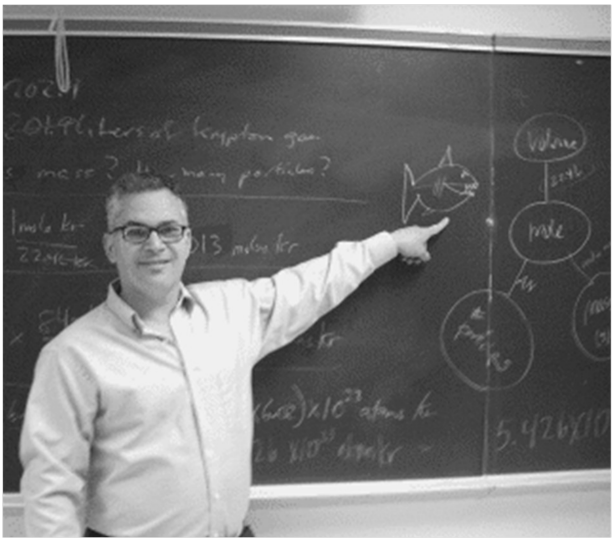
Moles and Percent Composition

Topic 4 in Regents Chem

Name: _____

MOLES & Percent Comp by Mass BASICS

MOLES



Any time that you get to draw a shark in chemistry class is a good day. Fishing is not one of my favorite "sports", but I do enjoy fishing at Wegmans for shark (and for salmon). This is your teacher in the fall of 2006, it's the first picture of me on the website!

There's the shark on the map how to do all of this math. It shows how moles are related to mass, volume, and to the number of particles.

The Mole is central to your understanding much more chemistry; you must work hard to truly grasp the significance of moles.

Avogadro's number sets the basic ratio between the mole and how many particles it is. Like a dozen is twelve, a mole is exactly 6.02×10^{23} particles. Particles can be atoms, or molecules, or even FU's.

Half of a dozen is six, and half of a mole is one half of Avogadro's Number, or 3.01×10^{23} particles. This relationship of moles to an exact number of particles allows us to mathematically connect masses of substances to the number of particles present.

Particles can be atoms if the substance exists as atoms, like the noble gases, or the metals. Sometimes particles can be FU's, or formula units - if the substance is an ionic compound. Particles can also be molecules - when if the substance is a molecular compound. Particles can even be ions, if you want to count how many ions are present in a substance. Having a mole of anything of "real" size is a problem. A mole of atoms is a huge number but they are so small. A mole of atoms is also pretty small.

Besides the "mole to number of particles" ratio, there is a special mass relationship between atoms on the periodic table and the concept of moles. If you look at your Periodic Table, and see that one atom of Helium has an atomic mass of 4.00260 amu (which we round to 4 amu), the mass of ONE MOLE OF HELIUM is 4.00260 grams, or 4 grams. An easy switcheroo.

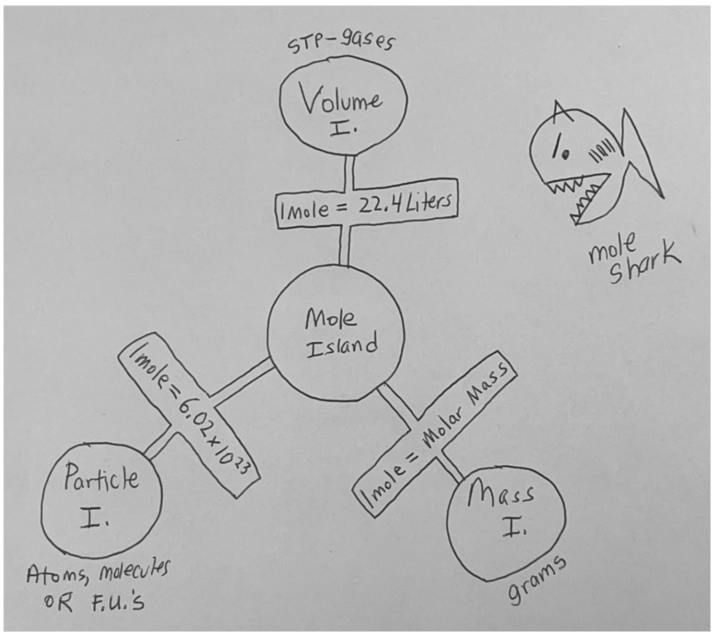
The units change between atoms (amu's) and moles (grams), but the periodic table provides the numbers. We can use these numbers to determine how many grams one mole of any element is, and to determine the MOLAR MASS of any compound (by just adding up individual atomic mole masses by the ratios of atoms in the compound - see below) Examples include

Particle	Formula	Atomic Mass	Molar Mass
niobium atom	Nb	93 amu	93 grams/mole
zinc atom	Zn	65 amu	65 grams/mole
sulfur atom	S	32 amu	32 grams/mole
silicon atom	Si	28 amu	28 grams/mole
sodium chloride	NaCl	(23 + 35 =) 58 amu	58 grams/mole
sodium hydroxide	NaOH	(23 + 16 + 1 =) 40 amu	40 grams/mole
glucose	$C_6H_{12}O_6$	(72 + 12 + 96 =) 180 amu	180 grams/mole

With gases, the mole to volume relationship is the "simplest" to connect. At standard temperature and pressure (zero centigrade and one atmosphere pressure), one mole of any gas is equal to 22.4 Liters of volume. In our class the gas parameters of pressure and temperature will be at STP until we study gases later in the year. So, the number to remember is 22.4 Liters. Examples include

gas	formula	math	volume at STP
1 mole of helium	He	1 x 22.4 L =	22.4 liters
2 mole of carbon dioxide	CO_2	2 x 22.4 L =	44.8 liters
3 moles of krypton	Kr	3 x 22.4 L =	67.2 liters
one half mole neon	Ne	0.5 x 22.4 L =	11.2 liters
1.0 mole nitrogen dioxide	NO_2	1.0 x 22.4 L =	22.4 liters
3.0 moles iodine gas	I_2	3.0 x 22.4 L =	67.2 liters

Mole Islands… The drawing below describes the mathematical connections between MOLES, with the "islands" that surround it. The only way to make your way from any island to another (to convert from one unit to another) is to take the ONLY BRIDGE available, and PAY THE TOLL (convert as indicated). Use the tolls to make your conversions. If you "cheat" and try to skip any conversions, the mole shark will eat you.



If you try to take a short cut, say from Liters to Mass, without going through Mole Island in the middle, the MOLE SHARK will eat you, and it won't be pretty. There are NO SHORT CUTS. That said, the biggest mole problem is just 2 conversions at most.

Mole Math Problems always start on one of these islands. You can start with a known number of grams, or a known number of particles, or a known number of liters of a gas. You could even start with a known number of moles. No matter what, you will do one or two conversions. Do the steps in the order that the bridges show you. If you ever skip a step, you're in the ocean and in danger!

Moles are central to chemistry and this diagram will help you keep it all straight. Everything can be converted to moles, moles can be converted to all other units you will ever need (or want!) It will require practice, and if you don't practice, it will become very apparent.

MOLAR MASS

By definition, how many grams exactly one mole of a substance weighs. If it is just an element, read the atomic mass on the periodic table, and change the "AMU" units to "GRAMS" instead. If it is a compound, write the PROPER FORMULA of the compound, and multiply the number of atoms by the proper atomic masses, and then add them all up. Units will be GRAMS PER MOLE.

Determine the MOLAR MASS of sodium Na	Put your finger into box 11 on the periodic table. Atomic mass is 23 AMU, so molar mass is 23 grams/mole
Determine the MOLAR MASS of sodium hydroxide NaOH It has 3 atoms, one each of sodium, oxygen, and hydrogen.	Molar Mass of NaOH Na - sodium 1 x 23 = 23 O - oxygen 1 x 16 = 16 H - hydrogen 1 x 1 = 1 sum = 40 grams/mole
Determine the MOLAR MASS of sulfur trioxide SO_3 It has 4 atoms, one sulfur, and 3 oxygen atoms.	Molar Mass of SO_3 S - sulfur 1 x 32 = 32 O - oxygen 3 x 16 = 48 sum = 80 grams/mole

Percent Composition by Mass

On the back of the reference table you see this formula:

Percent Composition by mass

$$\% \text{ composition by mass} = \frac{\text{Mass of part}}{\text{Mass of whole}} \times 100\%$$

% Composition by Mass

When you make a good fruit salad (I think) it should be big and include about five pounds of bananas, one pound of strawberries, three pounds of blueberries, one pound of ripe peaches, and two pounds of melon. A nice twelve pound fruit salad sounds just right to me.

If I asked you, what percent of the fruit salad is bananas, would you be able to figure that out?

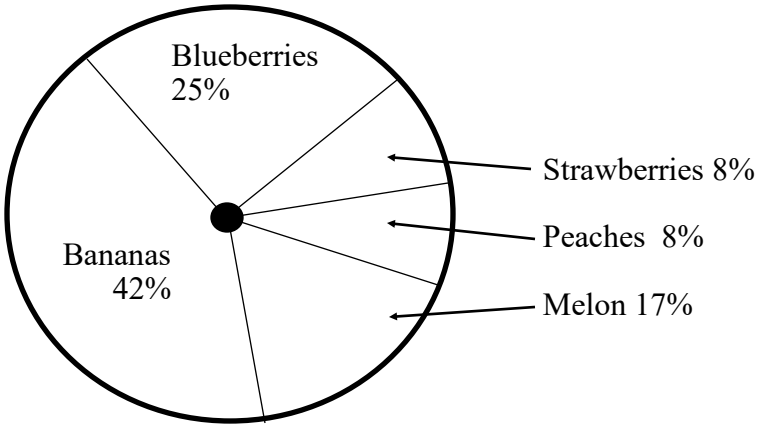
You would divide 5/12 and say it's 42% bananas.

The blueberries make up 3/12 pounds, so they make up 25% of this fruit salad.

1/12 of the salad is about 8%, so we can say that this fruit salad is 8% strawberries and 8% peaches.

Finally, the melon is 17% of the total salad.

That sums to 100% of the salad. Chemistry can be like making fruit salad (and doing math to it).



What is the percent composition by mass of magnesium in magnesium hydroxide? Do this…

$Mg(OH)_2$				% Comp			
Mg	1 x 24 g =	24 g		Mg	24/58	X 100% =	41.4%
O	2 x 16 g =	32 g		O	32/58	X 100% =	55.2%
H	2 x 1 g =	2 g		H	2/58	X 100% =	3.4%
		58 g/mole					100%

$Mg(OH)_2$ is 41.4% magnesium by mass. It's also 55.2% oxygen, and 3.4% hydrogen. Importantly, the sum of the three parts equals 100%, just like it should. Always do the whole problem, even if you are just asked for one part of the compound. Check yourself.

Another example… Find the % composition of chlorine in hydrogen monochloride (HCl).
First, do the MOLAR MASS on the left. Then do the percent comp by mass on the right side.

HCl				% Comp			
H	1 x 1 g =	1 g		H	1/36	X 100% =	2.8%
Cl	1 x 35 g =	35 g		Cl	35/36	X 100% =	97.2%
		36 g/mole					100%

HCl is only 2.8% hydrogen, and 97.2% chlorine by mass.

Another kind of problem…. If you have 50.0 grams of HCl, how many grams would be chlorine?

50.0 grams HCl X 0.972 = 48.6 grams is chlorine [97.2% = 0.972 AS A DECIMAL]

and

50.0 grams HCl X 0.028 = 1.4 grams hydrogen [2.8% = 0.028 AS A DECIMAL]

check: 48.6 g + 1.4 g = 50.0 grams total.

And Another example…

If you have 312 grams of HCl, how many grams would be chlorine?

312 grams HCl X 0.972 = 303.26 grams

312 grams HCl X 0.028 = 8.74 grams 303.26 + 8.74 = 312.00 grams (the whole amount, of course!)

For HCl, the proportions (the percent comp by mass) are constant.
No matter how much HCl that you have, HCl, it's always 97.2% chlorine and 2.8% hydrogen— by mass.

EMPIRICAL FORMULAS

An empirical formula is a math concept more than a chemistry one. It really is the lowest ratio of atoms or ions that make up a formula.

You are familiar with glucose, $C_6H_{12}O_6$, and the ratio of atoms in that is of course 6:12:6, which can be reduced to 1:2:1.

The EMPIRICAL FORMULA for glucose is just CH_2O.

The ratio has NOTHING to do with high school chemistry, density, molar mass, etc.

It is a way to categorize groups of compounds, and to make you think.

Formulas	Empirical Formulas
$C_5H_{10}O_5$	CH_2O
C_2H_2	CH
C_4H_{10}	C_2H_5
C_8H_{18}	C_4H_9
$MgSO_4$	$MgSO_4$ (this formula cannot be reduced to a lower ratio)
H_2O	H_2O (this formula cannot be reduced to a lower ratio)
CH_4	CH_4 (this formula cannot be reduced to a lower ratio)
$C_{44}H_{88}O_{44}$	CH_2O

Empirical formulas are about the LOWEST RATIO.

Often the "lowest ratio formula", such as C_4H_9, is not even a real compound.
If it could bond into a real compound, it certainly is not the compound you started with.

An EMPIRICAL FORMULA is more an IDEA than a real thing. Sometimes Empirical Formulas are the same as the formula of the real compounds, like with magnesium sulfate, water, or methane gas. This is nutty.

The last example shows that no matter how big the numbers, the lowest ratio makes the empirical formula. Note that the first and last compounds have the same empirical formulas. They are NOT the same compound, nor do they have the same properties.

Types of mole problems… (answers on next page)

There's a limited number of kinds of mole problems. Using your mole island map, do them now.

Problems for practice. Answers below in order.

1. How many grams are in 1.0 moles of $NaHCO_3$, which is baking soda?
2. How many moles are in 25.0 grams of baking soda?
3. How many moles is 145.6 liters of helium gas at STP?
4. If you have 2.75 moles of CO_2 gas, how many liters does it take up at STP?
5. If you have 2.75 moles of CO_2 gas, how many particles is that?
6. If you have 3.50×10^{27} atoms of neon gas, how many moles is that?
7. If you have 175 grams $Cl_{2(G)}$, how many molecules AND how many liters does it take up at STP?

1 The molar mass of $NaHCO_3$, sodium hydrogen carbonate is 84 g/mol.

2 $\frac{25.0 \text{ g baking soda}}{1} \times \frac{1 \text{ mole baking soda}}{84 \text{ g baking soda}} = 0.298 \text{ moles baking soda}$

3 $\frac{145.6 \text{ liters He}}{1} \times \frac{1 \text{ mole He}}{22.4 \text{ liters He}} = 6.50 \text{ moles He}$

4 $\frac{2.75 \text{ moles } CO_2}{1} \times \frac{22.4 \text{ liters } CO_2}{1 \text{ mole } CO_2} = 61.6 \text{ liters } CO_2$

5 $\frac{2.75 \text{ moles } CO_2}{1} \times \frac{6.02 \times 10^{23} \text{ molecules } CO_2}{1 \text{ mole } CO_2} = 16.555 \times 10^{23}$ changes to

$= 1.66 \times 10^{24}$ molecules CO_2

6 $\frac{3.50 \times 10^{27} \text{ atoms Ne}}{1} \times \frac{1 \text{ mole Ne}}{6.02 \times 10^{23} \text{ atoms Ne}} = \frac{3.50}{6.02} \times \frac{10^{27}}{10^{23}} = 0.581 \times 10^4$ changes to

$= 5.81 \times 10^3$ moles Neon

7 $\frac{175 \text{ grams } Cl_2}{1} \times \frac{1 \text{ mole } Cl_2}{70 \text{ grams } Cl_2} = 2.50 \text{ moles } Cl_2$ go to the next line

Now change those moles of chlorine into molecules. A different conversion here.

$\frac{2.50 \text{ moles } Cl_2}{1} \times \frac{22.4 \text{ liters } Cl_2}{1 \text{ mole } Cl_2} = 56.0 \text{ liters } Cl_2$

$\frac{2.50 \text{ moles } Cl_2}{1} \times \frac{6.02 \times 10^{23} \text{ molecules } Cl_2}{1 \text{ mole } Cl_2} = 15.05 \times 10^{23} \text{ molecules } Cl_2$

$= 1.51 \times 10^{24}$ molecules Cl_2

Moles and Percent Composition by Mass Notes

1. A mole is a certain _____

   You could have a mole of _____

2. A mole is _____ of things. That is _____

3. _____ is called Avogadro's Number, it is named for _____

4. How many atoms are in one mole of mercury? _____ atoms

5. How many atoms are in 0.50 mole of carbon? _____ atoms

6. One atom of Hg has a weighted average mass of _____ amu from the periodic table.

7. In our class we'd round that to this nearest whole number: _____

8. 1 mole, or: 6.02×10^{23} atoms of mercury has mass of _____

9. Determine the mass of… 1.0 mole of carbon = _____

   2.0 moles of aluminum _____ 4.0 moles of helium _____

   0.50 moles magnesium _____

10. What's the mass of 1.0 mole of oxygen gas? _____

11. The HONClBrIF Twins need special attention. The molar mass in grams for each is:

H_2 ____ g O_2 ____ g N_2 ____ g Cl_2 ____ g

Br_2 ____ g I_2 ____ g F_2 ____ g

12. What is the mass of one mole of magnesium oxide? (we'll figure this out soon)
12b. I could also have asked you, what is the molar mass of magnesium oxide? (that means the same thing)

14. _____ of a substance = it's _____. That's vocabulary.

15. MgO

MgO has a molar mass = _____ or _____ = _____

16. An important note about the HONClBrIF Twins, when bonded into a compound, like MgO, or as CO carbon monoxide…

_____in these compounds.

17. CCl_2 Determine the molar mass of carbon dichloride.

18. What is the mass of 2.70 moles of sulfur? (do what's below first)

19. The molar mass of sulfur is: _____

20. Which means, one mole sulfur = _____ grams of sulfur (Now do #18 below)

21. What is the mass of 0.356 moles of lead?

21b. What's her name? _____

22. What is the mass of 6.15 moles of boron?

Mole class #2

Calculating Molar Masses, and numbers of atoms in any mass of an element or compound

23. What's the name of $Al(MnO_4)_3$? _____

24. What is the Molar Mass for this compound?

$Al(MnO_4)_3$

25A+B. NYS Regents likes vocabulary. Instead of always saying molar mass, like they could, sometimes they like to use extra words like…

Gram Molecular Mass = molar mass of _____

Or

Gram Formula Mass = molar mass of _____

26. What is the molar mass of 1-octanol?

$C_8H_{16}OH$

(one mole of this = _____ molecules $C_8H_{16}OH$)

27. Calculate the gram formula mass (molar mass) of sodium sulfate. (write formula correctly first)

_____

28. If you have 183.2 g of sodium sulfate, how many moles do you have?

29. How many moles of gold is 551 grams of gold?

30. How many moles of silicon is 37.33 grams of silicon?

31. How many moles of zinc are in 1.25×10^{23} atoms of zinc?

32. How many moles of xenon gas are in 8.75×10^{24} atoms of Xe?

33. If you find 50.0 grams of pure silver, how many atoms of silver did you find? (two steps!)

Mole Class #3 Objective: _____

Review

34. One mole = _____

One mole = _____

NEW

35. One Mole ALSO = _____*

* _____

36. (MAP) don't draw ahead, listen first.

37. How many liters of neon gas are in 65.3 grams of neon? (first we look at the map and make a plan)

38. You win exactly 3.58×10^{24} atoms of aluminum in a contest. How many grams did you win? (fun prize!)

39. You find a canister labeled "exactly" 7.99×10^{25} molecules of carbon dioxide gas (CO_2).
What is the mass of this gas?

Objective: introduction to the idea of percent composition by mass. THINK:
If a tart is 100% blueberries, the mass is 100% blueberries.
If a tart has 16 ounces of fruit, and 8 are strawberries, 3 are blueberry and 5 are kiwi, there's a math problem!
Strawberries are 8/16 of the whole amount of fruit, the strawberries make up _____ % of the fruit by mass.
The blueberries are 3/16 of the whole amount of fruit, the blueberries make up _____ % of the fruit by mass.
The kiwi makes up 5/16 of the ounces of fruit. They make up _____ % of the fruit's total mass.

40. How do we determine the percent composition by mass of hydrogen and oxygen in water?

H_2O % Comp

41. What's the percent composition by mass of sodium and chlorine in sodium chloride?

NaCl % Comp

42. What's the percent composition by mass for Copper (II) sulfate?

$CuSO_4$ % Comp

43. So, imagine that you have a pocketful of this copper (II) sulfate, say, 86.5 grams. That's just more than a pound. How many grams of your pocketful of crystals is just copper? Or oxygen? Or sulfur?

86.5 g x _____ copper = _____ grams copper by mass

86.5 g x _____ sulfur = _____ grams sulfur

86.5 g x _____ oxygen = _____ grams oxygen by mass

44. There are 2 atoms of hydrogen for every one atom of oxygen. Why is the percent comp by mass so low for hydrogen? Shouldn't this be higher?

_____

45. You fill up a water balloon to 275 mL. (275 mL = 275 g). How many of those grams are just oxygen?

Water is always 89% oxygen, so: 275 g water X _____ = _____ g oxygen
(disregarding SF here, this is conceptual)

46. What's the % composition by mass of aluminum in aluminum hydroxide monohydrate?

_____

47. You find a box with a bar of metal that has stamped into it *PURE GOLD*.
The bar weighs 324.8 grams EXACTLY. How many atoms of gold do you have?

48. If you have 64.35 g of sodium hydroxide, how many grams of those are oxygen?

49. Calculate the mass of the neon in the balloon of 346 liters.

50. Empirical Formulas are _____. They are written like chemical formulas to confuse you.

51. The empirical formula of octane, or: C_8H_{18} is _____

52. $C4H_9$ _____

53. CHEMICAL FORMULAS	Ratio then reduced ratio	EMPIRICAL FORMULAS
C_6H_{14} (hexane)	6:14 → 3:7	C_3H_7
$C_6H_{12}H_6$ (glucose)		
$C_{24}H_{48}$ (candle wax)		
C_2H_2 (acetylene gas)		
H_2O_2 (hydrogen peroxide)		
C_6H_6 (cyclohexene)		
$C_{10}H_{22}$ (decane)		
C_5H_{10} (pentene)		
$C_5H_{10}O_5$ (pentose)		
H_2O (water)	"already reduced"	
CH_4 (methane)	"already reduced"	
CO_2 (carbon dioxide)	"already reduced"	

54. If you find 131.25 moles of silver, it is selling for about $1.05 gram, are you rich or just happy?

The slide show continues for you to review. Finish up these problems, and bring back any issues you had in trying to figure them out. Try hard, but feel free to ask questions. Skipping them would be a foolish choice. Do these, I beseech you.

55. Convert 4.87×10^{24} formula units of sodium chloride to grams.

56. You have 125 grams of carbon dioxide gas in a balloon at STP. What is its volume in liters?

57. If you happen to have 888 g of copper (II) sulfate, how many FU's Cu do you have?

58. You have 67.2 g of water, how many of those grams are just hydrogen?

59. What is the percent composition by mass of nickel in the compound nickel (II) carbonate?

60. What are the empirical formulas for the following compounds?

COMPOUND NAME	CHEMICAL FORMULA	EMPIRICAL FORMULA
paraffin wax	$C_{26}H_{54}$	
ethene	C_2H_4	
decene	$C_{10}H_{20}$	
sucrose	$C_{12}H_{22}O_{11}$	
heptane	C_7H_{16}	
hydrogen monochloride		
potassium sulfite		
cobalt (II) phosphate		

61. How many electrons in a Mg^{+2} cation? Many will choose 12 e^- _____

62. How many electrons in the following species?

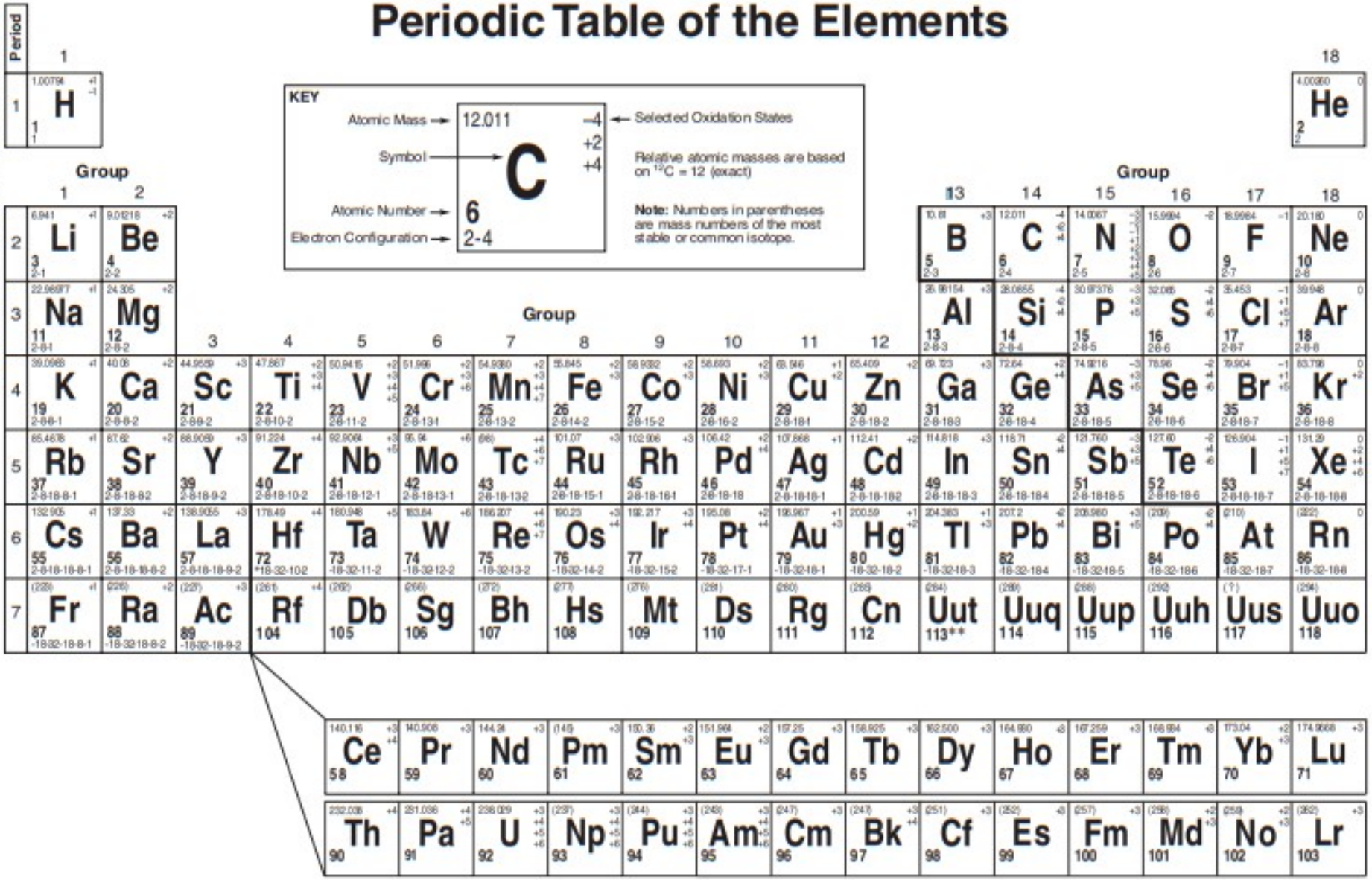
Al^{+3}	Al	Co^{+3}	Co^{+2}
Pb^{+2}	Pb^{+4}	F^{-1}	S^{-2}
N^{-3}	Au^{+1}	Au^{+3}	Cu
Cl^{-1}	Fe	Na^{+1}	Mn^{+7}

1	H	Hydrogen
2	He	Helium
3	Li	Lithium
4	Be	Beryllium
5	B	Boron
6	C	Carbon
7	N	Nitrogen
8	O	Oxygen
9	F	Fluorine
10	Ne	Neon
11	Na	Sodium
12	Mg	Magnesium
13	Al	Aluminum
14	Si	Silicon
15	P	Phosphorous
16	S	Sulfur
17	Cl	Chlorine
18	Ar	Argon
19	K	Potassium
20	Ca	Calcium
21	Sc	Scandium
22	Ti	Titanium
23	V	Vanadium
24	Cr	Chromium
25	Mn	Manganese
26	Fe	Iron
27	Co	Cobalt
28	Ni	Nickel
29	Cu	Copper
30	Zn	Zinc
31	Ga	Gallium
32	Ge	Germanium
33	As	Arsenic
34	Se	Selenium
35	Br	Bromine
36	Kr	Krypton
37	Rb	Rubidium
38	Sr	Strontium
39	Y	Yttrium
40	Zr	Zirconium

41	Nb	Niobium
42	Mo	Molybdenum
43	Tc	Technetium
44	Ru	Ruthenium
45	Rh	Rhodium
46	Pd	Palladium
47	Ag	Silver
48	Cd	Cadmium
49	In	Indium
50	Sn	Tin
51	Sb	Antimony
52	Te	Tellurium
53	I	Iodine
54	Xe	Xenon
55	Cs	Cesium
56	Ba	Barium
57	La	Lanthanum
58	Ce	Cerium
59	Pr	Praseodymium
60	Nd	Neodymium
61	Pm	Promethium
62	Sm	Samarium
63	Eu	Europium
64	Gd	Gadolinium
65	Tb	Terbium
66	Dy	Dysprosium
67	Ho	Holmium
68	Er	Erbium
69	Tm	Thulium
70	Yb	Ytterbium
71	Lu	Lutetium
72	Hf	Hafnium
73	Ta	Tantalum
74	W	Tungsten
75	Re	Rhenium
76	Os	Osmium
77	Ir	Iridium
78	Pt	Platinum
79	Au	Gold
80	Hg	Mercury

81	Tl	Thallium
82	Pb	Lead
83	Bi	Bismuth
84	Po	Polonium
85	At	Astatine
86	Rn	Radon
87	Fr	Francium
88	Ra	Radium
89	Ac	Actinium
90	Th	Thorium
91	Pa	Protactinium
92	U	Uranium
93	Np	Neptunium
94	Pu	Plutonium
95	Am	Americium
96	Cm	Curium
97	Bk	Berkelium
98	Cf	Californium
99	Es	Einsteinium
100	Fm	Fermium
101	Md	Mendelevium
102	No	Nobelium
103	Lr	Lawrencium
104	Rf	Rutherfordium
105	Db	Dubnium
106	Sg	Seaborgium
107	Bh	Bohrium
108	Hs	Hassium
109	Mt	Meitnerium
110	Ds	Darmastadtium
111	Rg	Roentgenium
112	Cn	Copernicium
113	Nh	Nihonium
114	Fl	Flerovium
115	Mc	Muscovium
116	Lv	Livermorium
117	Ts	Tennessine
118	Og	Organesson

Periodic Table of the Elements



*denotes the presence of (2-8-) for elements 72 and above

**The systematic names and symbols for elements of atomic numbers 113 and above will be used until the approval of trivial names by IUPAC.

Source: *CRC Handbook of Chemistry and Physics*, 91st ed., 2010–2011, CRC Press