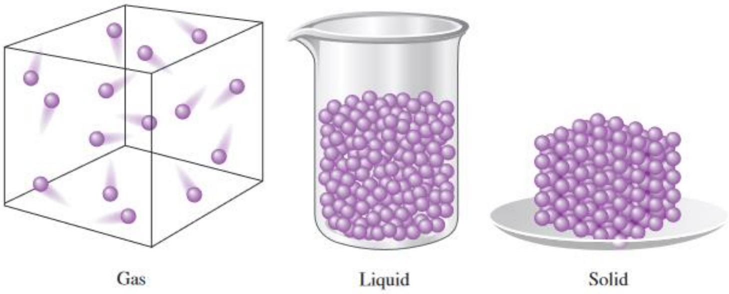
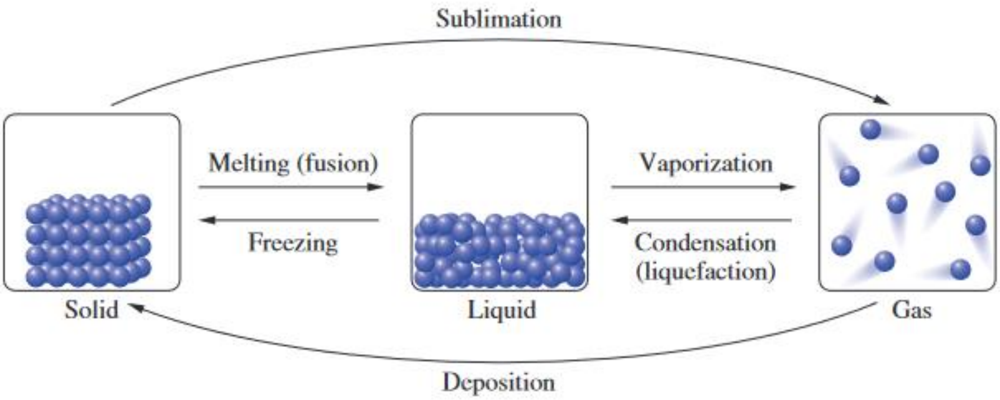
Inorganic Chemistry
Part 1

First year
Chemistry students
Dr Dotsha Jaleel

States of Matter and Physical Properties

- In a gas, the molecules are in constant random motion through largely empty space. In a liquid, the molecules are also in constant random motion, but they are more closely packed than in a gas. In a solid, the basic units (atoms, ions, or molecules) are closely packed and vibrate about fixed sites.





General Definitions (lack chemistry)

- Melting Point: The temperature at which a solid substance changes into a liquid state is called its melting point.

- Boiling Point: The temperature at which a liquid substance changes into a gaseous state is called its boiling point.
- For example, the melting point of water at 1 atmosphere of pressure is 0 ^{o}C and the boiling point of water is 100 ^{o}C.

- Sublimation: The process of transition of a substance from a solid state directly into a gaseous state without passing through the intermediate liquid state is called sublimation.

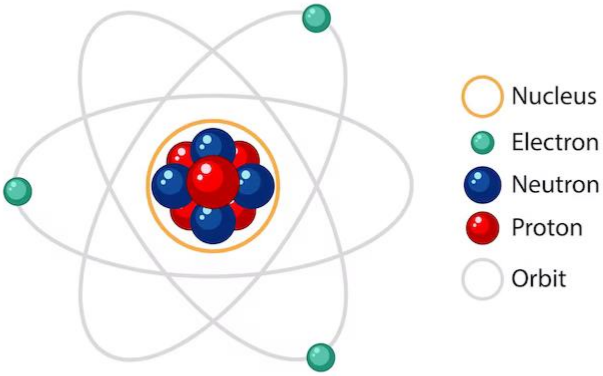
- Deposition: The process of transition of a substance from a gaseous state directly into a solid state without passing through the intermediate liquid state is called deposition.

- Sublimation: An example of a substance that undergoes sublimation is dry ice (solid carbon dioxide), which sublimates at -78.5°C and turns directly into gas.
- Deposition: An example of deposition is the formation of frost on a cold surface, which occurs when water vapor in the air turns directly into ice crystals without first becoming liquid.

Atomic Structure and Bonding

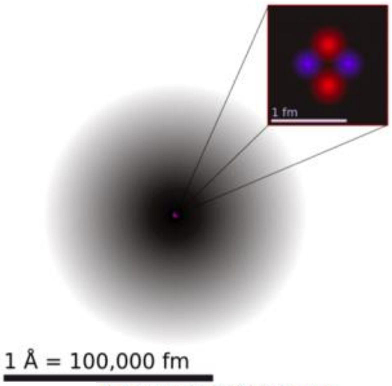
Atoms

Atoms are a collection of various subatomic particles containing negatively charged electrons, positively charged protons and neutral particles called neutrons.



- Neutrons and protons are located in the atomic nucleus
- The negatively charged electrons orbit around the nucleus and are distributed on a rather large cloud of electrons

- Each element has its own unique number of protons, neutrons and electrons.
- Both protons and neutrons have mass, whereas the mass of electrons is negligible.
- Protons and neutrons exist at the center of the atom in the nucleus.



A depiction of a helium atom.

Particle	Charge	Mass (g)	Mass (amu)
Proton	+1	1.6727×10^{-24}	1.007316
Neutron	0	1.6750×10^{-24}	1.008701
Electron	-1	9.110×10^{-28}	0.000549

Amu: Atomic Mass Unit

Elements

An element is a basic chemical substance that consists of only one type of atom and cannot be broken down or converted into simpler substances by chemical means. Some well-known elements include hydrogen (H), oxygen (O), carbon (C), and iron (Fe).

Each element has a unique atomic number that determines the number of protons in its nucleus and the number of electrons around its nucleus. This, in turn, determines the chemical and physical properties of an element.

Molecules

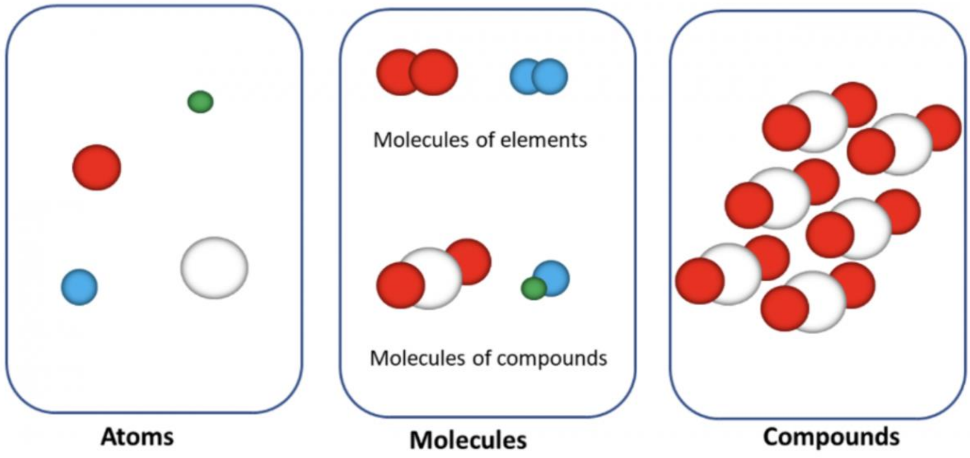
A molecule is a group of two or more atoms held together by chemical bonds.

Compounds

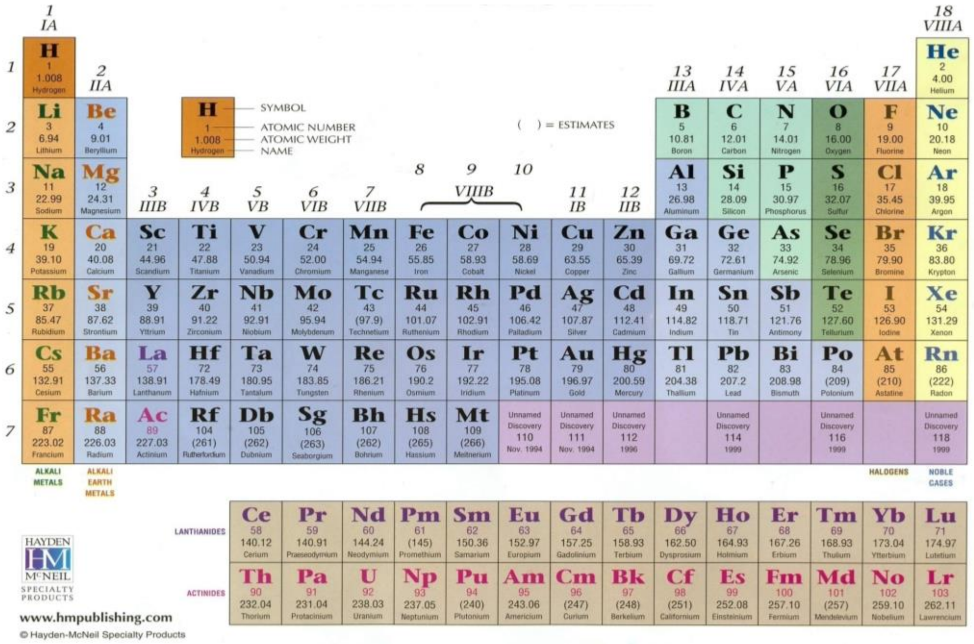
- A compound is a substance which is formed by two or more different types of elements joined together in a fixed proportion, e.g. NaCl, H_2O and HCl.

All compounds are molecules.

All molecules are not compounds.



The Periodic Table



	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	**H** 1 1.008 Hydrogen																	**He** 2 4.00 Helium
2	**Li** 3 6.94 Lithium	**Be** 4 9.01 Beryllium											**B** 5 10.81 Boron	**C** 6 12.01 Carbon	**N** 7 14.01 Nitrogen	**O** 8 16.00 Oxygen	**F** 9 19.00 Fluorine	**Ne** 10 20.18 Neon
3	**Na** 11 22.99 Sodium	**Mg** 12 24.31 Magnesium											**Al** 13 26.98 Aluminum	**Si** 14 28.09 Silicon	**P** 15 30.97 Phosphorus	**S** 16 32.07 Sulfur	**Cl** 17 35.45 Chlorine	**Ar** 18 39.95 Argon
4	**K** 19 39.10 Potassium	**Ca** 20 40.08 Calcium	**Sc** 21 44.96 Scandium	**Ti** 22 47.88 Titanium	**V** 23 50.94 Vanadium	**Cr** 24 52.00 Chromium	**Mn** 25 54.94 Manganese	**Fe** 26 55.85 Iron	**Co** 27 58.93 Cobalt	**Ni** 28 58.69 Nickel	**Cu** 29 63.55 Copper	**Zn** 30 65.39 Zinc	**Ga** 31 69.72 Gallium	**Ge** 32 72.61 Germanium	**As** 33 74.92 Arsenic	**Se** 34 78.96 Selenium	**Br** 35 79.90 Bromine	**Kr** 36 83.80 Krypton
5	**Rb** 37 85.47 Rubidium	**Sr** 38 87.62 Strontium	**Y** 39 88.91 Yttrium	**Zr** 40 91.22 Zirconium	**Nb** 41 92.91 Niobium	**Mo** 42 95.94 Molybdenum	**Tc** 43 (97.9) Technetium	**Ru** 44 101.07 Ruthenium	**Rh** 45 102.91 Rhodium	**Pd** 46 106.42 Palladium	**Ag** 47 107.87 Silver	**Cd** 48 112.41 Cadmium	**In** 49 114.82 Indium	**Sn** 50 118.71 Tin	**Sb** 51 121.76 Antimony	**Te** 52 127.60 Tellurium	**I** 53 126.90 Iodine	**Xe** 54 131.29 Xenon
6	**Cs** 55 132.91 Cesium	**Ba** 56 137.33 Barium	**La** 57 138.91 Lanthanum	**Hf** 72 178.49 Hafnium	**Ta** 73 180.95 Tantalum	**W** 74 183.85 Tungsten	**Re** 75 186.21 Rhenium	**Os** 76 190.2 Osmium	**Ir** 77 192.22 Iridium	**Pt** 78 195.08 Platinum	**Au** 79 196.97 Gold	**Hg** 80 200.59 Mercury	**Tl** 81 204.38 Thallium	**Pb** 82 207.2 Lead	**Bi** 83 208.98 Bismuth	**Po** 84 (209) Polonium	**At** 85 (210) Astatine	**Rn** 86 (222) Radon
7	**Fr** 87 223.02 Francium	**Ra** 88 226.03 Radium	**Ac** 89 227.03 Actinium	**Rf** 104 (261) Rutherfordium	**Db** 105 (262) Dubnium	**Sg** 106 (263) Seaborgium	**Bh** 107 (262) Bohrium	**Hs** 108 (265) Hassium	**Mt** 109 (266) Meitnerium	Unnamed Discovery 110 Nov. 1994	Unnamed Discovery 111 Nov. 1994	Unnamed Discovery 112 1996		Unnamed Discovery 114 1999		Unnamed Discovery 116 1999		Unnamed Discovery 118 1999
	ALKALI METALS	ALKALI EARTH METALS															HALOGENS	NOBLE CASES

LANTHANIDES	**Ce** 58 140.12 Cerium	**Pr** 59 140.91 Praeseodymium	**Nd** 60 144.24 Neodymium	**Pm** 61 (145) Promethium	**Sm** 62 150.36 Samarium	**Eu** 63 152.97 Europium	**Gd** 64 157.25 Gadolinium	**Tb** 65 158.93 Terbium	**Dy** 66 162.50 Dysprosium	**Ho** 67 164.93 Holmium	**Er** 68 167.26 Erbium	**Tm** 69 168.93 Thulium	**Yb** 70 173.04 Ytterbium	**Lu** 71 174.97 Lutetium
ACTINIDES	**Th** 90 232.04 Thorium	**Pa** 91 231.04 Protacinium	**U** 92 238.03 Uranium	**Np** 93 237.05 Neptunium	**Pu** 94 (240) Plutonium	**Am** 95 243.06 Americium	**Cm** 96 (247) Curium	**Bk** 97 (248) Berkelium	**Cf** 98 (251) Californium	**Es** 99 252.08 Einsteinium	**Fm** 100 257.10 Fermium	**Md** 101 (257) Mendelevium	**No** 102 259.10 Nobelium	**Lr** 103 262.11 Lawrencium

H — SYMBOL
1 — ATOMIC NUMBER
1.008 — ATOMIC WEIGHT
Hydrogen — NAME

(   ) = ESTIMATES

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Groups in the Periodic Table

Main Group Elements (Vertical Groups)
Group IA (1) **nS^1** - **Alkali Metals**
Group IIA (2) **nS^2- Alkaline Earth Metals**

Group IIIA(13) **nP^1** - **Boron** Family
Group IVA (14) **nP^2** - **Carbon** Family
Group VA(15) **nP^3** - **Nitrogen** Family
Group VIA (16) **nP^4** - **Oxygen** Family (**Calcogens**)
Group VIIA(17) **nP^5** - **Halogens**
Group VIIIA(18) **nP^6** - **Noble Gases**

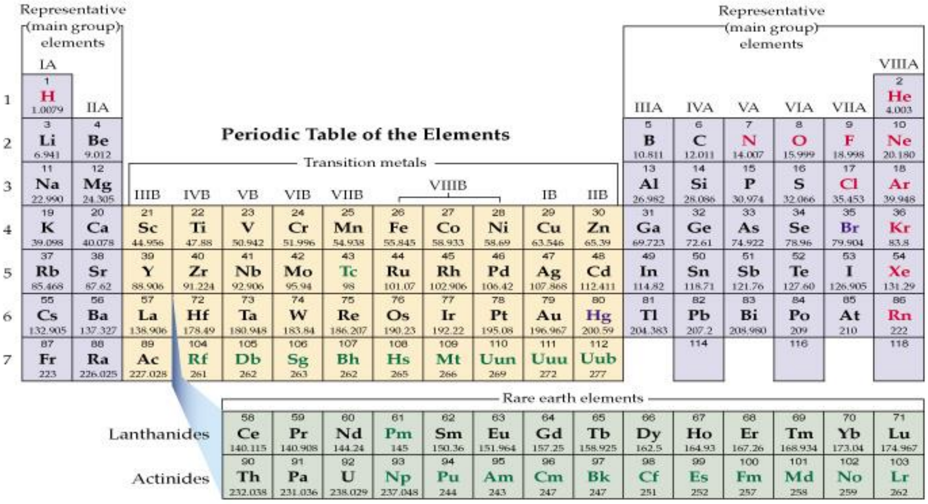
Other Groups (Vertical and Horizontal Groups)
Group **(IB - 8B)** - **Transition Metals**
Period **6** Group – **Lanthanides**
Period **7** Group – **Actinides**

- Elements are arranged in rows according to increasing atomic numbers and in columns based on having similar properties

- Groups of elements can be classified into:
  - S and p-block (main group elements)
  - d-block (transition elements)
  - f-block (actinides and lanthanides) sometimes called the Inner transition elements. would extend the table to a width of 32 members, if incorporated in the main body of the table. The table would generally be too wide to fit on a printed page, and so the f-block elements are extracted from the table and placed at the bottom.

- Groups can also be classified according to metallic character

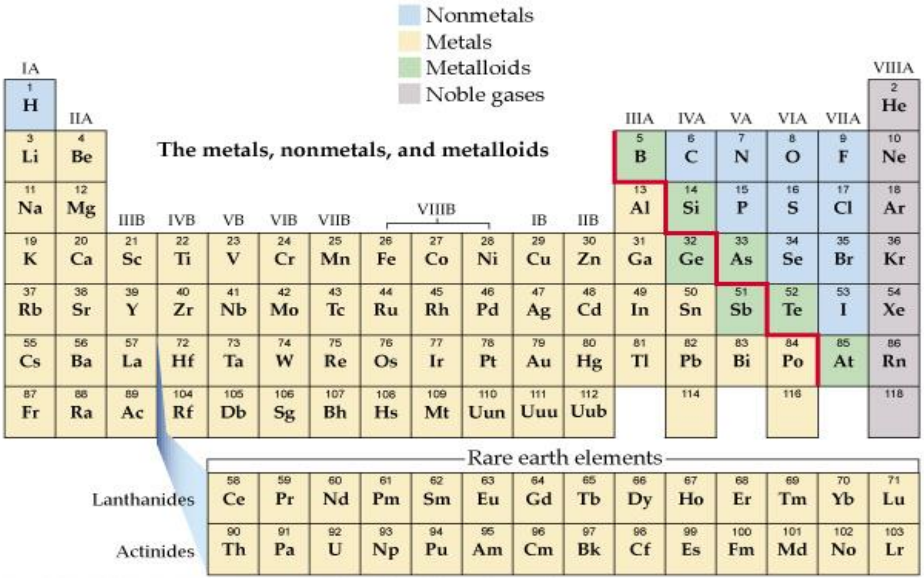
Classification: The three broad Classes
Main, Transition, Actinides and lanthanides



	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 H 1.0079																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
3	11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.066	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.8
5	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc 98	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.905	54 Xe 131.29
6	55 Cs 132.905	56 Ba 137.327	57 La 138.906	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po 209	85 At 210	86 Rn 222
7	87 Fr 223	88 Ra 226.025	89 Ac 227.028	104 Rf 261	105 Db 262	106 Sg 263	107 Bh 262	108 Hs 265	109 Mt 266	110 Uun 269	111 Uuu 272	112 Uub 277		114		116		118

Lanthanides	58 Ce 140.115	59 Pr 140.908	60 Nd 144.24	61 Pm 145	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.925	66 Dy 162.5	67 Ho 164.93	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.967
Actinides	90 Th 232.038	91 Pa 231.036	92 U 238.029	93 Np 237.048	94 Pu 244	95 Am 243	96 Cm 247	97 Bk 247	98 Cf 251	99 Es 252	100 Fm 257	101 Md 258	102 No 259	103 Lr 262

Classification According to Metallic Character



IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub		114		116		118

Lanthanides	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

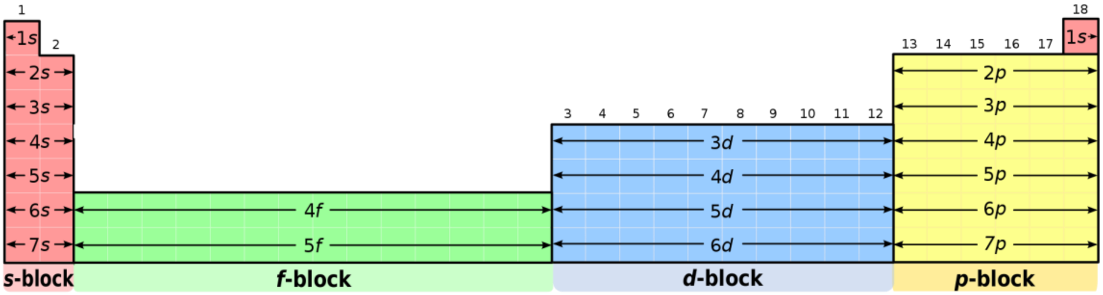
General Characteristics of Groups (Columns)

- ***Number of valence electrons***: on moving down a given group, the number of valence electrons does not change (atoms have the same valency. e.g., H, Li)
- ***Properties of elements***: All of elements of a given group possess similar physical and chemical properties. The reactivity of halogens decreases as we pass from F to I.
- ***Size of atoms***: increases on descending a group. Li<Na<K<Rb<Cs
- ***Metallic character***: increases in moving from top to bottom in group.
- ***Number of electron shells***: increases on descending a group and ultimately becomes equal to number of the period, Na, K.

General Characteristics of Periods (Rows)

- *Number of valence electrons*: increases when we proceed from left to right in a period.
- *Size of atoms:* decreases from left to right in a period.
- *Metallic character*: decreases on moving from left to right in a period.
- *Number of shells*: remains the same and the number of a period

The Extended Periodic Table



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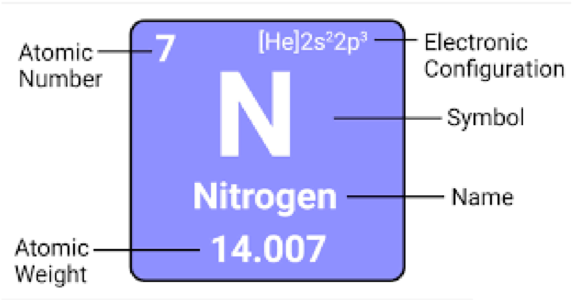
The Nuclear Symbol

- A notation that identifies the element (by symbol or atomic number) and the mass number of the element.
- The mass number is the sum of the number of nucleons (protons and neutrons) in the atomic nucleus.



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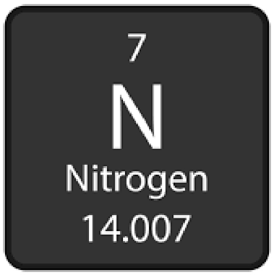
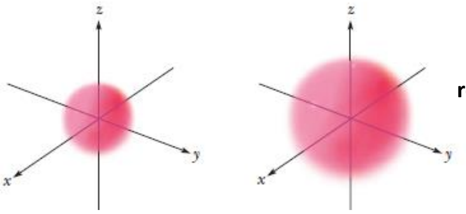


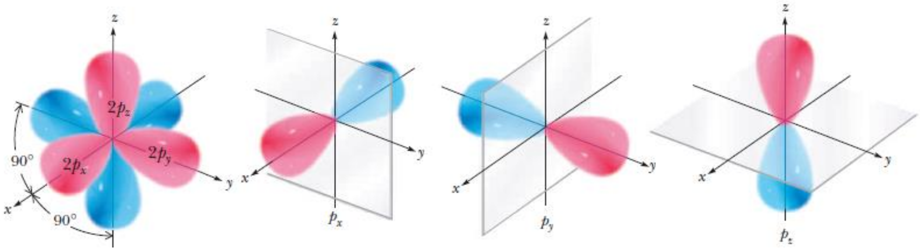
Atomic Orbitals

Atomic orbitals are the places surrounding the nucleus of an atom where the electrons are most likely to be at any given time. Electrons are not simply floating within the atom; instead, they are fixed within these electronic orbitals. Each orbital can hold two electrons.

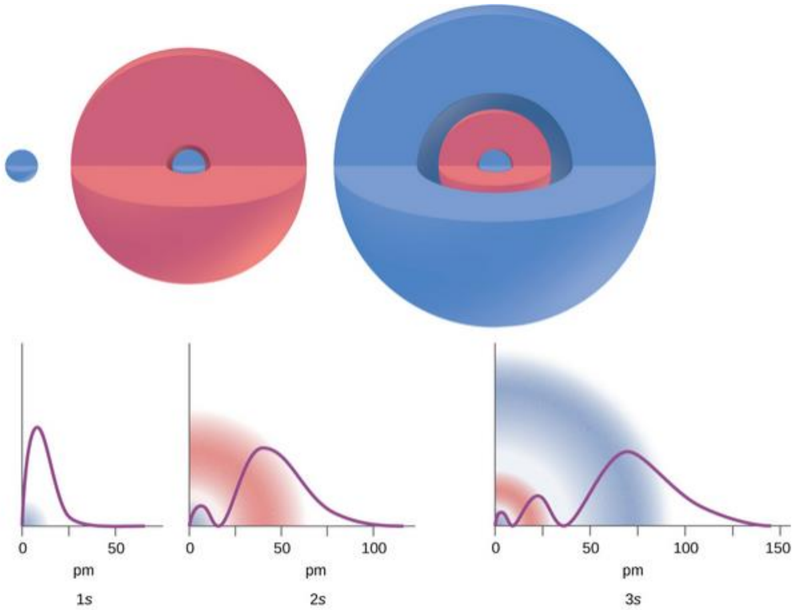
Orbital shapes



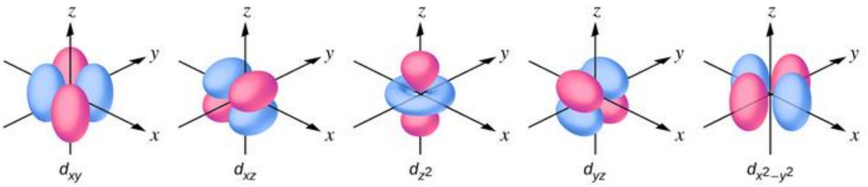
representations of 1s and 2s orbitals



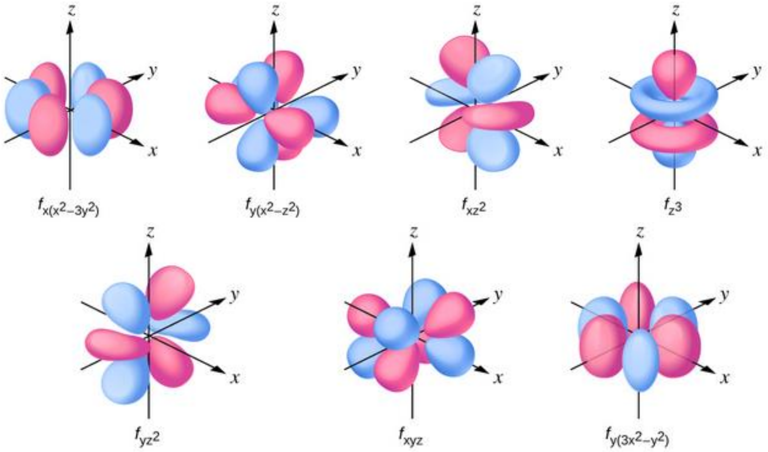
representations of 2*p* orbitals



Graphs showing the probability (on y axis) of finding an electron for 1s, 2s and 3s orbitals as a function of distance from the nucleus.



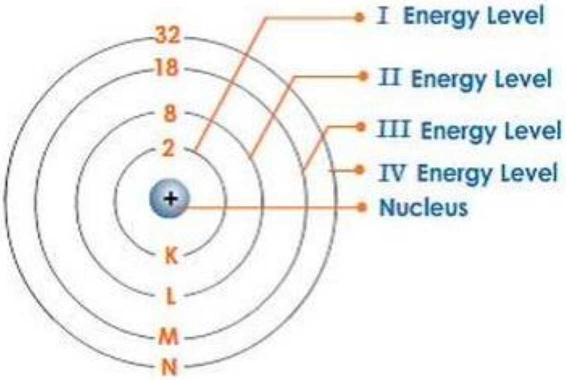
representations of d orbitals



representations of f orbitals

Electron Levels or Electronic Shells

- Electrons move around the nucleus, and are arranged in shells at increasing distances from the nucleus.
- These shells represent different energy levels, the outermost shell being the highest energy level



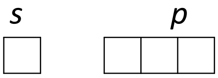
- The closest shell to the nucleus is called the "1 shell" (also called the "K shell"), followed by the "2 shell" (or "L shell"), then the "3 shell" (or "M shell"), and so. The shells correspond to the principal quantum numbers (n = 1, 2, 3, 4 ...) or are labeled alphabetically with the letters used in X-ray notation (K, L, M, ...).
- Each row on the periodic table of elements represents an electron shell.
- Each shell can contain only a fixed number of electrons: the first shell can hold up to two electrons, the second shell can hold up to eight (2 + 6) electrons, the third shell can hold up to 18 (2 + 6 + 10) and so on. The general formula is that the nth shell can in principle hold up to $2(n^2)$ electrons.
- **Each shell consists of one or more subshells, and each subshell consists of one or more atomic orbitals.**

Shell *n* = 1 (named K) has 1 sub-shell named *s* comprised of 1 orbital *s* can host a maximum of 2 electrons

H_1 notation $1s^1$
+ proton and 1 electron

He_2 notation $1s^2$
++ protons and 2 electrons

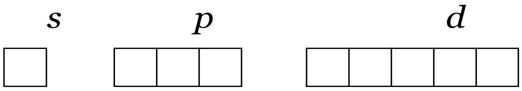
Shell *n* = 2 (named L) has 2 sub-shells; *2s* and *2p*



1 orbital , 3 sub-orbitals

Hosting maximum of (1x2e) + (3x2e) = 8 electrons

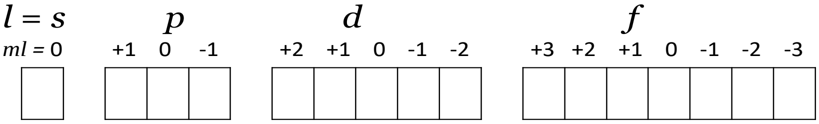
Shell 3 (named M) has 3 sub-shells *3s* , *3p* , *3d*



1 orbital 3 orbitals 5 orbitals

Hosting a maximum of (1x2) + (3x2) + (5x2) = 18 electron

Shell 4 (named N) has 4 sub-shells *4s, 4p, 4d, 4f*

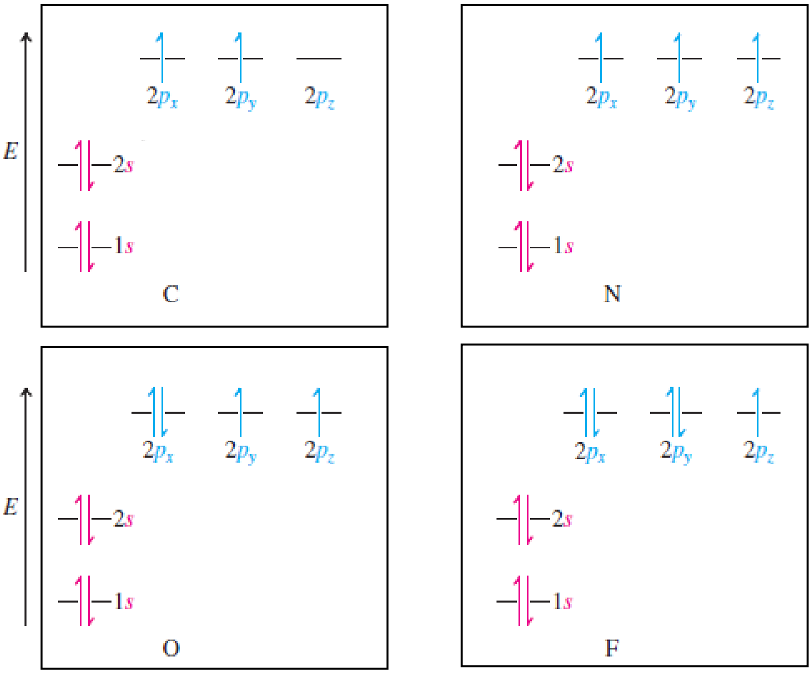


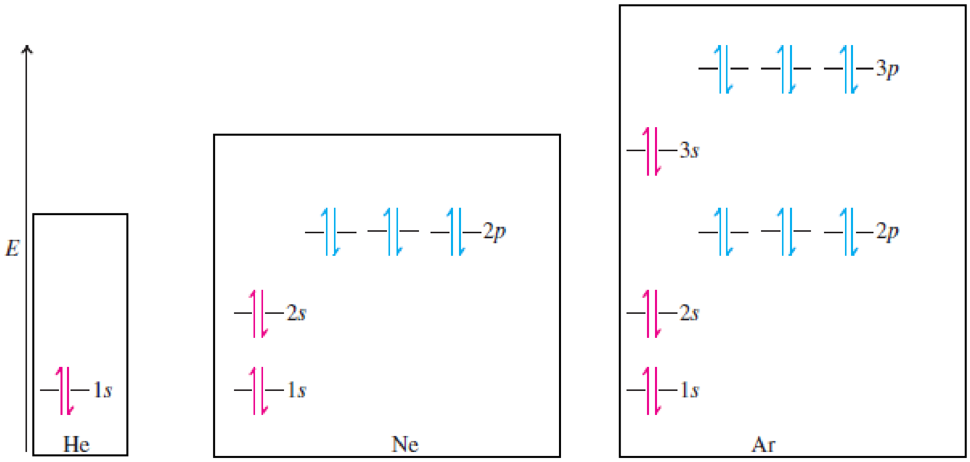
1 orbital 3 orbitals 5 orbitals 7 orbitals

Hosting maximum of (1x2) + (3x2) + (5x2) + (7x2) = 32 electron

Electronic Configuration

- The electron configuration is the distribution of electrons of an atom or molecule in atomic or molecular orbitals.
- Example, the electron configuration of Ne atom is $1s^2\ 2s^2\ 2p^6$, meaning that the 1s, 2s and 2p subshells are occupied by 2, 2 and 6 electrons respectively.
- Knowledge of the electron configuration of different atoms is useful in:
  - understanding the structure of the periodic table
  - for describing the chemical bonds that hold atoms together
  - understanding the chemical formulas of compounds and the geometries of molecules.



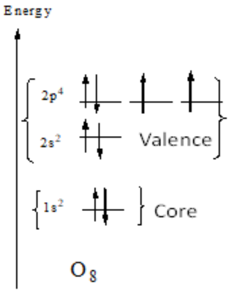


Valence and Core Electrons

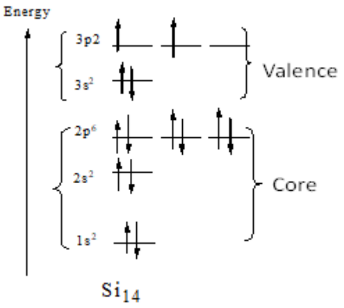
- Valence electrons: the outer electrons of an atom that determine its chemical properties
- Core electrons: are electrons that occupy lower energy levels. Core electrons shield the valence electrons from the nuclear charge.

Examples,

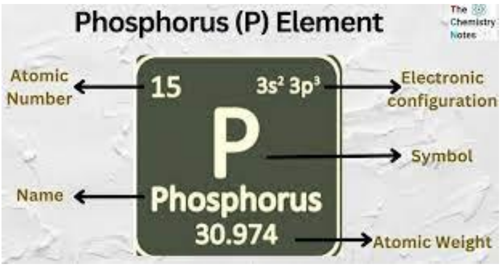
O_8 1s2 2s2 2p4 **(2 core & 6 valence es)**



Si_{14} 1s2 2s2 2p6 3s2 3p2 **(10 core & 4 valence es)**



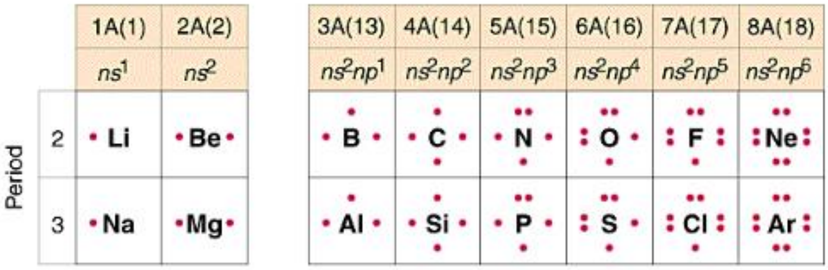
- It is common to write the electronic configuration of an atom in an abbreviated form by writing only the valence electrons explicitly, while the core electrons are replaced by the symbol for the last previous noble gas in the periodic table, placed in square brackets.



Example: phosphorus atom,
^{15}P: 1s2 2s2 2p6 3s2 3p3
Also, ^{15}P: [Ne] $3s^2\ 3p^3$

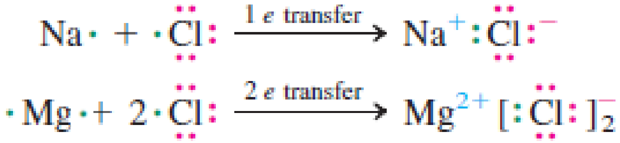
Lewis structures

- Outer-shell electrons are called valence electrons, and the energy level in which they are found is called the valence shell.
- To show the outermost electrons of an atom, a representation called a Lewis dot structure is commonly used



		1A(1)	2A(2)	3A(13)	4A(14)	5A(15)	6A(16)	7A(17)	8A(18)
		ns^1	ns^2	ns^2np^1	ns^2np^2	ns^2np^3	ns^2np^4	ns^2np^5	ns^2np^6
Period	2	Li	Be	B	C	N	O	F	Ne
	3	Na	Mg	Al	Si	P	S	Cl	Ar

- This is a convenient way of depicting valence electrons by means of dots around the symbol for the element.
- In this case, the letters represent the nucleus including all the electrons in the inner shells, together called the core configuration



- According to Lewis theory, an atom will give up, accept or share electrons in order to achieve a filled outer shell that contains eight electrons
- This stable configuration of electrons is called an octet.
- Except for hydrogen and helium, a filled valence shell contains eight electrons