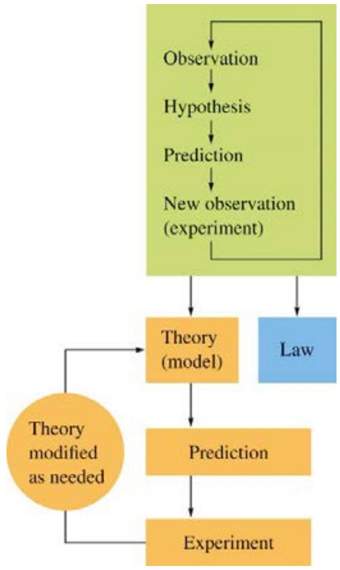
MATTER AND MEASUREMENT________ Z Appendix 1,2, Ch 1; H Ch 0–1-1, 3-1–3-3

"... those sciences are vain and full of errors that are not born from experiment, the mother of all certainty, and that do not end with one clear experiment."
Leonardo da Vinci, 1452-1519

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge but you have scarcely, in your thoughts, advanced to the stage of science."
William Thomson, Lord Kelvin, 1891

Z 1.3 The Scientific Method (good approach to use in lab)



Science (Latin *scientia*, *scire*, to know) provides a framework for systematically studying ourselves, our environment, and the universe. Progress in science is cumulative – building upon and extending prior knowledge via what has come to be known as the scientific method: the interplay of observations, judicious reasoning, predictions and new experiments to test the predictions.

Chemistry is broadly concerned with the analysis of substances (composition, structure, properties), their transformation into other substances (chemical reactions), and the energy changes that accompany these transformations.

Experiments require the ability to transform, characterize, and/or measure matter – anything that occupies space and has mass.

H 1-1, Table 1-3 Units of Measurement

Fundamental SI Units			SI Prefixes					
Quantity	Unit	Symbol	Factor	Prefix	Symbol	Factor	Prefix	Symbol
length	meter	m	10^{-1}	deci	d	10	deca	da
mass	kilogram	kg	10^{-2}	centi	c	10^{2}	hecto	h
time	second	s	10^{-3}	milli	m	10^{3}	kilo	k
temperature	kelvin	K	10^{-6}	micro	μ	10^{6}	mega	M
amount of substance	mole	mol	10^{-9}	nano	n	10^{9}	giga	G
electric current	ampere	A	10^{-12}	pico	p	10^{12}	tera	T
luminous intensity	candela	cd	10^{-15}	femto	f	10^{15}	peta	P
			10^{-18}	atto	a	10^{18}	exa	E
			10^{-21}	zepto	z	10^{21}	zetta	Z
			10^{-24}	yocto	y	10^{24}	yotta	Y

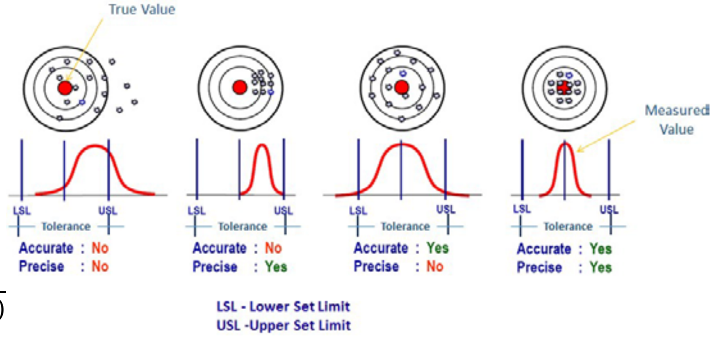
H 3-3; Z A1.5-A1.6 Precision, Accuracy, Experimental Error

accuracy – deviation from true value (systematic error)

precision – agreement of replicate measurements (random error)

mean

standard deviation, $s = \sqrt{\sum_i[(x_i - \langle x \rangle)^2]/(n-1)}$



H 3-1; Z A1.6 Mathematics

scientific notation – all digits given are significant figures

significant figures

all nonzero digits significant: 489 has 3 sig figs, 111.1 four

constants, exact numbers, defined quantities – infinite number of sig figs

zeros

leading – preceding first nonzero digit, not significant: 0.0046 has two sig fig

captive – surrounded by nonzero digits, significant: 1005 has four sig fig

trailing – at end of number, significant when a decimal point is present: 13.620 has five sig figs, 150 two

rounding – never round off intermediate results, only at the end of the calculation

Harris frequently carries extra nonsignificant digits written as subscripts to prevent round-off errors

EX 1. A student makes the following six independent measurements of pressure, *P*, in torr

762.2, 761.8, 762.0, 761.5, 762.2, and 760.0.

Calculate the average value of *P* and its standard deviation. (NOTE: useful for lab reports!)

H 3-2 Significant Figures in Arithmetic

multiplication and division – sig fig of final result same as least precise number used in the calculation

$8.247 \div 4.34 = 1.90023$
1.90

$2.3 \times 19.987 = 45.9701$
46

addition and subtraction – sig fig of final result has the same number of decimal places as the least precise number used in the calculation

$14 + 6.6 + 12.6 = 34.2$
34

$7.33 - 4.9 = 2.43$
2.4

EX 2. Concentration Calculations: A solution is made by transferring 1 mL of a 0.1245_3 M solution, using a volumetric pipet, into a 200-mL volumetric flask. Calculate the final concentration. Remember that concentration

= moles / liter, $c = n/L$ where the number of moles is given by volume × molarity, $n = VM$).

Solution: The volume of the flask has 5 significant figures and all other values have 4. The calculations all involve multiplication and division, so the final answer should be expressed with 4 significant figures.

$$1.000 \times 0.1245_3 \text{ M} / 200.00 = 0.0006226_5 \text{ M} = 6.227 \times 10^{-4} \text{ M}$$

ATOMS, MOLECULES, AND IONS____________________ Z Ch 2

Democritus introduced the word atom (Greek, *atomos* - indivisible):

"According to convention there is a sweet and a bitter, a hot and a cold, and according to convention there is a color. In truth there are atoms and a void." **Democritus, 5th century B.C.**

parts of Dalton's Atomic Theory:

"... there must be some point beyond which we cannot go in the division of matter. The existence of these ultimate particles of matter can scarcely be doubted, though they are probably much too small ever to be exhibited by microscopic improvements. I have chosen the word atom to signify those ultimate particles ... [which for] all homogeneous bodies are perfectly alike in weight, figure, etc. In other words, every particle of hydrogen is like every other particle of hydrogen ...." **John Dalton, 1808**

Z 2.1-2.4 Atomic Theory of Matter

ancient Greek philosophy and Indian philosophy– all matter composed of the four "elements": air, earth, fire, water (Chinese five elements – air replaced by wood and metal); this concept prevailed in Western thought through the Middle Ages

Heraclitus (535-475 BC; Greek philosopher in Asia Minor) everything in a state of flux, becoming, element fire; Parmenides (515-450 BC, Greek philosopher in southern Italy) change is impossible, being

Leucippus (480-420 BC; Greek philosopher) disagreed and he and his student Democritus (460-371 BC; mathematician, astronomer, physicist; suggestions that he traveled in India, Babylon, Persia, Egypt, Ethiopia – concept of finite divisibility of matter appeared in these areas) – postulated existence of atoms – tiny particles always in motion who interacted by collision; all change due to motion of atoms; Epicurus (341–270 BC, Greek philosopher) refined Democritus theory, he and the Pythagoreans were atomists

concept of the infinite indivisibility of matter also found early in 6th century BC – Kashyapa or Kanada (Hindu sage) , Vaisesika school of philosophy – cannot infinitely divide matter, has a limit (perhaps the eariest concept of an atom); Mimamsa school agreed; later Jainas (3rd century AD) were atomists

Socrates taught Plato and Plato taught Aristotle (384-322 BC, Greek philosopher, physicist, and biologist – his ideas were and still are extremely influential in Western thought) – all knowledge must proceed directly from observation, only four elements, atoms rejected by Aristotle as it was implausible since it could not be reconciled with the world as perceived by the senses; Stoics, Cicero, Seneca, St. Augustine (354-430 AD – now Western religion, also followed Aristotelian logic) opposed atomism

Lucretius (99-55 BC; Roman poet and philosopher) explained enumerous natural processes with the existence of the atom, even negating the necessity of a supreme being – branded an atheist and atomism condemned.

however there were pockets of resistence even within the church - Venerable Bede (762-735 AD) was an atomist

medieval Arabic speaking world the intellectual tradition of kalam supported atomism; Rhazes - Abu Bakr al-Razi (841-926; Persian physician, philosopher, astronomer, alchemist)

in the 12th century the works of Aristotle were rediscovered which brought back the concept of an atom, controvery heightened in 14th century. But Epicureanism contradicted orthodox Christian teachings so it was a “heresy”.

Pierre Gassendi (1592-1655) got around the objection by stating that atoms were created by God

Rene Descartes (1596-1650), Issac Newton (1642-1727) and Robert Boyle (1627-1691) defended atomism and generally accepted by end of 17th century.

1775 - Lavoisier did experiments on the combustion of mercury and formulated the **law of conservation of mass**

1799 – by examining the amount of oxygen in iron oxide Proust developed the **law of definite proportion** ("In a given chemical compound the proportions by mass of the elements that comprise it are fixed independent of the origin of the compound or its mode of preparation.")

1803 – Dalton states the **law of multiple proportions** ("When two elements form a series of compounds the masses of one element that combine with a fixed mass of the other element are in the ratio of small integers to each other.")

EX 3. Chlorine (Cl) and oxygen form four different binary compounds. Analysis gives the following results:

compound	mass of O combined with 1.0000 g Cl
A	0.22564 g
B	0.90255
C	1.3539
D	1.5795

a) Show that the **law of multiple proportions** holds for these compounds.

b) If the formula of compound A is a multiple of Cl_2O, then determine the formulas of the other compounds.

Dalton used atomic theory to explain the law of multiple proportions by experimentation and analysis –

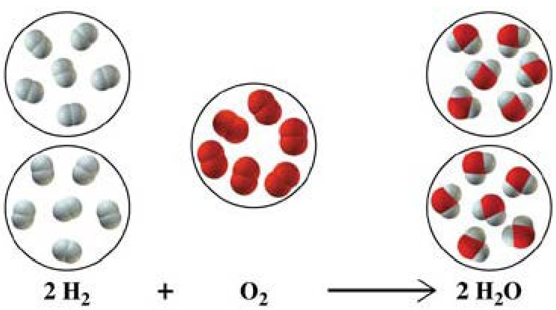
flaw did not realize that some elements were composed of more than one atom and that simplest combination was not always one atom of each element

1803 – Dalton's Atomic Theory

all matter consists of individual atoms, atoms are indestructible
all atoms of the same element are identical, different elements have different kinds of atoms
compounds formed from elements combining in small whole-number ratios

1808 – Guy-Lussac: gases (same *T, P)* combine in simple whole number ratios

1811 – **Avogadro's Hypothesis -** equal *V* (gas; same *T*, *P)* contain equal number of particles



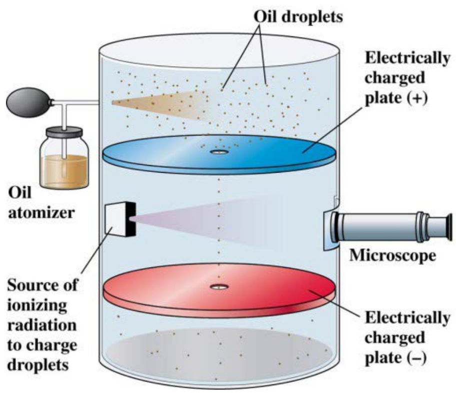
Avogadro's law corrected Dalton's flaw and showed that many gases exist as diatomics

1860 – Cannizzaro: experiments convinced world that Avogadro was correct

Z 2.5 Building Blocks of the Atom

electrons, protons, neutrons
(fundamental particles are actually electrons and quarks)

FIG II. 1909 – Mullikan: charge
(oil drop experiment)



oil droplets charged – electric field between charged plates can change rate of decent of drop - can determine net charges on drop by comparing their rate of decent in the absence and presence of the electric field – net charges whole number multiples of the charge on the electron

FIG III. 1909 - Geiger/Marsden (Rutherford) Experiment - scattering α particles off gold

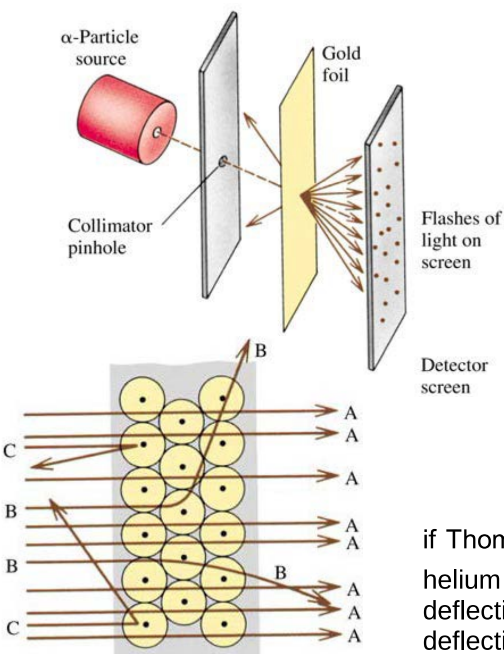
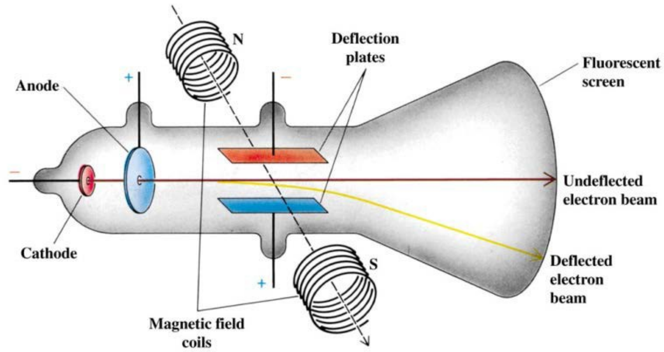


FIG I. 1897 – Thomson: charge / mass of e^-
(Plum Pudding Model: electrons dispersed in a cloud of charge)



magnetic field (N → S) and electric field (– → +)

magnetic field alone deflects the electron beam up while the electric field deflects it down – from the strengths of the two fields when there is no deflection one can calculate the velocity of the electrons – the charge to mass ratio is found from the velocity and the strength of the electric field alone

1898 –Rutherford discovered α, β particles – Nobel Prize 1908

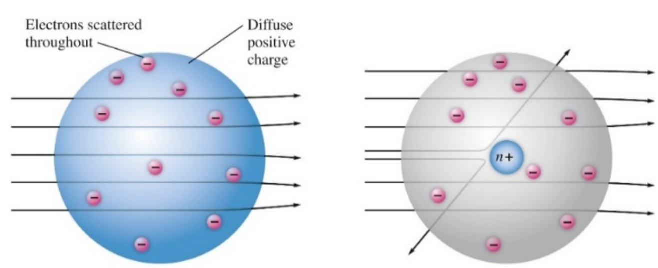
1909 – Geiger and Marsden: scattering α particles off gold

1911 – Rutherford's explanation – **FIG III**

1919 – proton discovered by Rutherford

1932 – neutron discovered by Chadwick

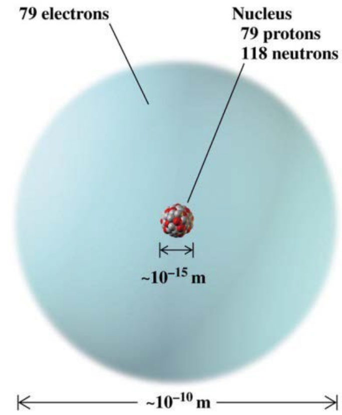
Rutherford Nuclear Model of the Atom
nearly all the volume occupied by electrons, nearly all the mass concentrated in a small positively charged nucleus



(a) Thomson (b) Rutherford

if Thomson plum pudding model were correct α particles (nucleus of helium atom, ${}^{4}_{2}He^{2+}$) should go through gold foil with only small deflections – mostly small deflections observed, occasionally large deflection angles were seen and rarely, rebounds directly backward

Z 2.6 Basics of the Atom – An Introduction



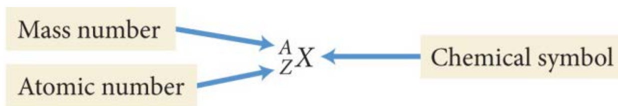
small, dense world – example of an atom of gold

diameter of a nucleus, 10^{-15} m

diameter of atom, 10^{-10} m

density of 2.3×10^{14} g cm^{-3}

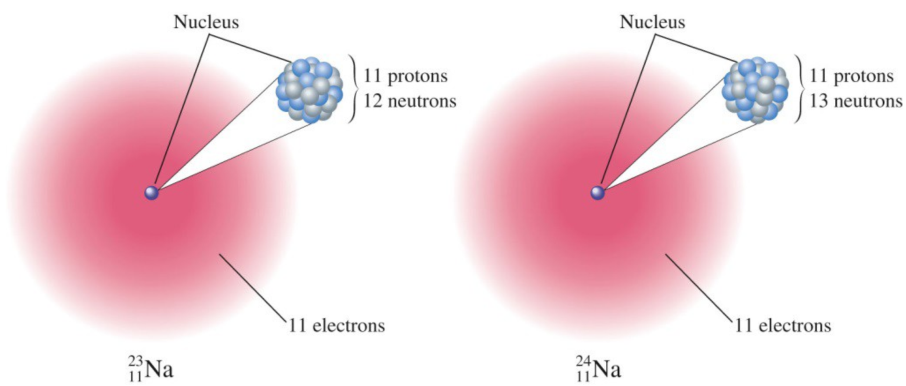
designation



Z = atomic number (number of protons)

A = mass number (sum of the numbers of protons and neutrons) – there can be isotopes

particle	charge	atomic mass units (amu)
electron	–1	0.000548579911
proton	+1	1.0072764669
neutron	0	1.0086649158

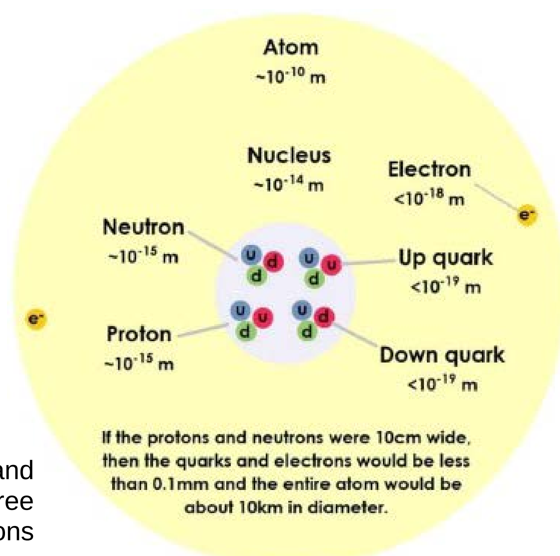


Two Isotopes of Sodium

leptons (*e.g.,* electrons and neutrinos) and **quarks** are the true elementary particles of matter

proton consists of 2 up and 1 down quarks
charge: 2u (+ $^2/_3$) + 1d (– $^1/_3$) = +1

neutron consists of 1 up and 2 down quarks
charge: 1 u (+ $^2/_3$) + 2d (– $^1/_3$) = 0

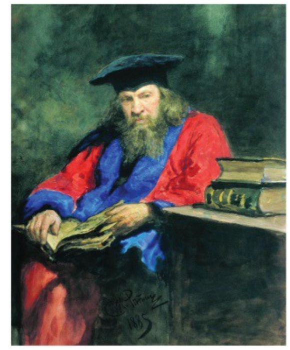


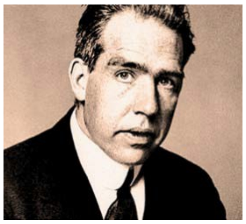
Rendering of structure of helium nucleus (two protons and two neutrons). Protons and neutrons are composed of three quarks where protons have an excess up quark and neutrons an excess of a down quark.

PERIODICITY AND NOMENCLATURE___________

"...I have tried to base a system on the magnitudes of the atomic weights of the elements. My first attempt in this respect was the following: I chose the smallest atomic weights and arranged them according to the sizes of their atomic weights. This showed that there existed a periodicity in the properties of these simple substances and that even according to their atomicity [valence] the elements followed one another in the arithmetical sequence of their atomic weights."

Dimitri Ivanovich Mendeleyev (Mendeleev), 1869





"The periodicity in the properties of the elements is connected with the continuing build up and completion of the various electron groups that takes place with increasing atomic number."

Niels Henrik David Bohr, 1923

(Nobel Prize in Physics in 1922 "for his services in the investigation of the structure of atoms and of the radiation emanating from them".)

Z 2.8 The Periodic Table, Its Organization, Chemistry (a beginning ...)

nonmetals

metals

1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	(8)	8B (9)	(10)	1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
1 **H** 1.008																	2 **He** 4.0026
3 **Li** 6.94	4 **Be** 9.0122											5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
11 **Na** 22.990	12 **Mg** 24.305											13 **Al** 26.982	14 **Si** 28.085	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.098	20 **Ca** 40.08	21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.85	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.55	30 **Zn** 65.4	31 **Ga** 69.723	32 **Ge** 72.63	33 **As** 74.922	34 **Se** 78.97	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.22	41 **Nb** 92.906	42 **Mo** 95.95	43 **Tc** (97/8)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.6	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.5	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 **Ac** (227)	104 **Rf** (267)	105 **Db** (268)	106 **Sg** (269)	107 **Bh** (271)	108 **Hs** (277)	109 **Mt** (276/7)	110 **Ds** (281)	111 **Rg** (282)	112 **Cn** (285)	113 **Nh** (286)	114 **Fl** (289)	115 **Mc** (290)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

Lanthanides	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.96	64 **Gd** 157.3	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
Actinides	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	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)

Major Classifications
metals
nonmetals
metalloids

Periods/Groups
main group
transition
lanthanides
actinides

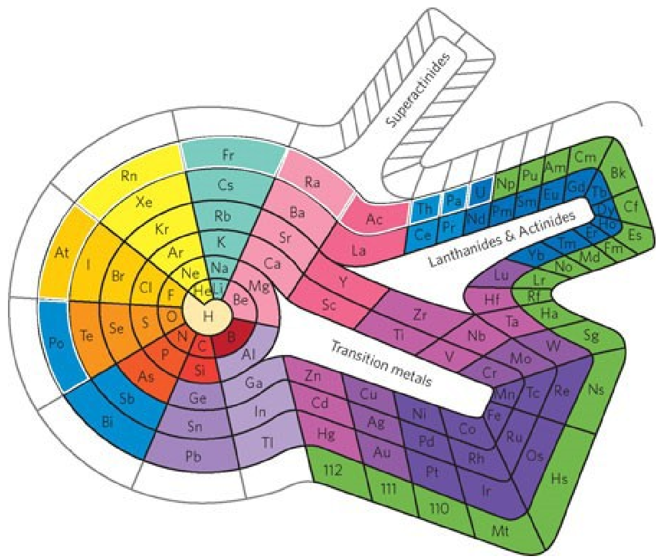
Main Group Elements
alkali metals
alkaline earth metals
chalcogens
halogens
noble gases

Electronegativity, increases
across a period
up a group

Left Step Periodic Table, Charles Janet, 1929

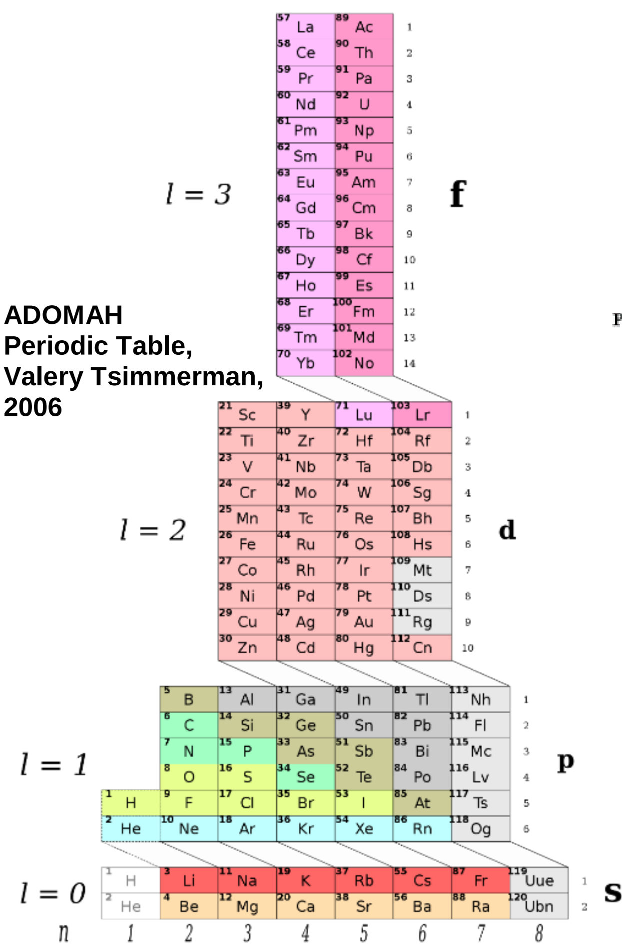
																														H	He
																														Li	Be
																								B	C	N	O	F	Ne	Na	Mg
																								Al	Si	P	S	Cl	Ar	K	Ca
														Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr
														Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	Cs	Ba
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Fr	Ra
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og	119	120

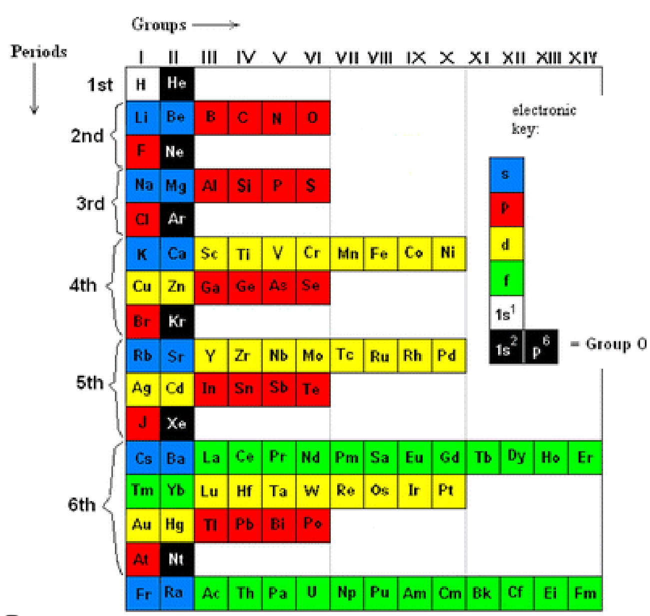
3D Periodic Table, Roy Alexander, 1965 (Chicago museum science exhibit designer)



Spiral Periodic Table, Theodor Benfey, 1964

ADOMAH Periodic Table, Valery Tsimmerman, 2006





Marks Brothers' Periodic Table, 2010

7 oldest known metals   not modern   spelling   __ium most common ending   5 end with ___um

ACTINIUM	**Ac**	**GOLD**	**Au**	polonium	Po
ALUMINUM	**Al**	hafnium	Hf	**POTASSIUM**	**K**
americium	Am	hassium	Hs	praseodymium	Pr
ANTIMONY	**Sb**	**HELIUM**	**He**	promethium	Pm
ARGON	**Ar**	holmium	Ho	protactinium	Pa
ARSENIC	**As**	**HYDROGEN**	**H**	**RADIUM**	**Ra**
astatine	At	indium	In	**RADON**	**Rn**
BARIUM	**Ba**	**IODINE**	**I**	rhenium	Re
berkelium	Bk	iridium	Ir	rhodium	Rh
BERYLLIUM	**Be**	**IRON**	**Fe**	roentgenium	Rg
BISMUTH	**Bi**	**KRYPTON**	**Kr**	**RUBIDIUM**	**Rb**
bohrium	Bh	**LANTHANUM**	**La**	ruthenium	Ru
BORON	**B**	lawrencium	Lr	rutherfordium	Rf
BROMINE	**Br**	**LEAD**	**Pb**	samarium	Sa
CADMIUM	**Cd**	**LITHIUM**	**Li**	scandium	Sc
CALCIUM	**Ca**	livermorium	Lv	seaborgium	Sg
californium	Cf	lutetium	Lu	**SELENIUM**	**Se**
CARBON	**C**	**MAGNESIUM**	**Mg**	**SILICON**	**Si**
cerium	Ce	**MANGANESE**	**Mn**	**SILVER**	**Ag**
CESIUM	**Cs**	meitnerium	Mt	**SODIUM**	**Na**
CHLORINE	**Cl**	mendelevium	Md	**STRONTIUM**	**Sr**
CHROMIUM	**Cr**	**MERCURY**	**Hg**	**SULFUR**	**S**
COBALT	**Co**	molybdenum	Mo	tantalum	Ta
copernecium	Cn	moscovium	Mc	technetium	Tc
COPPER	**Cu**	neodymium	Nd	**TELLURIUM**	**Te**
curium	Cm	**NEON**	**Ne**	tennessine	Ts
darmstadtium	Ds	neptunium	Np	terbium	Tb
dubnium	Db	**NICKEL**	**Ni**	thallium	Tl
dysprosium	Dy	nihonium	Nh	thorium	Th
einsteinium	Es	niobium	Nb	thulium	Tm
erbium	Er	**NITROGEN**	**N**	**TIN**	**Sn**
europium	Eu	nobelium	No	titanium	Ti
fermium	Fm	oganesson	Og	**TUNGSTEN**	**W**
flevorium	Fl	osmium	Os	**URANIUM**	**U**
FLUORINE	**F**	**OXYGEN**	**O**	vanadium	V
francium	Fr	palladium	Pd	**XENON**	**Xe**
gadolinium	Gd	**PHOSPHORUS**	**P**	ytterbium	Yb
gallium	Ga	**PLATINUM**	**Pt**	yttrium	Yr
germanium	Ge	**PLUTONIUM**	**Pu**	**ZINC**	**Zn**
				zirconium	Zr

halogens end with ___ine, non-halogen diatomic gases with ___gen;
noble gases (not He), B, C, Si with ___on

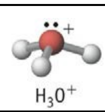
																	He
Li	**Be**											**B**	**C**	**N**	**O**	**F**	**Ne**
Na	**Mg**											**Al**	**Si**	**P**	**S**	**Cl**	**Ar**
K	**Ca**	Sc	Ti	V	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	Ga	Ge	**As**	**Se**	**Br**	**Kr**
Rb	**Sr**	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	**Ag**	**Cd**	In	**Sn**	**Sb**	**Te**	**I**	**Xe**
Cs	**Ba**	**La**	Hf	Ta	**W**	Re	Os	Ir	**Pt**	**Au**	**Hg**	Tl	**Pb**	**Bi**	Po	At	**Rn**
Fr	**Ra**	**Ac**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
				Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
				Th	Pa	**U**	Np	**Pu**	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

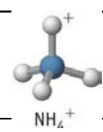
Z 2.7, 2.9 Nomenclature of Some Monatomic and Polyatomic Ions (Know)

hydride	H^-	oxide	O^{2-}
fluoride	F^-	sulfide	S^{2-}
chloride	Cl^-	nitride	N^{3-}
bromide	Br^-	phosphide	P^{3-}
iodide	I^-	**monatomic anions end with ___ide**	
hydroxide	OH^-	sulfite	SO_3^{2-}
peroxide	O_2^{2-}	hydrogen sulfite	HSO_3^{2-}
cyanide	CN^-	sulfate	SO_4^{2-}
nitrite	NO_2^-	hydrogen sulfate	HSO_4^{2-}
nitrate	NO_3^-	chromate	CrO_4^{2-}
carbonate	CO_3^{2-}	dichromate	$Cr_2O_7^{2-}$
hydrogen carbonate	HCO_3^-	permanganate	MnO_4^-
phosphate	PO_4^{3-}	hypochlorite	ClO^-
hydrogen phosphate	HPO_4^{2-}	chlorite	ClO_2^-
dihydrogen phosphate	$H_2PO_4^-$	chlorate	ClO_3^-
arsenate	AsO_4^{3-}	perchlorate	ClO_4^-
hydronium	H_3O^+	mercury(I)	Hg_2^{2+}
ammonium	NH_4^+		

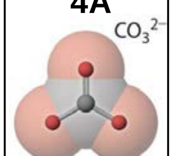
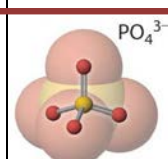
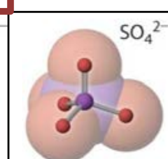
less oxygen ___ite

more oxygen ___ate

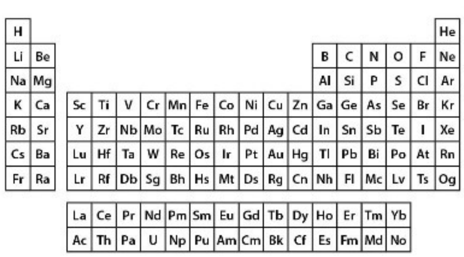




charge increases →

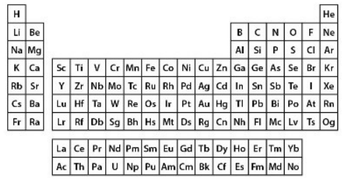
3A	4A	5A	6A	7A
borate BO_3^{3-}		nitrate NO_3^-		**second period different**
aluminate AlO_4^{5-}	silicate SiO_4^{4-}			perchlorate ClO_4^-
		arsenate AsO_4^{3-}		
		5B	**6B**	**7B**
		vanadate VO_4^{3-}	chromate CrO_4^{2-}	permanganate MnO_4^-
		XO_4^{3-}	XO_4^{2-}	XO_4^-

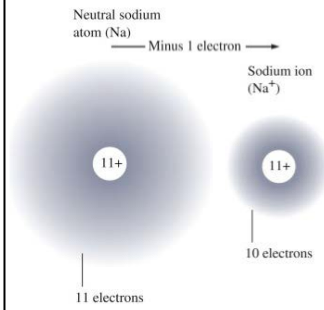
size increases ↓

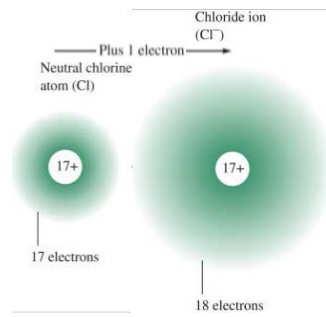


Positive Ions (Cations)[1]

Monatomic		Polyatomic
Only One Ion Possible	More Than One Ion Possible	
Rule: Name of element + "ion". **Examples:** Na^+ sodium ion Mg^{2+} magnesium ion H^+ hydrogen ion Al^{3+} aluminum ion Ag^+ silver ion Zn^{2+} zinc ion Cd^{2+} cadmium ion **Comment:** The number of positive charges is *not* indicated in the name because it is not necessary, *e.g.,* Group I elements (1+) and Group II elements (2+).	**Rule:** (a) Newer rule: positive charges indicated by a roman numeral. **Examples:** Fe^{2+} iron(II) ion Fe^{3+} iron(III) ion Cu^+ copper(I) ion Cu^{2+} copper(II) ion (b) Older rule (still used): Latin stem for the element + "ous" for the lesser charge and + "ic" for the greater charge. (We will use newer rule except for coordination compounds) **Examples:** Fe^{2+} ferrous ion Fe^{3+} ferric ion	**Rule:** Special cases. **Examples:** NH_4^+ ammonium ion H_3O^+ hydronium ion Hg_2^{2+} mercury(I) ion **Comment:** Hg_2^{2+} is Hg^+– Hg^+ but Hg^+ does not exist, therefore mercury(I) ion is Hg^+. (Hg^{2+} is mercury(II) ion, but that is a monatomic ion.)







Negative Ions (Anions)[1]

(note similarity in nomenclature between A and B groups)

Monatomic	Oxyanions (Containing Oxygen)		Others and Exceptions
	(Without Hydrogen)	Containing Hydrogen	
Rule: Stem of the element name + "ide". **Examples:** H^- hydride ion F^- fluoride ion O^{2-} oxide ion N^{3-} nitride ion	**Rule:** least oxygen: hypo_ite ion less oxygen: _ite ion more oxygen: _ate ion most oxygen: per_ate ion **Examples:** ClO^- hypochlorite ion ClO_2^- chlorite ion ClO_3^- chlorate ion ClO_4^- perchlorate ion SO_3^{2-} sulfite ion SO_4^{2-} sulfate ion **Comment:** Halogens (except F) form all four ions. When only two of the four ions exist, they are the -ite and the -ate ions. Cl Group 7A S Group 6A	**Rule:** H - oxyanion: "hydrogen" + name of oxyanion or "bi" + oxyanion H_2 - oxyanion: "dihydrogen" + name of oxyanion **Examples:** HCO_3^- hydrogen carbonate (or bicarbonate) ion HSO_4^- hydrogen sulfate (or bisulfate) ion HPO_4^{2-} hydrogen phosphate ion $H_2PO_4^-$ dihydrogen phosphate ion **Comment:** H_2CO_3 is not named according to this rule because it is a compound and not an ion.	**Rule:** These items do not follow simple rules: they must be memorized. **Examples:** OH^- hydroxide ion O_2^{2-} peroxide ion CN^- cyanide ion AsO_4^{3-} arsenate ion MnO_4^- permanganate ion CrO_4^{2-} chromate ion $Cr_2O_7^{2-}$ dichromate ion **Comment:** Note that arsenate is a Group V element and forms a polyatomic ion with oxygen identical to phosphorus. Mn Group 7B Cr Group 6B As Group 5A, like PO_4^{3-}

[1]adapted from Gerhard Lind, *Journal of Chemical Education,* 69, 613 (1992)

Compounds (Metalloid Can Be Substituted for Nonmetal)[1]

Ionic (Cation-Anion)	Covalent (Nonmetals)		
	Nonmetal-Nonmetal	Compounds Containing Hydrogen	
		H-Nonmetal	H-Oxyanion
Rule: Name of cation + name of anion (word "ion" dropped). **Examples:** $ZnSO_4$ zinc sulfate $NaNO_2$ sodium nitrite $CaCl_2$ calcium chloride Fe_3N_2 iron(II) nitride Li_2CO_3 lithium carbonate NH_4I ammonium iodide $Cu(IO_3)_2$ copper(II) iodate BaH_2 barium hydride **Comment:** The name does not indicate the numbers of cations and anions because there is only one possibility for the ions to combine to form a compound.	**Rule:** (a) Less electronegative element generally first (exception: when one of the elements is hydrogen). (b) Greek prefixes specify number of atoms of each kind (c) Initial prefix mono dropped. **Prefixes:** 1 = mono 6 = hexa 2 = di 7 = hepta 3 = tri 8 = octa 4 = tetra 9 = nona 5 = penta 10 = deca **Examples:** SCl_6 sulfur hexachloride N_2O_4 dinitrogen tetroxide CO carbon monoxide CO_2 carbon dioxide NO_2 nitrogen dioxide N_2O dinitrogen monoxide **Comment:** Tetraoxide becomes tetroxide, monooxide becomes monoxide, etc., so that the name sounds better	**Rule 1:** (without the presence of H_2O) hydrogen _ide **Examples:** HCl hydrogen chloride HF hydrogen fluoride H_2S hydrogen sulfide H_2Se hydrogen selenide **Rule 2:** (H acids - when dissolved in H_2O) hydro_ic acid **Examples:** HCl hydrochloric acid HF hydrofluoric acid H_2S hydrosulfuric acid H_2Se hydroselenic acid **Comment:** (a) These H-containing compounds are named as if they were ionic. (b) Often the (*aq*) in the formulas of the acids is omitted when it is obvious from the context that they are acids.	**Rule 1:** (without the presence of H_2O) like ionic compounds: cation + anion hydrogen hypo_ite hydrogen _ite hydrogen _ate hydrogen per_ate **Rule 2:** (HO acids - when dissolved in H_2O) hypo_ous acid _ous acid _ic acid per_ic acid **Examples:** HClO hypochlorous acid $HClO_2$ chlorous acid $HClO_3$ chloric acid $HClO_4$ perchloric acid HNO_2 nitrous acid HNO_3 nitric acid H_2SO_3 sulfurous acid H_2SO_4 sulfuric acid H_3PO_4 phosphoric acid **Comment:** The (*aq*) is usually omitted.

[1] adapted from Gerhard Lind, *Journal of Chemical Education,* **69,** 613 (1992)

when we study acids

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No

Ordering of elements in formula of binary molecular compounds: order according to Group number, bottom to top; for any pair, element furthest right behaves as the "anion" (H, O need to be memorized):

	B	Si C	Sb As P N	**H**	Te Se S	I Br Cl	**O**	F
Group #	3A	4A	5A		6A	7A		