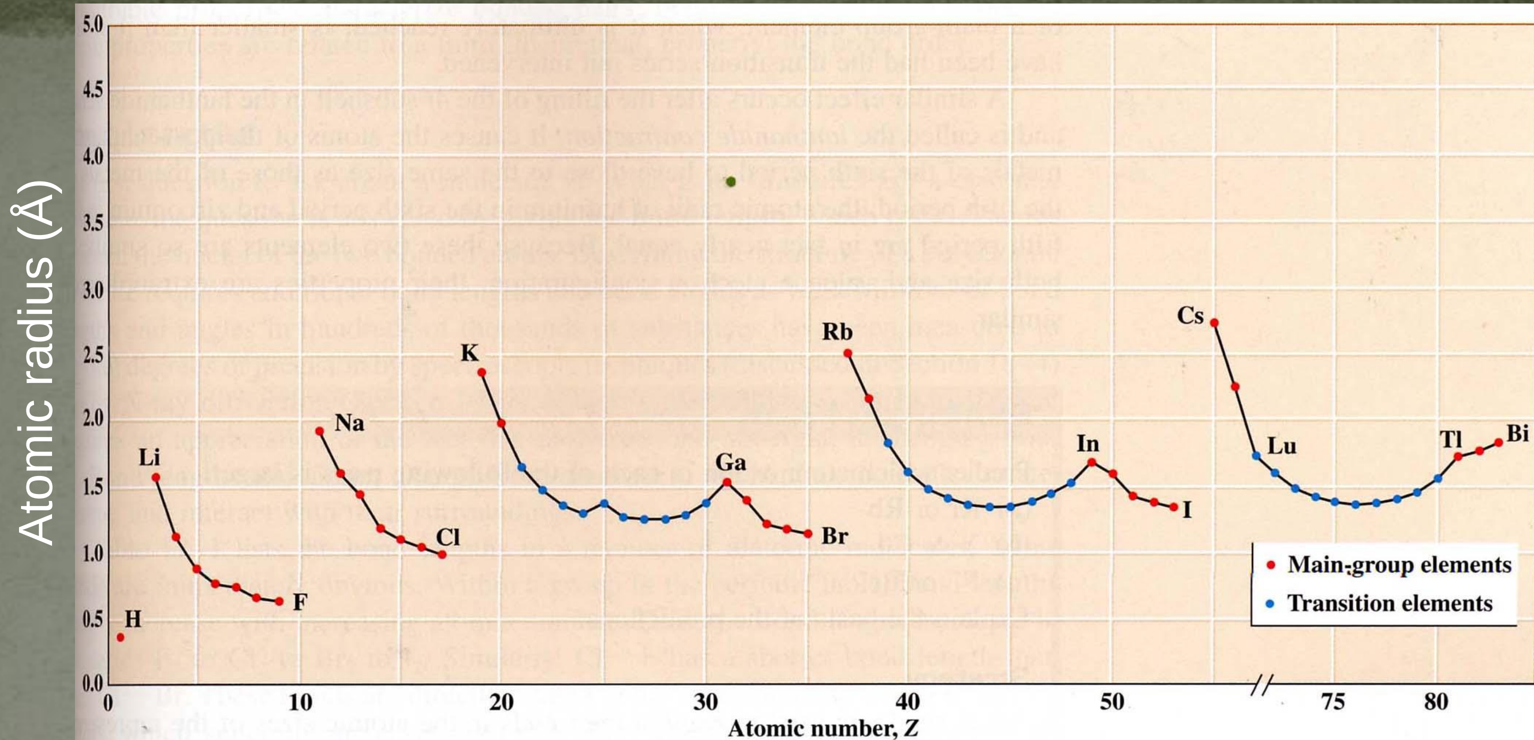
The transition elements are all metals, and are solids at room temp, except for Hg.

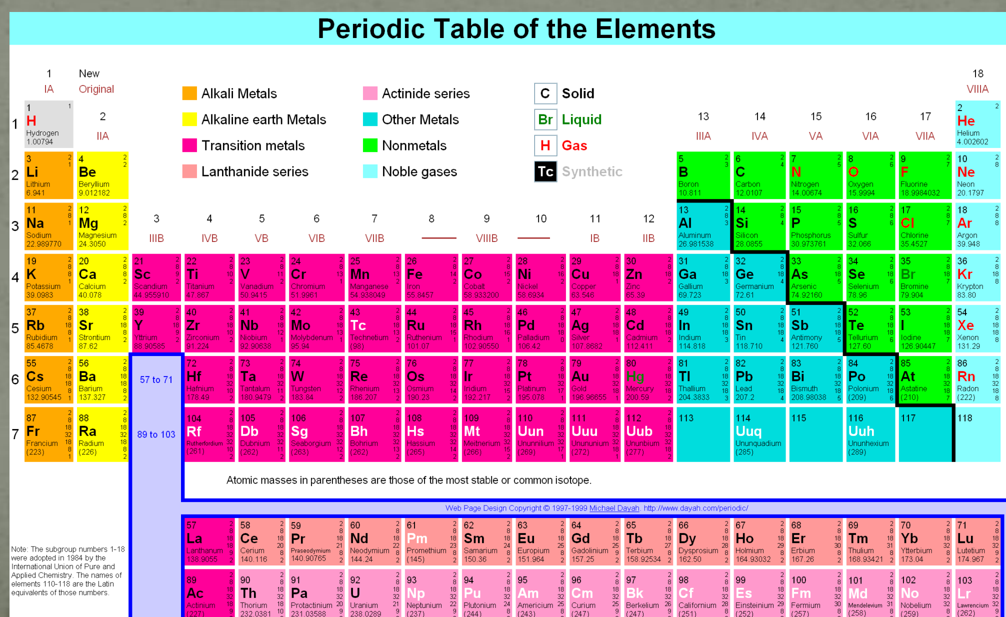
Among the transition elements are two sets of 14 elements - the LANTHANIDES and the ACTINIDES



Physical and Chemical properties such as melting points, thermal and electrical conductivity, atomic size, vary systematically across the periodic table.

Elements within a column have similar properties


Atomic radius (Å)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
H
Li
F
Na
Cl
K
Ga
Br
Rb
In
I
Cs
Lu
Tl
Bi
0
10
20
30
40
50
75
80
Atomic number, Z
Main-group elements
Transition elements


Periodic Table of the Elements
Alkali Metals
Alkaline earth Metals
Transition metals
Lanthanide series
Actinide series
Other Metals
Nonmetals
Noble gases
Solid
Liquid
Gas
Synthetic
Atomic masses in parentheses are those of the most stable or common isotope.
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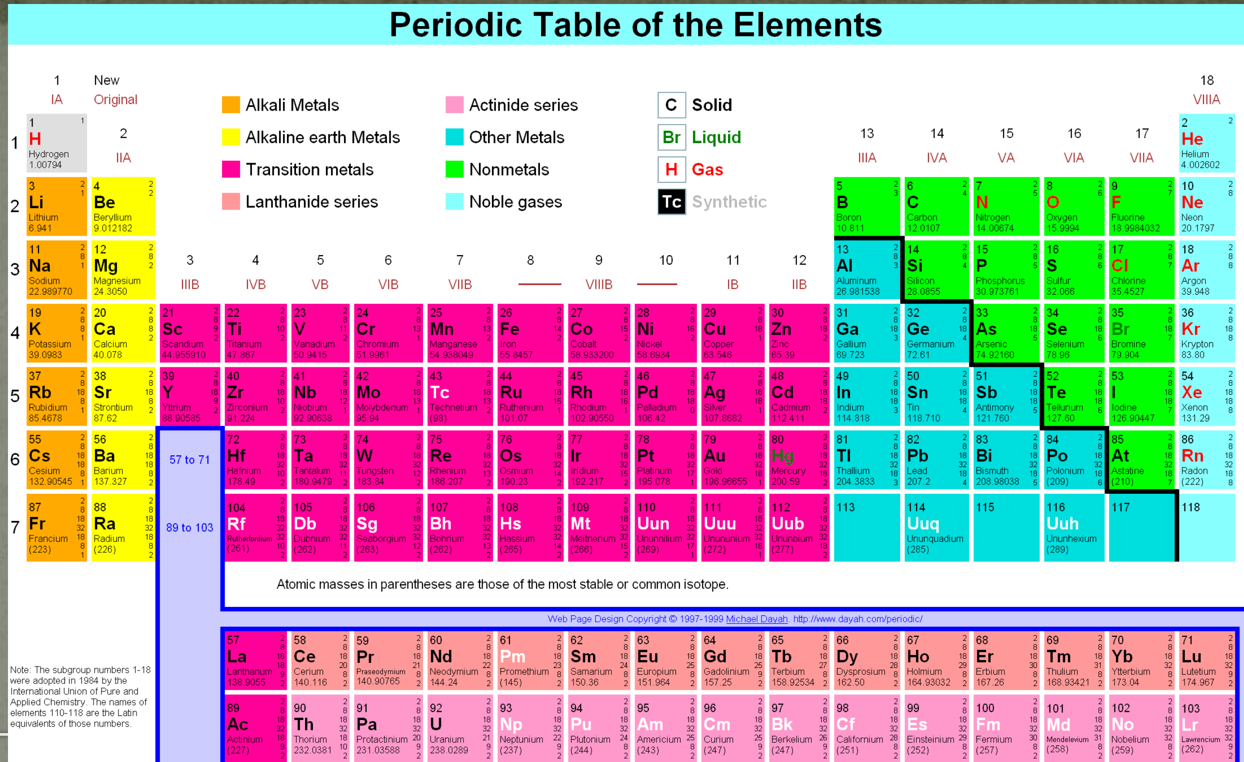
Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 110-118 are the Latin equivalents of those numbers.



A "zig-zag" division of the table divides metals from non-metals.

Elements to the left of the zig-zag line are metals (except for hydrogen, which is unique) and to the right are non-metals.

Elements along the border have intermediate properties and are called metalloids.

TABLE

Electronegativity

The type of bond formed between a pair of atoms is determined by the ability of the atoms to attract electrons from the other.

A positively charged ion (CATION) is formed when an atom looses one or more electrons and a negatively charged ion (ANION) is formed when an atom accepts one or more electrons.

For a free, isolated atom its ability to loose an electron is measured by its IONIZATION ENERGY, while the ability to gain an electron is measured by its ELECTRON AFFINITY

The average of these two properties for isolated atoms define the atom's ELECTRONEGATIVITY which measures the tendency of one atom to attract electrons from another atom to which it is bonded.

For example, Metallic elements loose electrons (to form positive ions) more readily than non-metallic elements

Metallic elements are hence referred to as being more ELECTROPOSITIVE that non-metals.

Non-metals are more ELECTRONEGATIVE compared to metals

The periodic table's arrangement results in a separation of metals from non-metals (metallic nature increasing to the left and down, non metallic increasing right and up).

This allows for a comparative scale for the electronegativity of elements.

TABLE 6.3 Pauling Electronegativity Scale for the Elements (Part I)

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
0.97	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
0.90	1.0	1.3	1.5	1.6	1.6	1.5	1.8	1.8	1.8	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
0.89	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	2.0	2.1	2.5
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At
0.83	0.97	1.1	1.3	1.5	1.7	1.9	2.2	2.2	2.2	2.4	1.9	1.8	1.8	1.9	2.0	2.2
Fr	Ra	Ac	Th	Pa	U	Np										
0.7	0.9	1.1	1.3	1.5	1.7	1.3										

Electronegativity Scale

Fluorine is the most electronegative element, and francium the least electronegative.

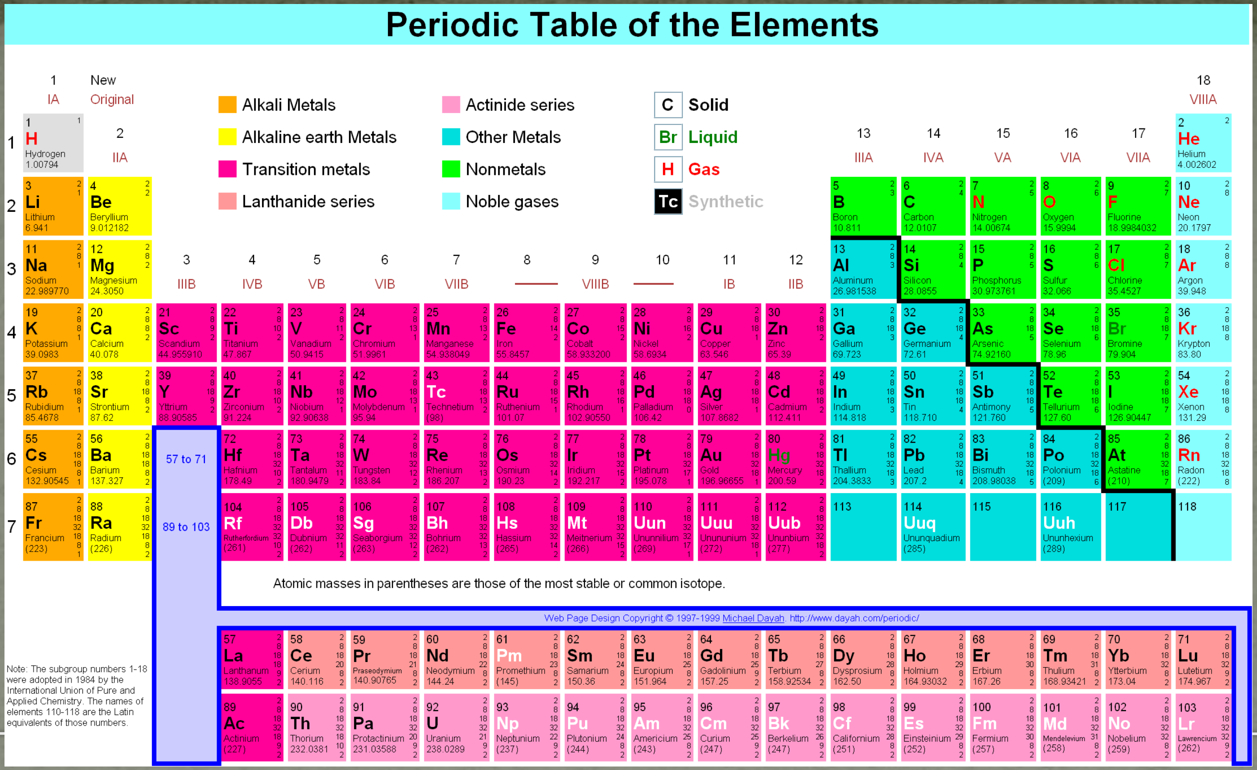
TABLE

Large differences in electronegativity between two bonded atoms favor the transfer of electrons from the less electronegative (more electropositive) atom to the more electronegative atom resulting in a bond between the two atoms that is IONIC.

Smaller differences result in a more equitable "sharing" of electrons between the bonded atoms, resulting in a COVALENT bond between the two atoms.

The kinds of bonds formed between elements (covalent vs ionic) can be determined by comparing electronegativity of the two elements.

TABLE



Na and Cl form ionic bonds.

Na gives up an electron and Cl accepts the electron to form Na^{+} and Cl^{-}.

As differences between electronegativity between the two bonding elements decreases, there is more equitable sharing of electrons and the elements form covalent bonds.

Based on the position of elements in the periodic table, we can determine the kind of bond formed

Generally:

Nonmetallic element + nonmetallic element → Molecular compound

Molecular compounds are typically gases, liquids, or low melting point solids and are characteristically poor conductors. Examples are H_2O, CH_4, NH_3.

TABLE

Generally,

Metallic compound + nonmetallic compound → IONIC compound

Ionic compounds are generally high-melting solids that are good conductors of heat and electricity in the molten state.

Examples are NaCl, common salt, and NaF, sodium fluoride.

TABLE

NAMING COMPOUNDS

The chemical formula represents the composition of each molecule.

In writing the chemical formula, in almost all cases the element farthest to the left of the periodic table is written first.

So for example the chemical formula of a compound that contains one sulfur atom and six fluorine atoms is SF_6.

If the two elements are in the same period, the symbol of the element of that is lower in the group (i.e. heavier) is written first e.g. IF_3.

In naming covalent compounds, the name of the first element in the formula is unchanged.

The suffix “-ide” is added to the second element.

Often a prefix to the name of the second element indicates the number of the element in the compound

SF_6 – sulfur hexafluoride

P_4O_{10} – tetraphosphorous decoxide

CO – carbon monoxide

CO_2 – carbon dioxide

The binary compounds of hydrogen are special cases. They were discovered before a convention was adopted and hence their original names have stayed

Water H_2O is not called dihydrogen monoxide

Hydrogen forms binary compounds with almost all non-metals except the noble gases.

Example
HF - hydrogen fluoride
HCl - hydrogen chloride
H_2S - hydrogen sulfide

Organic molecules (containing C) have a separate nomenclature

The molecular formulas for compounds containing C and H (called hydrocarbons) are written with C first. Example, CH_4, C_2H_6, etc.

BINARY IONIC COMPOUNDS

Compounds formed by elements on opposite sides of the periodic table which either give up (left side) or take up electrons (right side).

Depending on the atom, there can be an exchange of more than one electron resulting in charges greater than ≤1.

IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
H/H^+							He
Li/Li^+	Be/Be^{2+}		C/C^{4+} C^{4-}	N/N^{3-}	O/O^{2-}	F/F^-	Ne
Na/Na^+	Mg/Mg^{2+}	Al/Al^{3+}	Si/Si^{4+} Si^{4-}	P/P^{3-}	S/S^{2-}	Cl/Cl^-	Ar
K/K^+	Ca/Ca^{2+}	Ga/Ga^{3+}	Ge/Ge^{4+}	As/As^{3-}	Se/Se^{2-}	Br/Br^-	Kr
Rb/Rb^+	Sr/Sr^{2+}	In/In^{3+}	Sn/Sn^{4+}		Te/Te^{2-}	I/I^-	Xe
Cs/Cs^+	Ba/Ba^{2+}	Tl/Tl^{3+}	Pb/Pb^{4+}			At/At^-	Rn

Group IA – alkali metals – loose 1 e^- to form +1 (Na^+)

Group II A– alkaline earth metals –loose 2 e^- to form +2 (Ca^{+2})

Group III A– loose three e^- to form +3 (Al^{+3})

Group IV A– loose four e^- to form +4 (Sn^{+4})

Group V A– accept three e^- to form –3 (N^{-3})

Group VI A– accept two e^- to form –2 (O^{-2})

Group VIIA – accept one e^- to form –1 (Cl^{-1})

Naming IONIC compounds

Anions – suffix – "ide"

So Cl^- is chloride

Oxygen O^{2-} is OXIDE

S^{2-} is SULFIDE

Cations

For Na^+, Ca^{2+}, the name of the ion is the same except refer to the ion.

So SODIUM ION or SODIUM CATION

NaCl - sodium chloride

$CaCl_2$ - calcium chloride

Covalent, charged compounds - MOLECULAR IONS

Positive Molecular Ions

End the name with “ium” or “onium”

NH_4^+ is ammonium, H_3O^+ is hydronium

Negative Molecular Ions

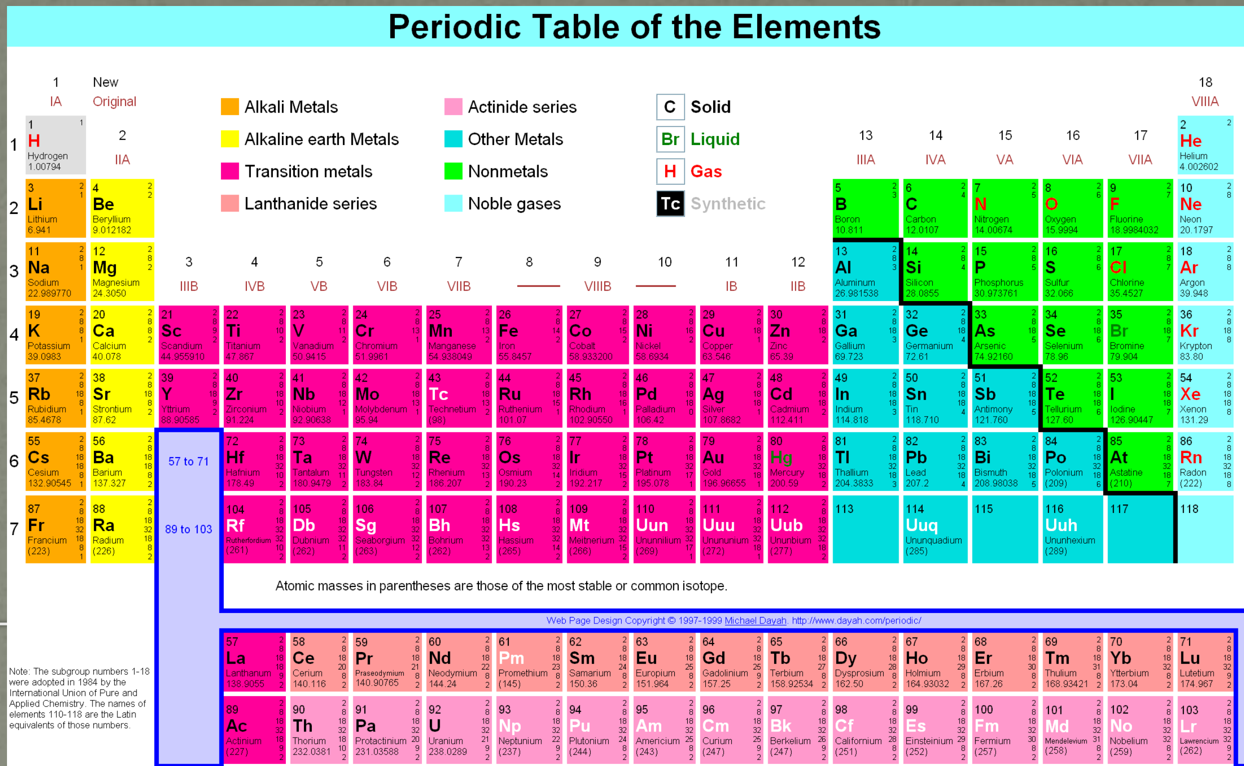
NO_3^- - NITRATE

SO_4^{2-}- SULFATE

NO_2^- - NITRITE

PO_4^{3-}- PHOSPHATE

Transition Elements



The transition elements are chemically quite different from the metals in the "A" block, due to differences in electronic configuration

For example, Fe can loose two or three electrons to become Fe^{2+} and Fe^{3+}, respectively.

To identify the charge of Fe in a compound the following nomenclature is used.

Fe^{2+} is iron(II)

Fe^{3+} is iron (III)

So iron(III) chloride is $FeCl_3$

An older scheme differentiated between the lower and higher charge by ending the name of the element with “ous” to indicate the lower charge and “ic” for the higher.

ferrous chloride => $FeCl_2$

ferric chloride => $FeCl_3$

However, this convention does not indicate the numerical value of the charge.