

Lecture 4: C1403      Monday, September 19, 2005

Stoichiometry : Mass relationships involved  
in compositions of compounds and in  
balanced chemical equations.

Converting mass of substances to moles  
(numbers of atoms and molecules) and moles  
to mass.

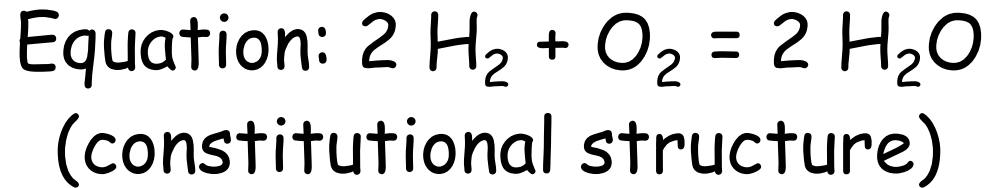
Creation of a ranking of atomic masses through Avogadro's hypothesis and the mass of volumes of gases.

*From the mass of 22.4 L of gases to atomic and molecular molar masses.*

22.4 L determined as containing a mole of a gas.

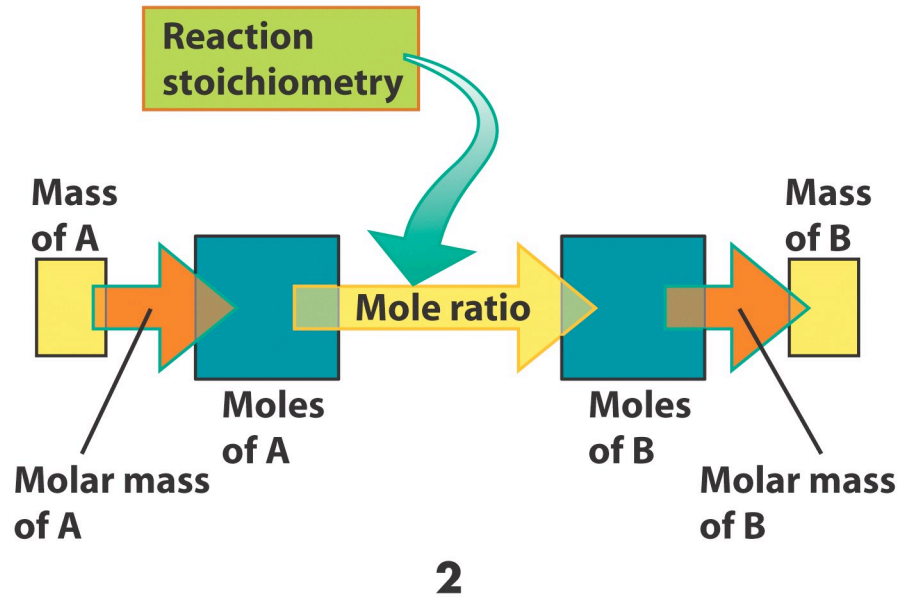
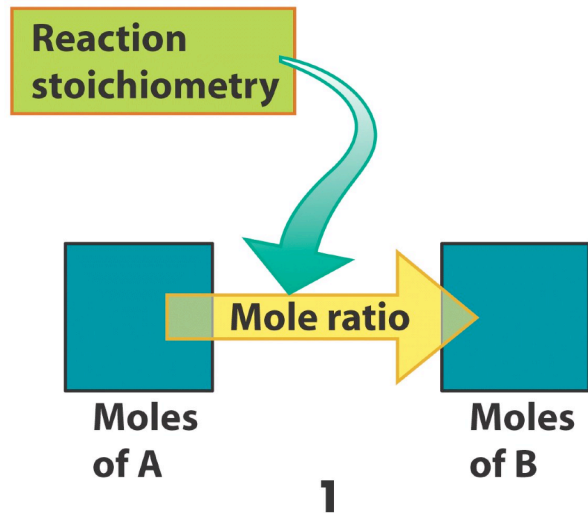
Compound (22.4 L)	Mass	% of O	Mass of O
Water	18 g	89% O	16 g O/mole
Carbon dioxide	44 g	73% O	32 g O/mole
Sulfur trioxide	80 g	60% O	48 g O/mole
Oxygen	32 g	100% O	32 g O/mole

Data consistent with atomic molar mass of H = 1 & O = 16.

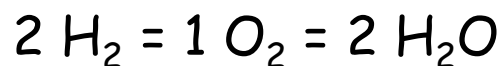


Molecular compositions

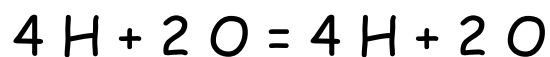
Balanced equations



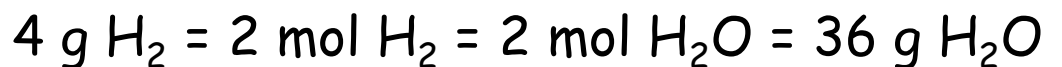
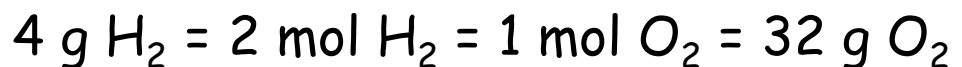
**Mole equivalents:**

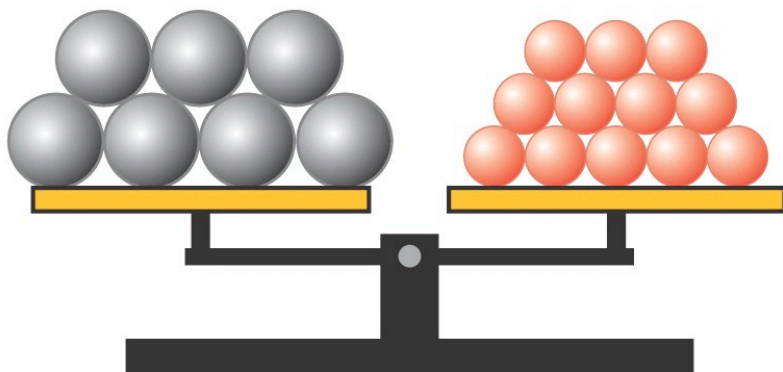


**Atom equivalents:**

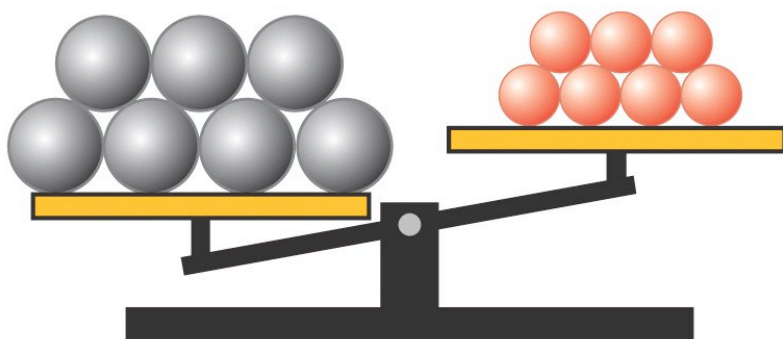


**Mass to mole to mole to mass conversion**





**(a) Equal masses**

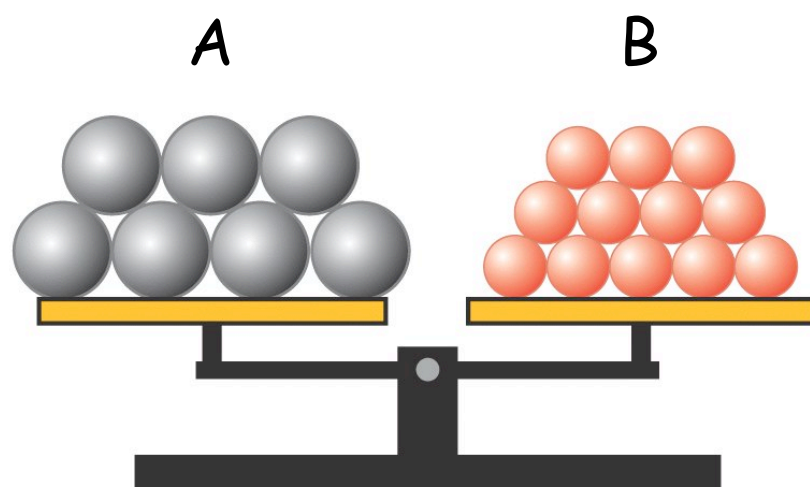


**(b) Equal amounts**

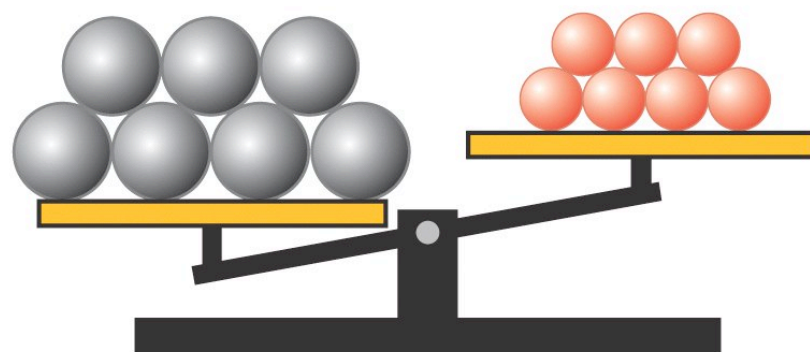
Laboratory  
amounts: masses

Chemical amounts:  
numbers of atoms  
or molecules. Equal  
amounts means  
equal numbers of  
atoms

## Limiting reactant depends on number not on mass.

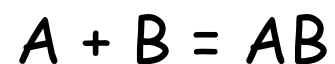


**(a) Equal masses**



**(b) Equal amounts**

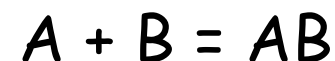
Equal masses: excess of lighter atom in reaction



A is limiting reactant

Equal number:

No excess of either A or B in reaction



## Chapter 3 Chemical Periodicity and the Formation of Simple Compounds. Lewis structures of molecules.

### Learning goals:

#### Periodic Table

- (3.1) The characteristics of groups of the 8 representative groups (I-VIII) of elements.
- (3.2) The relationships among the elements in the columns and rows of the Periodic Table.
- (3.2) Periodic Properties. Electronegativity.

#### Lewis structures

- (3.3) Lewis dot electronic structures of atoms.
- (3.4, 3.5) Lewis dot-line constitutional structures of molecules. How atoms are connected.
- (3.7) Predicting the dipole moments and the configuration (3D) structure of molecules from Lewis structures.

### *(3.2) The Periodic Table*

Classical example of the building of a paradigm: Repeated patterns of similarity in the composition of binary compounds triggered a search for order and organization of the elements in terms of observable properties.

First organization of the periodic: By atomic mass.

Periodicity of properties appeared as an arrangement by mass.

About 1870 Mendeleev (Russia) and Meyer (Germany) proposed the initial forms of the periodic table.

Mendeleev dared to propose that deviations from periodicity were due to either incorrect atomic weights or undiscovered elements. He predicted the properties of six undiscovered elements. Mendeleev's paradigm wins (for a while)!

### *(3.1) Groups of Elements in the Periodic Table*

Eight Groups (the 7 groups of representative elements and the group of noble gases):

I. Alkali metals:	(H), Li, Na, K, Rb, Cs
II. Alkali earth metals:	Be, Al, Ca, Sr, Ba, Ra
III. Boron family:	B, Al, Ga, In, Tl
IV. Carbon family:	C, Si, Ge, Sn, Pb
V. Nitrogen family:	N, P, As, Sb, Bi
VI. Chalcogens	O, S, Se, Te, Po
VII. Halogens	F, Cl, Br, I, At
VIII. Noble gases:	(He), Ne, Ar, Kr, Xe, Rn

Representative metals (I and II) and non-metals (VI and VII).



Group I (The alkali metals): Li, Na, K, Rb, Cs



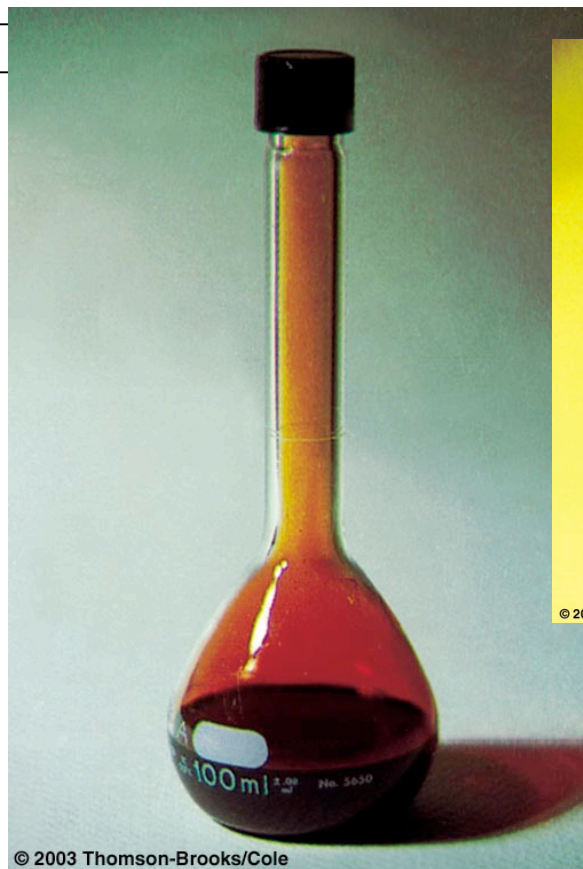
Most of the elements in the periodic table are metals



Group VI (The chalcogens):

O (oxygen), S (sulfur), Ge (germanium), Sn (tin)

# Halogens (elemental forms)

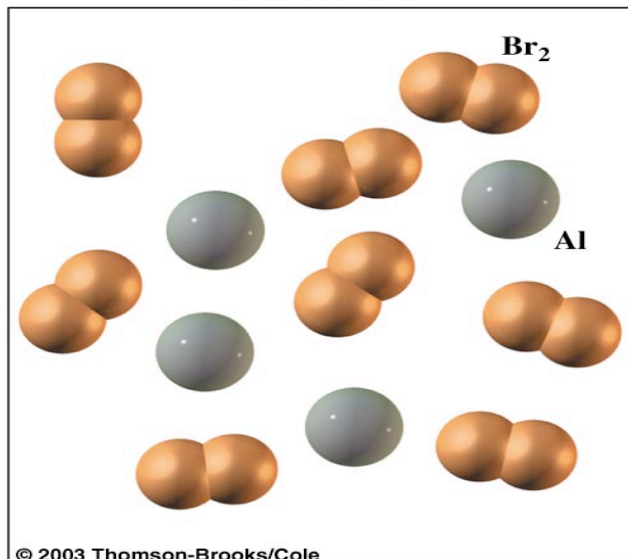


Group VII (The halogens): F (not shown), Cl (gas), Br (liquid), I (solid)

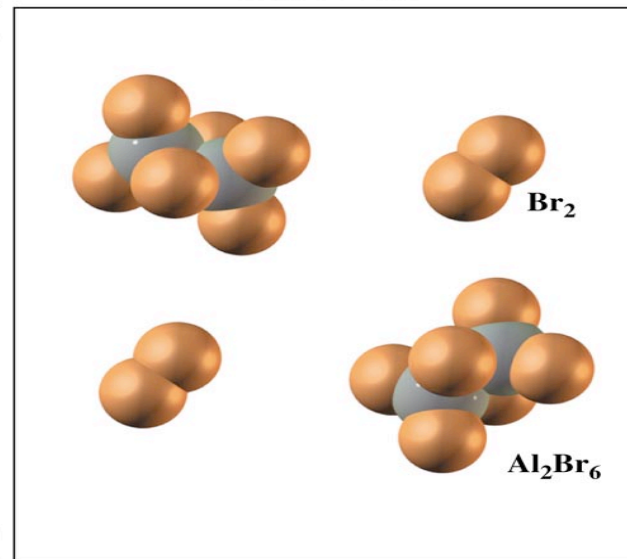
What is the basis of chemical reactivity?



REACTANTS



PRODUCTS



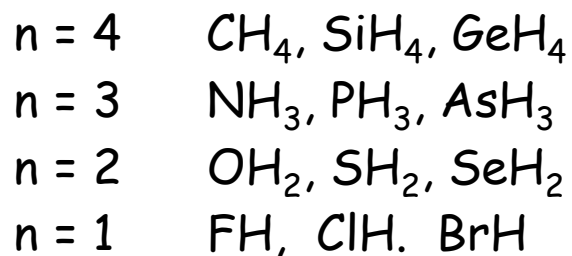
- . Grouping elements by similarities. Science is an exercise in collecting data, detecting similarities in the data and in determining the source of the similarities at an atomic (microscopic) level.

Many elements form binary compounds with H. Since H is the "simplest" element (smallest atomic mass), it is natural to consider the properties of the compounds formed between elements, X, and H. These binary compounds,  $XH_n$ , are called **hydrides**.

Exemplars:  $CH_4$ ,  $NH_3$ ,  $OH_2$ ,  $FH$  ( $XH_n$   $n = 4, 3, 2, 1$ , respectively)

Group binary hydrides of that bind the same number of H.

Examples of grouping of hydrides of elements:



Clear cut grouping of metals (Groups I and II) forming binary compounds with non-metals (Groups VI and VII)

Alkali metals, X:

Li, Na, K, Rb, Cs

$X_2O$

$Li_2O, Na_2O, K_2O, Rb_2O, Cs_2O$

$XCl$

$LiCl, NaCl, KCl, RbCl, CsCl$

Alkali earth metals, X: Be, Mg, Ca, Sr, Ba

$XO$

$BeO, MgO, CaO, SrO, BaO$

$XCl_2$

$BeCl_2, MgCl_2, CaCl_2, SrCl_2, BaCl_2$

Chalcogens, X:

O, S, Se, Te

$Na_2X$

$Na_2O, Na_2S, Na_2Se, Na_2Te$

$CaX$

$CaO, CaS, CaSe, CaTe$

Halogens, X:

F, Cl, Br, I

$LiX$

$LiF, LiCl, LiBr, LiI$

$CaX_2$

$CaF_2, CaCl_2, CaBr_2, CaI_2$

## Organize Elements by Stable Oxides, Hydrides, Halides

I      II      III      IV      V      VI      VII      VIII

Li <sub>2</sub> O LiCl	BeO BeCl <sub>2</sub>	B <sub>2</sub> O <sub>3</sub> BCl <sub>3</sub>	CO <sub>2</sub> CCl <sub>4</sub>	NO NCl <sub>3</sub>	[O] H <sub>2</sub> O	F <sup>-</sup> HF	Ne
Na <sub>2</sub> O NaCl	MgO MgCl <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub> AlCl <sub>3</sub>	SiO <sub>2</sub> SiCl <sub>4</sub>	PO PCl <sub>3</sub>	SO <sub>4</sub> <sup>2-</sup> H <sub>2</sub> S	Cl <sup>-</sup> HCl	Ar
K <sub>2</sub> O KCl	CaO CaCl <sub>2</sub>	Ga <sub>2</sub> O <sub>3</sub> GaCl <sub>3</sub>	GeO <sub>2</sub> GeCl <sub>4</sub>	AsO AsCl <sub>3</sub>	SeO <sub>4</sub> <sup>2-</sup> H <sub>2</sub> Se	Br <sup>-</sup> HBr	Kr
Rb <sub>2</sub> O RbCl	SrO SrCl <sub>2</sub>	In <sub>2</sub> O <sub>3</sub> InCl <sub>3</sub>	SnO <sub>2</sub> SnCl <sub>4</sub>	SbO SbCl <sub>3</sub>	TeO <sub>4</sub> <sup>2-</sup> H <sub>2</sub> Te	I <sup>-</sup> HI	Xe

### *(3.2) The Periodic Table*

- (1) The elements can be arranged in groups (columns) of elements that possess related chemical and physical properties.
- (2) The elements can be arranged in periods (rows) of elements that possess progressively different physical and chemical properties.
- (3) **Original Paradigm**: The chemical and physical properties of the element are periodic functions of their **atomic masses**.
- (4) **Modern Paradigm**: The chemical and physical properties of the elements are periodic functions of the **atomic number** (number of protons in the nucleus = number of electrons in the neutral atom).

# Organization of the elements by relative atomic mass and periodic properties.



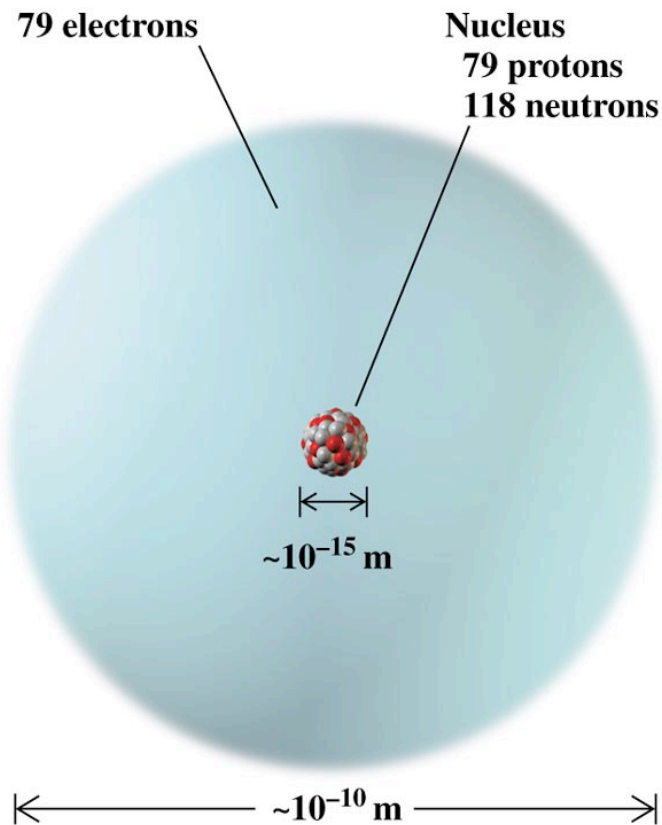
Dmitri Mendeleev

**TABELLE II**

REIHEN	GRUPPE I. — R <sup>2</sup> O	GRUPPE II. — RO	GRUPPE III. — R <sup>2</sup> O <sub>3</sub>	GRUPPE IV. RH <sup>4</sup> RO <sub>2</sub>	GRUPPE V. RH <sup>3</sup> R <sub>2</sub> O <sub>5</sub>	GRUPPE VI. RH <sup>2</sup> RO <sub>3</sub>	GRUPPE VII. RH R <sub>2</sub> O <sub>7</sub>	GRUPPE VIII. — RO <sub>4</sub>
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	—	—

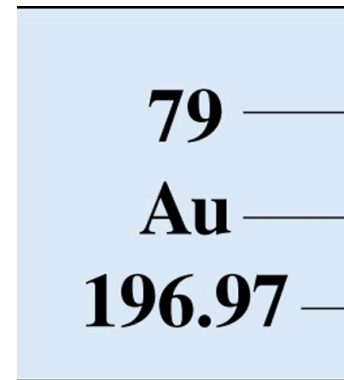
**Figure 2.5** Dmitri Mendeleev's 1872 periodic table. The spaces marked with blank lines represent elements that Mendeleev deduced existed but were unknown at the time, so he left places for them in the table. The symbols at the top of the columns (e.g., R<sup>2</sup>O and RH<sup>4</sup>) are molecular formulas written in the style of the 19th century.

Modern basis for the periodic table: the number of protons in the atomic nucleus (atomic number)



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$^{198}\text{Au}$



Atomic number

Symbol

Relative atomic mass

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# An alphabetical arrangement of the elements (information)

**TABLE OF ATOMIC MASSES**

Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass	Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	[227] <sup>§</sup>	Hafnium	Hf	72	178.5	Promethium	Pm	61	[145]
Aluminum	Al	13	26.98	Hassium	Hs	108	[265]	Protactinium	Pa	91	[231]
Americium	Am	95	[243]	Helium	He	2	4.003	Radium	Ra	88	226
Antimony	Sb	51	121.8	Holmium	Ho	67	164.9	Radon	Rn	86	[222]
Argon	Ar	18	39.95	Hydrogen	H	1	1.008	Rhenium	Re	75	186.2
Arsenic	As	33	74.92	Indium	In	49	114.8	Rhodium	Rh	45	102.9
Astatine	At	85	[210]	Iodine	I	53	126.9	Rubidium	Rb	37	85.47
Barium	Ba	56	137.3	Iridium	Ir	77	192.2	Ruthenium	Ru	44	101.1
Berkelium	Bk	97	[247]	Iron	Fe	26	55.85	Rutherfordium	Rf	104	[261]
Beryllium	Be	4	9.012	Krypton	Kr	36	83.80	Samarium	Sm	62	150.4
Bismuth	Bi	83	209.0	Lanthanum	La	57	138.9	Scandium	Sc	21	44.96
Bohrium	Bh	107	[264]	Lawrencium	Lr	103	[260]	Seaborgium	Sg	106	[263]
Boron	B	5	10.81	Lead	Pb	82	207.2	Selenium	Se	34	78.96
Bromine	Br	35	79.90	Lithium	Li	3	6.941	Silicon	Si	14	28.09
Cadmium	Cd	48	112.4	Lutetium	Lu	71	175.0	Silver	Ag	47	107.9
Calcium	Ca	20	40.08	Magnesium	Mg	12	24.31	Sodium	Na	11	22.99
Californium	Cf	98	[251]	Manganese	Mn	25	54.94	Strontium	Sr	38	87.62
Carbon	C	6	12.01	Meitnerium	Mt	109	[268]	Sulfur	S	16	32.07
Cerium	Ce	58	140.1	Mendelevium	Md	101	[258]	Tantalum	Ta	73	180.9
Cesium	Cs	55	132.90	Mercury	Hg	80	200.6	Technetium	Tc	43	[98]
Chlorine	Cl	17	35.45	Molybdenum	Mo	42	95.94	Tellurium	Te	52	127.6
Chromium	Cr	24	52.00	Neodymium	Nd	60	144.2	Terbium	Tb	65	158.9
Cobalt	Co	27	58.93	Neon	Ne	10	20.18	Thallium	Tl	81	204.4
Copper	Cu	29	63.55	Neptunium	Np	93	[237]	Thorium	Th	90	232.0
Curium	Cm	96	[247]	Nickel	Ni	28	58.69	Thulium	Tm	69	168.9
Dubnium	Db	105	[262]	Niobium	Nb	41	92.91	Tin	Sn	50	118.7
Dysprosium	Dy	66	162.5	Nitrogen	N	7	14.01	Titanium	Ti	22	47.88
Einsteinium	Es	99	[252]	Nobelium	No	102	[259]	Tungsten	W	74	183.9
Erbium	Er	68	167.3	Osmium	Os	76	190.2	Uranium	U	92	238.0
Europium	Eu	63	152.0	Oxygen	O	8	16.00	Vanadium	V	23	50.94
Fermium	Fm	100	[257]	Palladium	Pd	46	106.4	Xenon	Xe	54	131.3
Fluorine	F	9	19.00	Phosphorus	P	15	30.97	Ytterbium	Yb	70	173.0
Francium	Fr	87	[223]	Platinum	Pt	78	195.1	Yttrium	Y	39	88.91
Gadolinium	Gd	64	157.3	Plutonium	Pu	94	[244]	Zinc	Zn	30	65.38
Gallium	Ga	31	69.72	Polonium	Po	84	[209]	Zirconium	Zr	40	91.22
Germanium	Ge	32	72.59	Potassium	K	19	39.10				
Gold	Au	79	197.0	Praseodymium	Pr	59	140.9				

\*The values given here are to four significant figures where possible.    §A value given in parentheses denotes the mass of the longest-lived isotope.



Same information (atomic numbers and atomic masses),  
 provided with a constitutional (connected) structure =  
 knowledge (connecting properties and function)

**IUPAC Periodic Table of the Elements**

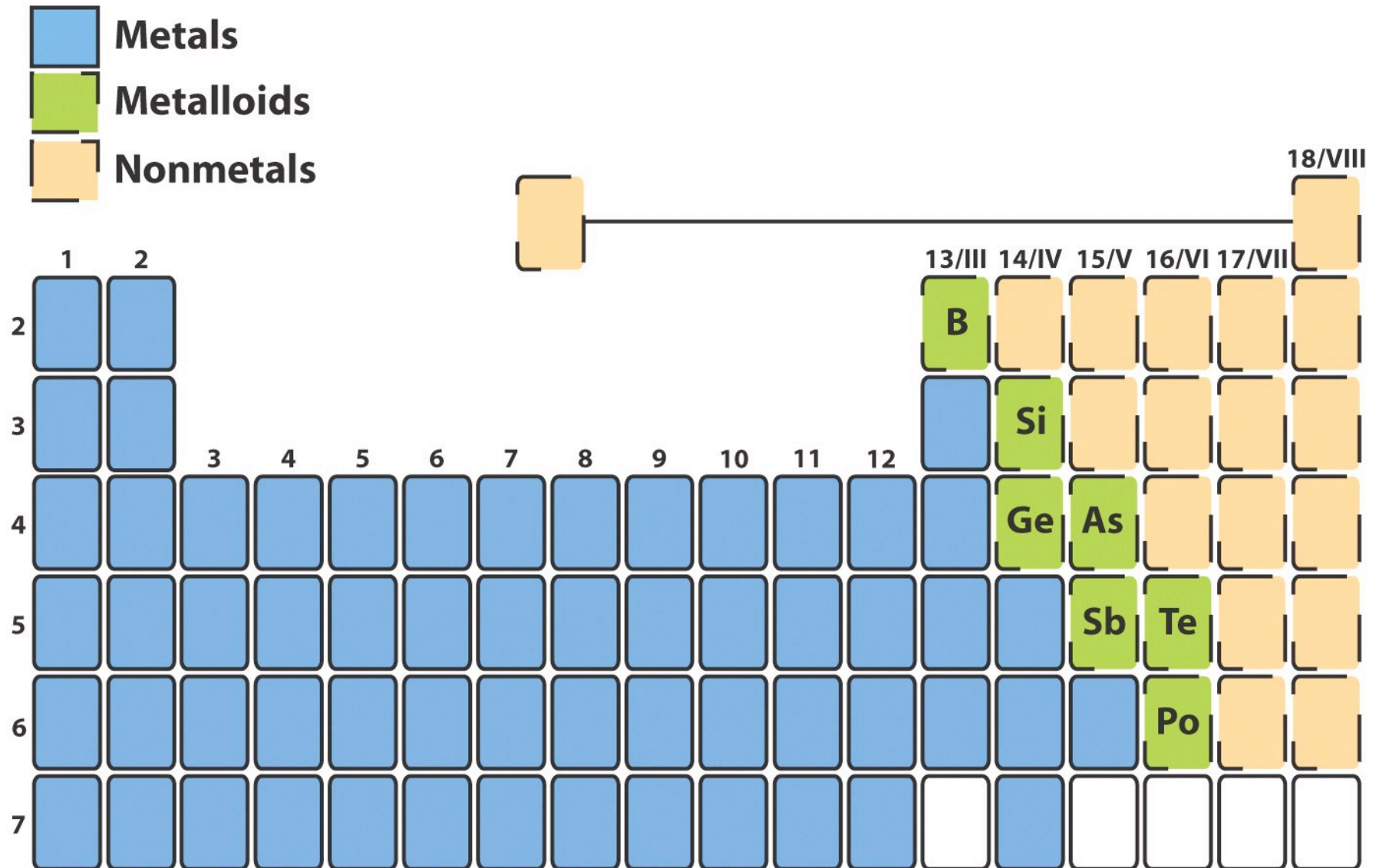
IUPAC Periodic Table of the Elements																	
1 <b>H</b> hydrogen 1.007 84(7)																	2 <b>He</b> helium 4.002 602(2)
3 <b>Li</b> lithium 6.941(2)	4 <b>Be</b> beryllium 9.012 182(3)	Key: atomic number symbol name standard atomic weight										5 <b>B</b> boron 10.811(7)	6 <b>C</b> carbon 12.0107(8)	7 <b>N</b> nitrogen 14.0064(2)	8 <b>O</b> oxygen 15.9994(3)	9 <b>F</b> fluorine 18.998 4032(5)	10 <b>Ne</b> neon 20.1797(6)
11 <b>Na</b> sodium 22.989 770(2)	12 <b>Mg</b> magnesium 24.3050(6)											13 <b>Al</b> aluminium 26.981 538(2)	14 <b>Si</b> silicon 28.0855(3)	15 <b>P</b> phosphorus 30.973 761(2)	16 <b>S</b> sulfur 32.065(5)	17 <b>Cl</b> chlorine 35.453(2)	18 <b>Ar</b> argon 39.948(1)
19 <b>K</b> potassium 39.0983(1)	20 <b>Ca</b> calcium 40.078(4)	21 <b>Sc</b> scandium 44.955 910(8)	22 <b>Ti</b> titanium 47.867(1)	23 <b>V</b> vanadium 50.9415(1)	24 <b>Cr</b> chromium 51.9961(6)	25 <b>Mn</b> manganese 54.938 045(5)	26 <b>Fe</b> iron 55.845(2)	27 <b>Co</b> cobalt 58.933 200(3)	28 <b>Ni</b> nickel 58.6934(2)	29 <b>Cu</b> copper 63.546(3)	30 <b>Zn</b> zinc 65.409(4)	31 <b>Ga</b> gallium 69.723(1)	32 <b>Ge</b> germanium 72.64(1)	33 <b>As</b> arsenic 74.921 60(2)	34 <b>Se</b> selenium 78.96(3)	35 <b>Br</b> bromine 79.904(1)	36 <b>Kr</b> krypton 83.798(2)
37 <b>Rb</b> rubidium 85.4678(3)	38 <b>Sr</b> strontium 87.62(1)	39 <b>Y</b> yttrium 88.905 85(3)	40 <b>Zr</b> zirconium 91.224(2)	41 <b>Nb</b> niobium 92.906 38(2)	42 <b>Mo</b> molybdenum 95.94(2)	43 <b>Tc</b> technetium [97.9072]	44 <b>Ru</b> ruthenium 101.07(2)	45 <b>Rh</b> rhodium 102.905 50(2)	46 <b>Pd</b> palladium 106.42(1)	47 <b>Ag</b> silver 107.8682(2)	48 <b>Cd</b> cadmium 112.411(8)	49 <b>In</b> indium 114.818(3)	50 <b>Sn</b> tin 118.710(7)	51 <b>Sb</b> antimony 121.760(1)	52 <b>Te</b> tellurium 127.60(3)	53 <b>I</b> iodine 126.904 47(3)	54 <b>Xe</b> xenon 131.293(6)
55 <b>Cs</b> caesium 132.905 45(2)	56 <b>Ba</b> barium 137.327(7)	57-71 <b>lanthanoids</b>	72 <b>Hf</b> hafnium 178.49(2)	73 <b>Ta</b> tantalum 180.9479(1)	74 <b>W</b> tungsten 183.84(1)	75 <b>Re</b> rhenium 186.207(1)	76 <b>Os</b> osmium 190.23(3)	77 <b>Ir</b> iridium 192.2217(3)	78 <b>Pt</b> platinum 195.078(2)	79 <b>Au</b> gold 196.966 55(2)	80 <b>Hg</b> mercury 200.59(2)	81 <b>Tl</b> thallium 204.3833(2)	82 <b>Pb</b> lead 207.2(1)	83 <b>Bi</b> bismuth 208.980 38(2)	84 <b>Po</b> polonium [208.9824]	85 <b>At</b> astatine [209.9871]	86 <b>Rn</b> radon [222.0176]
87 <b>Fr</b> francium [223.0197]	88 <b>Ra</b> radium [226.0254]	89-103 <b>actinoids</b>	104 <b>Rf</b> rutherfordium [261.1088]	105 <b>Db</b> dubnium [262.1141]	106 <b>Sg</b> seaborgium [266.1219]	107 <b>Bh</b> bohrium [269.12]	108 <b>Hs</b> hassium [277]	109 <b>Mt</b> meitnerium [269.1388]	110 <b>Ds</b> darmstadtium [271]	111 <b>Uuu</b> ununium [272]							
57 <b>La</b> lanthanum 138.9055(2)	58 <b>Ce</b> cerium 140.116(1)	59 <b>Pr</b> praseodymium 140.907 45(2)	60 <b>Nd</b> neodymium 144.24(3)	61 <b>Pm</b> promethium [144.9127]	62 <b>Sm</b> samarium 150.36(3)	63 <b>Eu</b> europium 151.964(1)	64 <b>Gd</b> gadolinium 157.25(3)	65 <b>Tb</b> terbium 158.925 34(2)	66 <b>Dy</b> dysprosium 162.500(1)	67 <b>Ho</b> holmium 164.930 32(2)	68 <b>Er</b> erbium 167.259(3)	69 <b>Tm</b> thulium 168.934 21(2)	70 <b>Yb</b> ytterbium 173.04(3)	71 <b>Lu</b> lutetium 174.967(1)			
89 <b>Ac</b> actinium [227.0277]	90 <b>Th</b> thorium 232.0381(1)	91 <b>Pa</b> protactinium 231.036 88(2)	92 <b>U</b> uranium 238.028 91(3)	93 <b>Np</b> neptunium [237.0482]	94 <b>Pu</b> plutonium [244.0642]	95 <b>Am</b> americium [243.0614]	96 <b>Cm</b> curium [247.0794]	97 <b>Bk</b> berkelium [247.0793]	98 <b>Cf</b> californium [251.0796]	99 <b>Es</b> einsteinium [252.0830]	100 <b>Fm</b> fermium [257.0951]	101 <b>Md</b> mendelevium [258.0984]	102 <b>No</b> nobelium [259.1019]	103 <b>Lr</b> lawrencium [262.1097]			



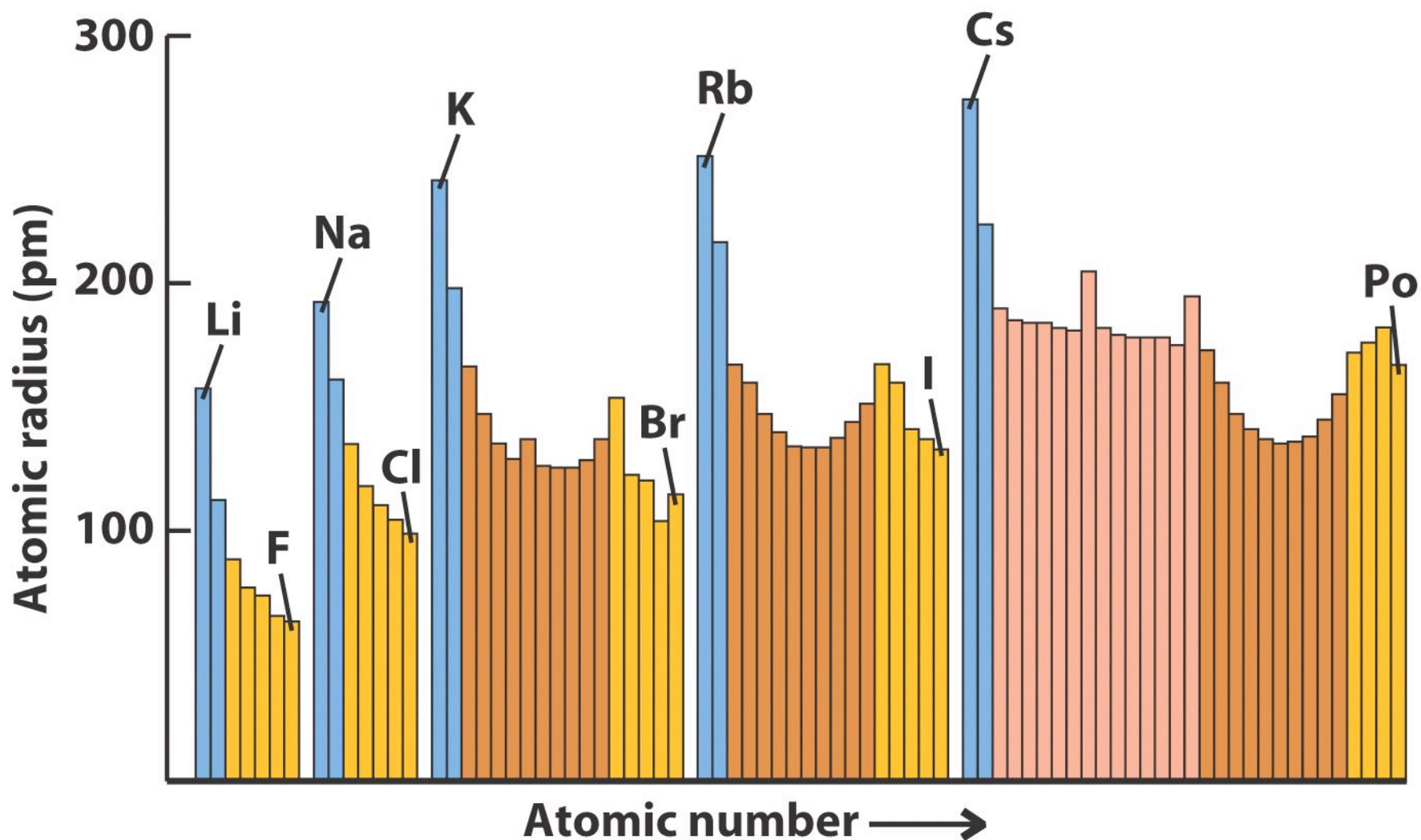
**Notes**

- Aluminium and caesium are commonly used English-language spellings for aluminium and caesium.
- IUPAC 2001 standard atomic weights (mean relative atomic masses) are listed with uncertainties in the last figure in parentheses [R. D. Loss, *Pure Appl. Chem.* **75**, 1107-1122 (2003)].
- These values correspond to current best knowledge of the elements in natural terrestrial sources. For elements with no IUPAC assigned standard value, the atomic mass (in unified atomic mass units) or the mass number of the nuclide with the longest known half-life is listed between square brackets.
- Element with atomic number 111 has not yet been named. The IUPAC provisional name is shown.
- Elements with atomic numbers 112, 114, and 116 have been reported but not fully authenticated.

# Substructure of the periodic table by properties



# *The periodic table by “sizes” (atomic radius ) of atoms*



## (3.2) Periodic Properties. Electronegativity.

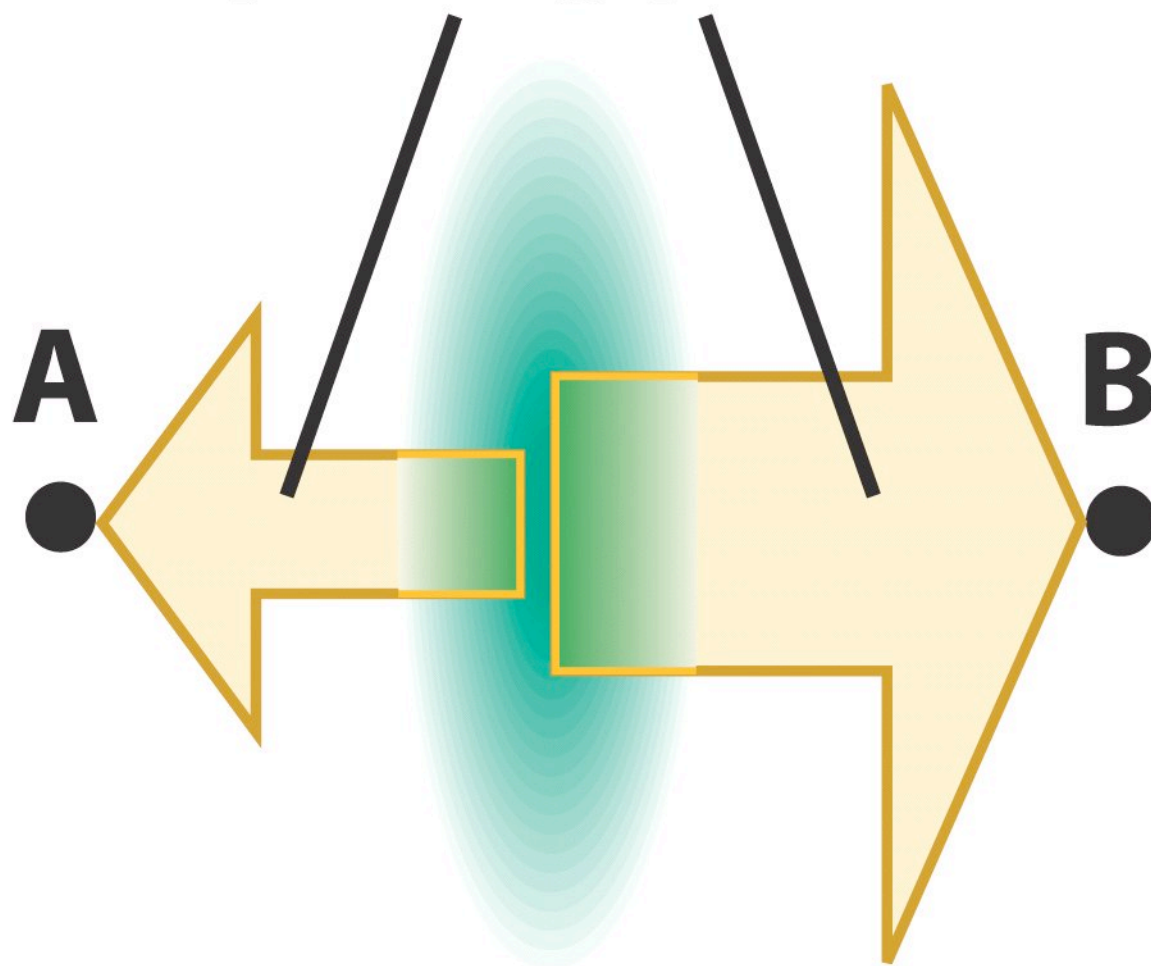
Two critical properties determining chemical reactivity are the energies involved in adding or removing an electron from an atom.

*Electronegativity is measure of the power of an atom to attract electrons to itself.*

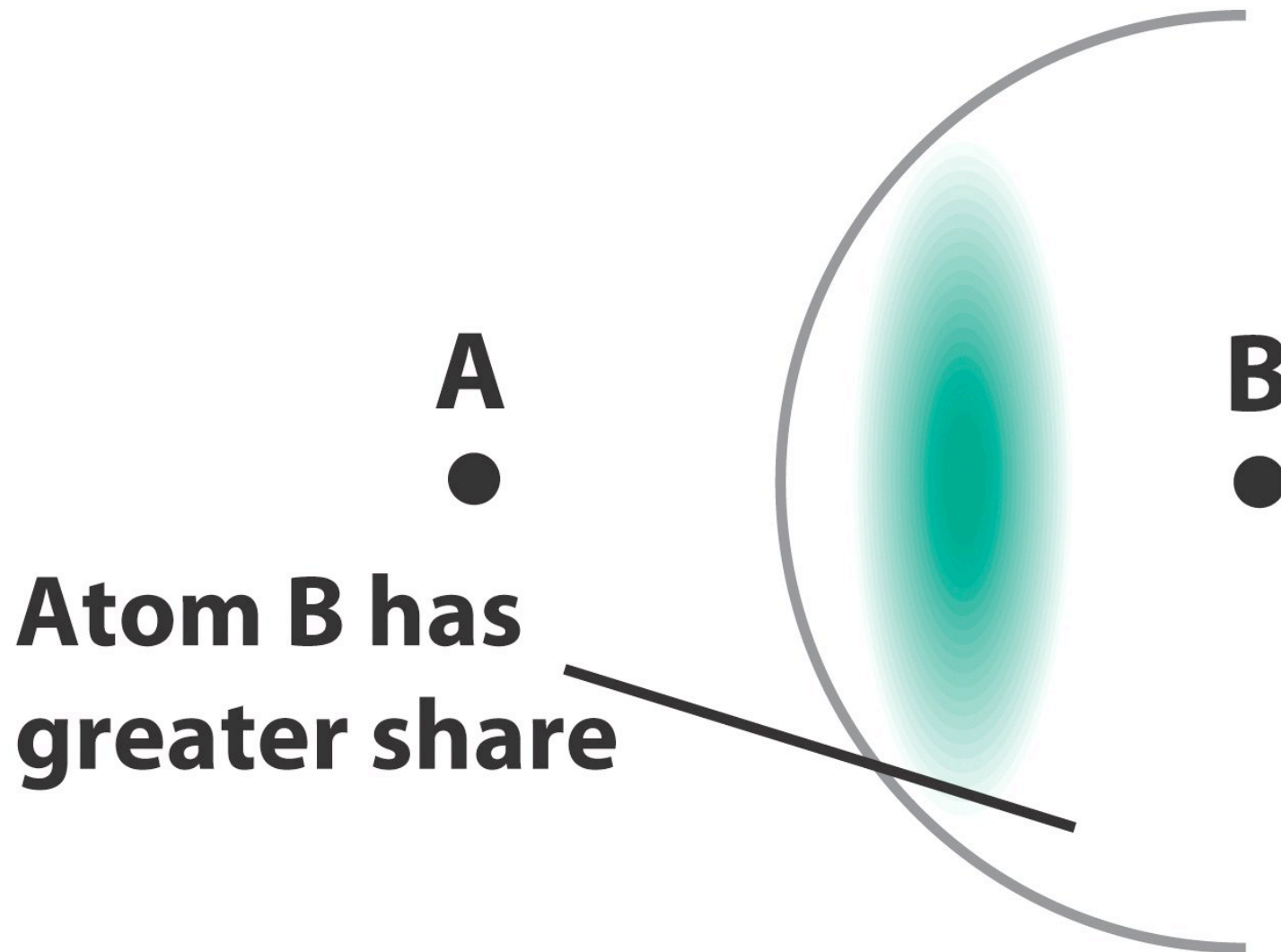
Metals: Low tendency to attract electrons, high tendency to release electrons.

Non-metals: High tendency to attract electrons, low tendency to release electrons.

# Relative pulling power of atom

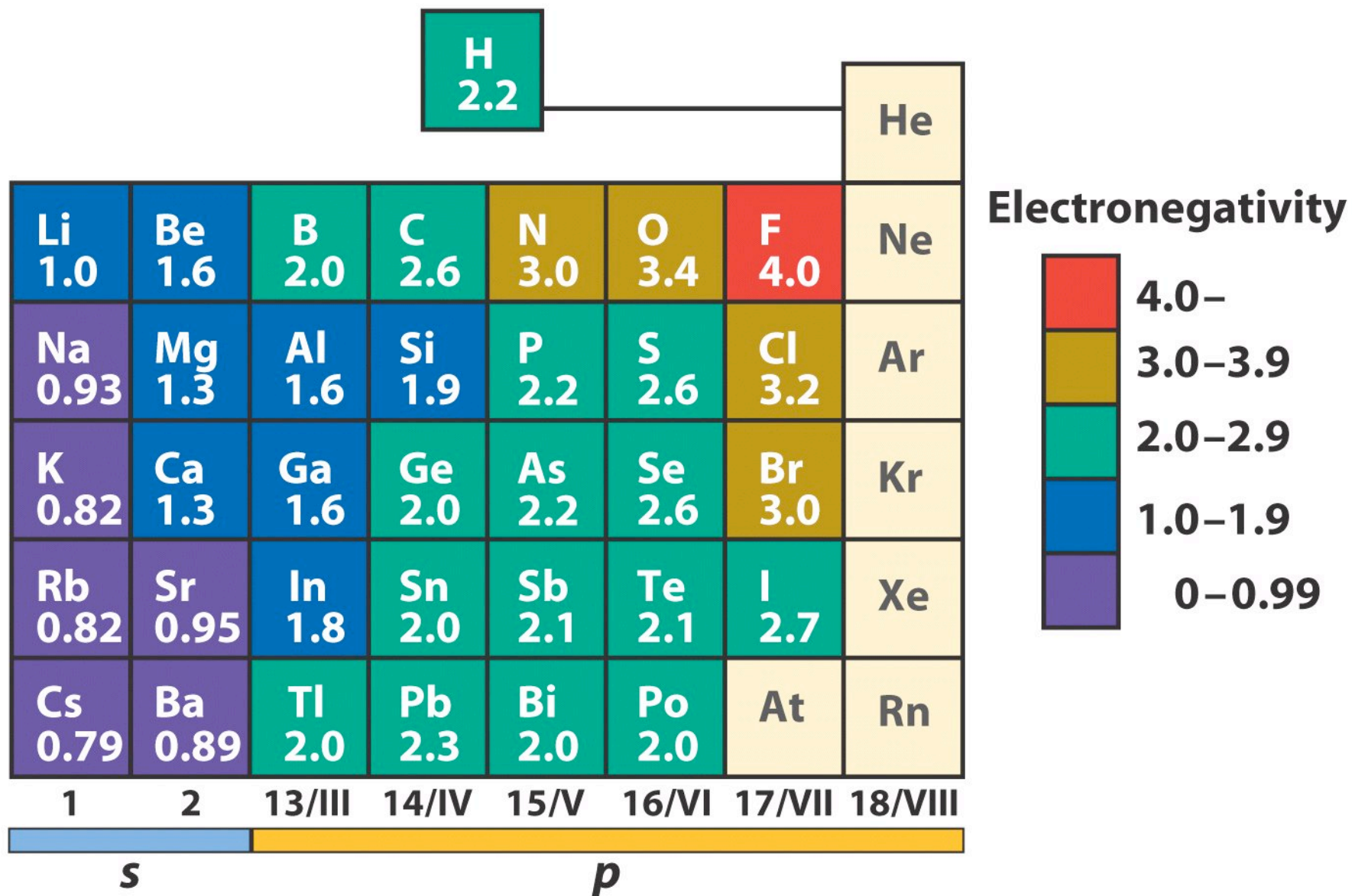


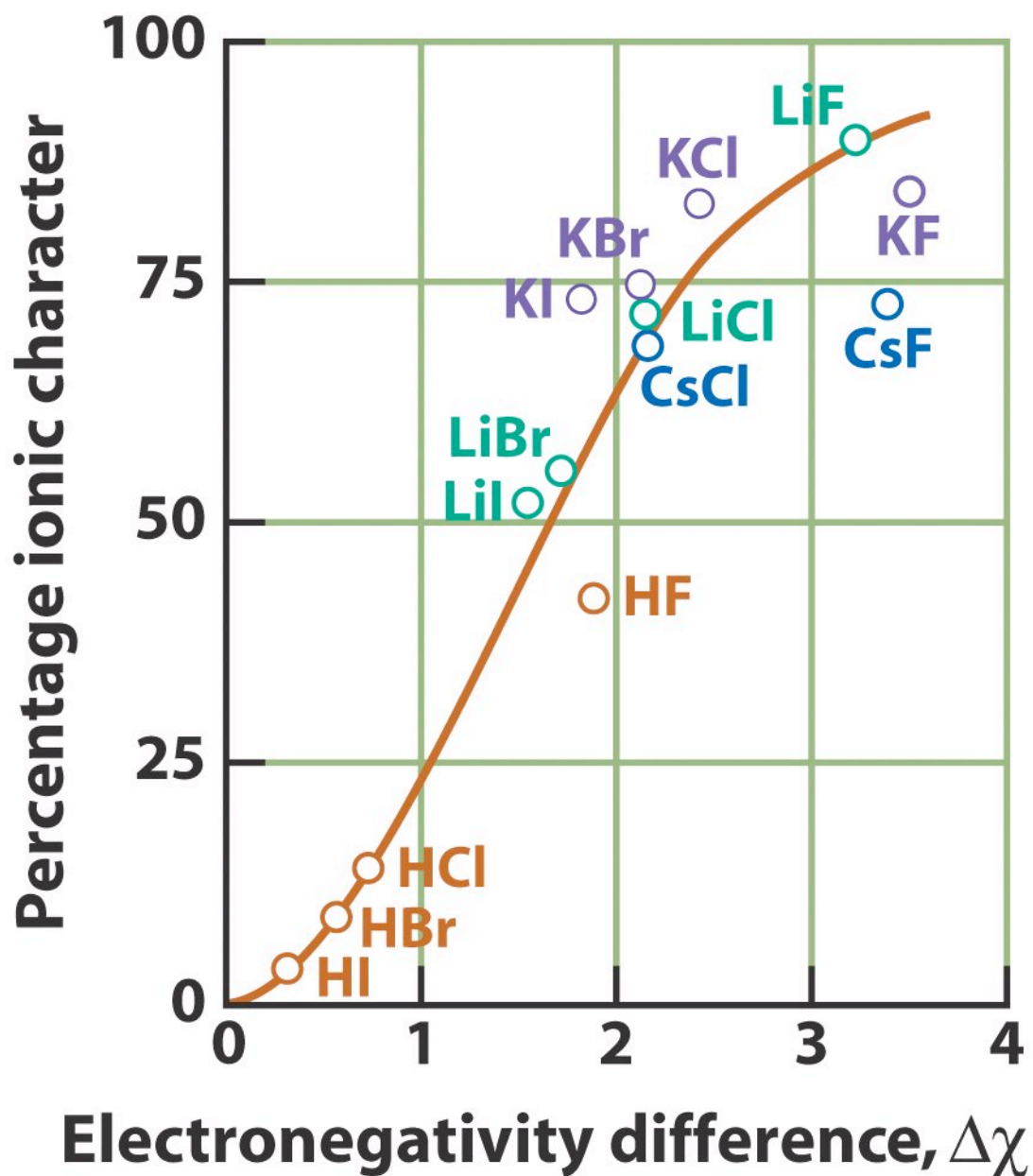
B has a bigger "pull" on the electrons in an A-B bond than A



Electrons are closer to the more electronegative atom B.

## The periodic table by electronegativity





Rule of thumb:  
 Binary compounds with an electronegativity difference of less than 1 are generally molecular; binary compounds with an electronegativity difference  $>2.0$  are generally ionic.

**Electronegativity** and **electron affinity** are two key features which determine the nature of the chemical bond.

**More later....**

**Chapter 16**

### 3.3 What is a fundamental model or theory that provides an understanding of the chemical and physical properties of substances?

#### Questions:

What determines chemical reactivity?

Why do certain substances react with some substances and not others?

Why do substances contain certain compositions ( $H_2$ ) and constitutions and not others ( $H_{15}$ )?

Why are some elements very reactive (K) and others totally inert (He)?

#### Answers:

Questions concerning chemical structure and reactivity are determined by the *electrons* of an atom or molecule.

Similarities in chemical and physical properties echo similarities in the organization of electrons around atoms.

## Understanding the basis behind the periodicity of the properties of the elements and exceptions to periodicity.

The underlying basis for the periodicity is due to the periodic recurring *electronic structure* of atoms, which in turn causes the similarities in the atomic properties and their correlation with atomic mass.

We need a theory and model to describe the electronic structure about atoms in order to understand the fundamental basis for the periodic table.

We start with the simplest theory of electronic structure of atoms and molecules: The Lewis theory.

























