Moles and Percent Composition

MOLES & Percent Comp by Mass BASICS

MOLES

Any day 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 salmon).

This is your teacher in the fall of 2006, it's the first picture of me on the website!

There's a shark on the map to remind you of 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 chemistry.

A mole is equal to a certain number of things.
A mole is also equal to a certain mass of whatever substance you are working with.
And a mole is equal to a certain volume of gas (at normal conditions).

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

Particles can be atoms if the substance exists as atoms, like the noble gases, or metals. Sometimes particles can be FU's, or formula units - if the substance is an ionic compound like NaCl. Particles can also be molecules - when if the substance is a molecular compound like CO_2.

A mole of atoms is also pretty small. A mole of hardboiled eggs is bigger than the Earth.

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 switch of the units, no math required.

Atomic mass is the mass of atoms (or other particles) in AMU's. The same number of grams is the MOLAR MASS. The units change between atoms (amu's) and moles (grams), but the numbers from periodic table stay the same.

Particle	Formula	Atomic Mass (mass per particle)	Molar Mass (mass of one mole)
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

With gases, the mole to volume relationship is a simple relationship. At normal science conditions, called the standard temperature and pressure (STP = 0°C and 1 atm of pressure) a mole of any gas is equal to 22.4 Liters in 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
1.00 mole of helium	He	1 x 22.4 L =	22.4 liters
2.00 moles of carbon dioxide	CO_2	2 x 22.4 L =	44.8 liters
3.00 moles of krypton	Kr	3 x 22.4 L =	67.2 liters
0.500 mole neon	Ne	0.5 x 22.4 L =	11.2 liters
1.00 mole nitrogen dioxide	NO_2	1.0 x 22.4 L =	22.4 liters
3.00 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 one 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

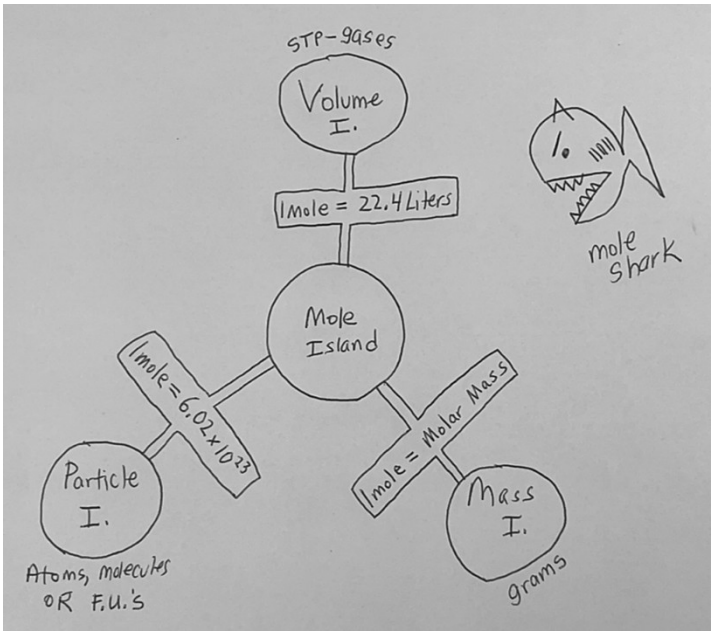
Any short cuts, say from Liters to Mass, without going through Mole Island, the MOLE SHARK will eat you, and it won't be pretty.

There are NO SHORT CUTS. That said, the biggest mole is just 2 conversions.

Mole Math Problems always start on one of the islands. You can start with a known number of grams, or a known number of particles, or a known number of liters of gas.

You could even start with a known number of moles.

No matter what, you will do one or two conversions. Do these 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. Mass, Volume, and numbers of Particles can all be converted to moles, moles can be converted to all these units. This math is complicated, and you will need to practice. If you don't, it will become very apparent.

MOLAR MASS

Means how many grams one mole of a substance is. With elements, use your periodic table to determine the mass. Atomic mass is in AMU, molar mass is that same number in grams.

If it is a compound, write the 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 = 23 AMU molar mass = 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 1 x 23 = 23 O 1 x 16 = 16 H 1 x 1 = 1 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 1 x 32 = 32 O 3 x 16 = 48 80 grams/mole

Percent Composition by Mass

On the back page of the reference tables, find this formula:

Percent Composition by mass

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

% 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 big twelve-pound fruit salad sounds just right to me.

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

You would divide 5/12 then X 100% = and say this salad is 42% bananas.

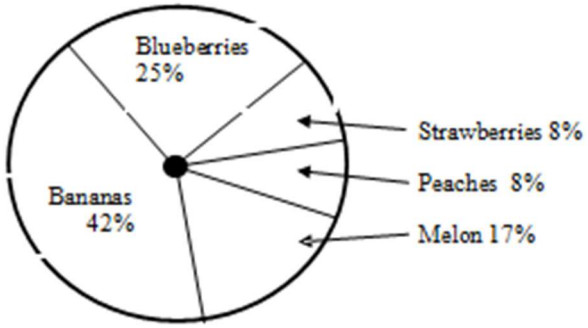
The blueberries make up 3/12 pounds X 100% = , blueberries make up 25% of this fruit salad.

1/12 X 100% = 8% (strawberries)

1/12 X 100% = 8% (peaches)

The melon is 2/12 X 100% =17% of the total fruit salad.

That sums up to 100% of the salad.
Chemistry can be like making fruit salad.



What is the percent composition by mass of magnesium in magnesium hydroxide? Molar mass first, on the left side of the page, then do the percent comp by mass on the right side.

$Mg(OH)_2$			% 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, the mass is always 97.2% chlorine and 2.8% hydrogen.

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, $C_6H_{12}O_6$, 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.

Empirical formulas are about the LOWEST RATIO.

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 cannot be reduced to a lower ratio)
H_2O	H_2O (this cannot be reduced to a lower ratio)
CH_4	CH_4 (this cannot be reduced to a lower ratio)
$C_{44}H_{88}O_{44}$	CH_2O

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 your practice. Answers them in order.

1. How many grams are in 1.0 moles of $NaHCO_3$, which is baking soda?

2. How many moles are 25.0 grams of baking soda?

3. How many moles are 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 do you have?

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 = 84 g/mol.

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

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

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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

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

$= 5.81 \times 10^3$ moles Neon

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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

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

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

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

Moles & Percent Composition by Mass Notes

1. A mole is a certain _____

You could have a mole of _____

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

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

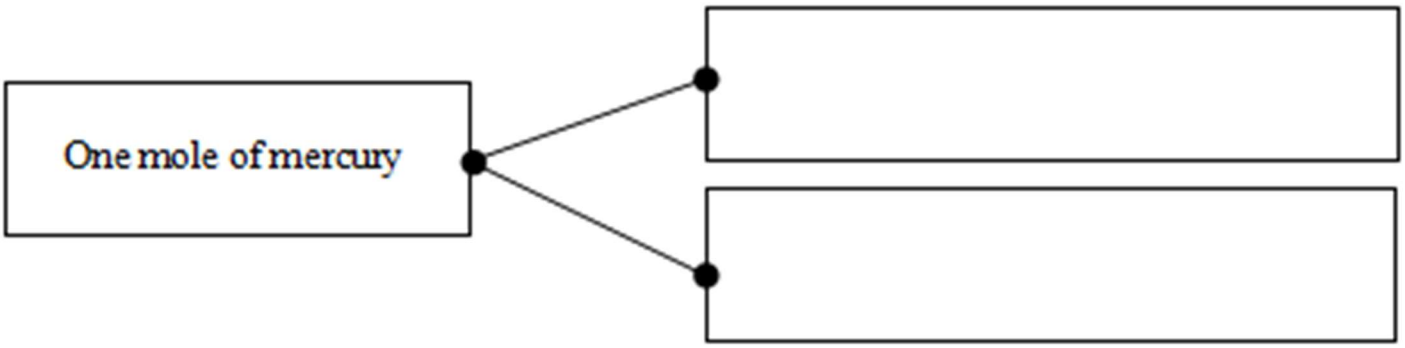
4. How many atoms are in one mole of mercury? _____ atoms = 1 mole of Hg

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

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: _____

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



9	Molar mass	If you had…	The total mass would be…
Carbon	g/mole	1.0 mole	grams
Aluminum	g/mole	2.0 moles	grams
Helium	g/mole	3.0 moles	grams
Magnesium	g/mole	0.5 moles	grams
Iron	g/mole	2.50 moles	grams
Oxygen	g/mole	1.0 moles	grams
Fluorine	g/mole	2.0 moles	grams

10	The HONClBrIF twins, the diatomic elements, need special attention		
Twins	Formula	Two x amu in grams	Molar Mass
Hydrogen	H_2	2 x 1 g =	2 g/mole
Oxygen			g/mole
Nitrogen			g/mole
Chlorine			g/mole
Bromine			g/mole
Iodine			g/mole
Fluorine			g/mole

11. _____ of a substance = its _____

12. Calculate the molar mass of carbon dioxide.

$\underline{CO_2}$

C

O _____

Do not use this space

13. Skip

14. We say CO_2 has a molar mass = _____ or

_____ = _____

15. Calculate the molar mass of Iron (III) nitrate. write out the ions here: _____

_____

_____

Do not use this space

16.

17. What is the mass of 2.70 moles of sulfur? _____ (We'll get back to this soon, keep going!)

18. First turn the molar mass of sulfur into an equality. The molar mass of sulfur is _____

19. As an equality, this means: _____

20. What is the mass of 2.70 moles of sulfur?

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

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

end for today

Mole Class #2

Calculating Molar Masses, and how many atoms or molecules are in any mass of a compound or element.

What's the molar mass of aluminum permanganate? write ions here: _____

_____

Al

Mn

O

_____

Do not use this space

24. Define:

gram molecular mass

gram formula mass

25. What is the molar mass of octanol? formula: _____

_____

C

H

O

H

_____

Do not use this space

26. Calculate the gram formula mass (molar mass) of sodium sulfate.

_____

Na

S

O

_____

Do not use this space

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

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

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

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

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

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

Mole Class #3 Objective:

You know this…

33. One mole = _____

One mole = _____

This is new…

34. One Mole of any gas = _____at STP

STP is standard temperature and standard pressure, which means…

35. Mole Map - don't draw yet, listen first.

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

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

38. What is the mass of 7.99×10^{25} molecules of CO_2?

Percent Composition by Mass Class #1

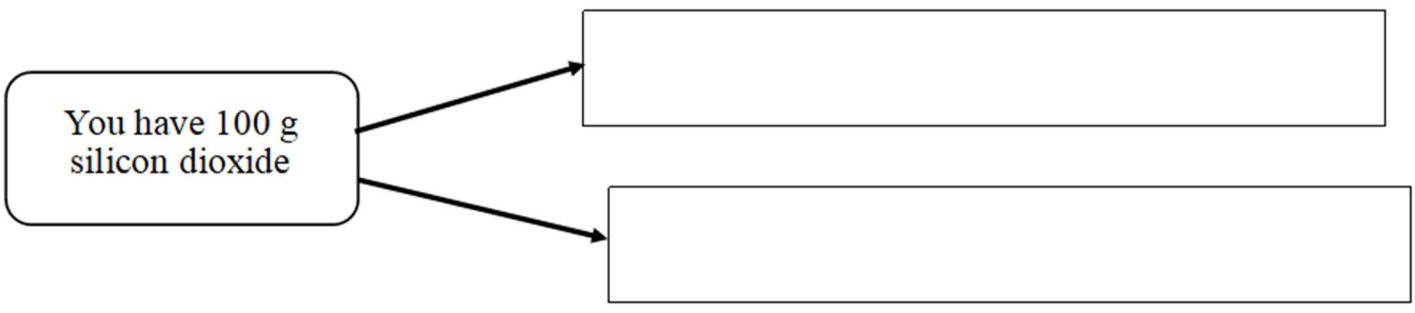
Objective: introduction to the mathematics of percent composition by mass. THINK:

Fancy Tart Recipe 12 oz. strawberries 6 oz blueberries 4 oz of raspberries 2 oz kiwi _____ 24 ounces total		Strawberries make up 50% of the fruit by mass. Blueberries make up 25% of the fruit by mass. Raspberries make up 17% of the fruit by mass. Kiwi make up 8% of the fruit by mass. That's a total of 100% of the fruit (duh!)

39. What is the percent composition by mass of silicon and oxygen in silicon dioxide?

Molar mass	Percent comp by mass
_____ Si O _____	_____ Si O _____

40. Silicon dioxide is _____ silicon, and _____ oxygen. So, for example…



41. What's the percent composition by mass of calcium & chlorine in calcium chloride? Ions: _____

_____	Percent comp by mass
Ca	Ca
Cl	Cl
_____	_____

42. What is the percent composition by mass for Cobalt (III) nitrate?

_____	Percent comp by mass
Co	Co
N	N
O	O
_____	_____

43. So, imagine that you have a hunk of this cobalt (III) nitrate, say 186 grams, in your pocket. That's less than a half-pound. How many of those 185 grams are cobalt? How many of them are nitrogen? And how many of those 185 grams are oxygen?

Cobalt	186 grams	X	=	grams
Nitrogen	186 grams	X	=	grams
Oxygen	186 grams	X	=	grams
			%	grams

44. You blow up a balloon. It has mass of 64.0 grams.

45. How many grams are just carbon? Just oxygen?

_____

C

O

_____

Percent comp by mass

C

O

_____

Carbon	64.0 grams	X	=	
Oxygen	64.0 grams	X	=	
			%	g

46. What is the percent comp by mass of aluminum in aluminum hydroxide monohydrate? (3 SF here)

_____	Percent comp by mass
Al	Al
O	O
H	H
H_2O	H_2O
_____	_____

47. You find a box with a bar of metal that is stamped *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 helium in a balloon of 346 liters at STP.

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

51. The molecular formula of octane is _____ The empirical formula of octane is _____

52. C_4H_9 _____

53. CHEMICAL FORMULAS	Ratio can be reduced	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 8.251 moles of platinum, and is selling for $32.67 per gram, are you rich or just happy?

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

56. You have 125 g of $CO_{2(G)}$ at STP. What's the volume of the ballon in liters?

57. If you happen to have 325 g of titanium (II) sulfate, how many FU's are present?

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

59. What is the percent comp by mass of nickel in the compound nickel (II) carbonate?
How many grams of nickel are present in 235. g of $NiCO_3$?

60. 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		

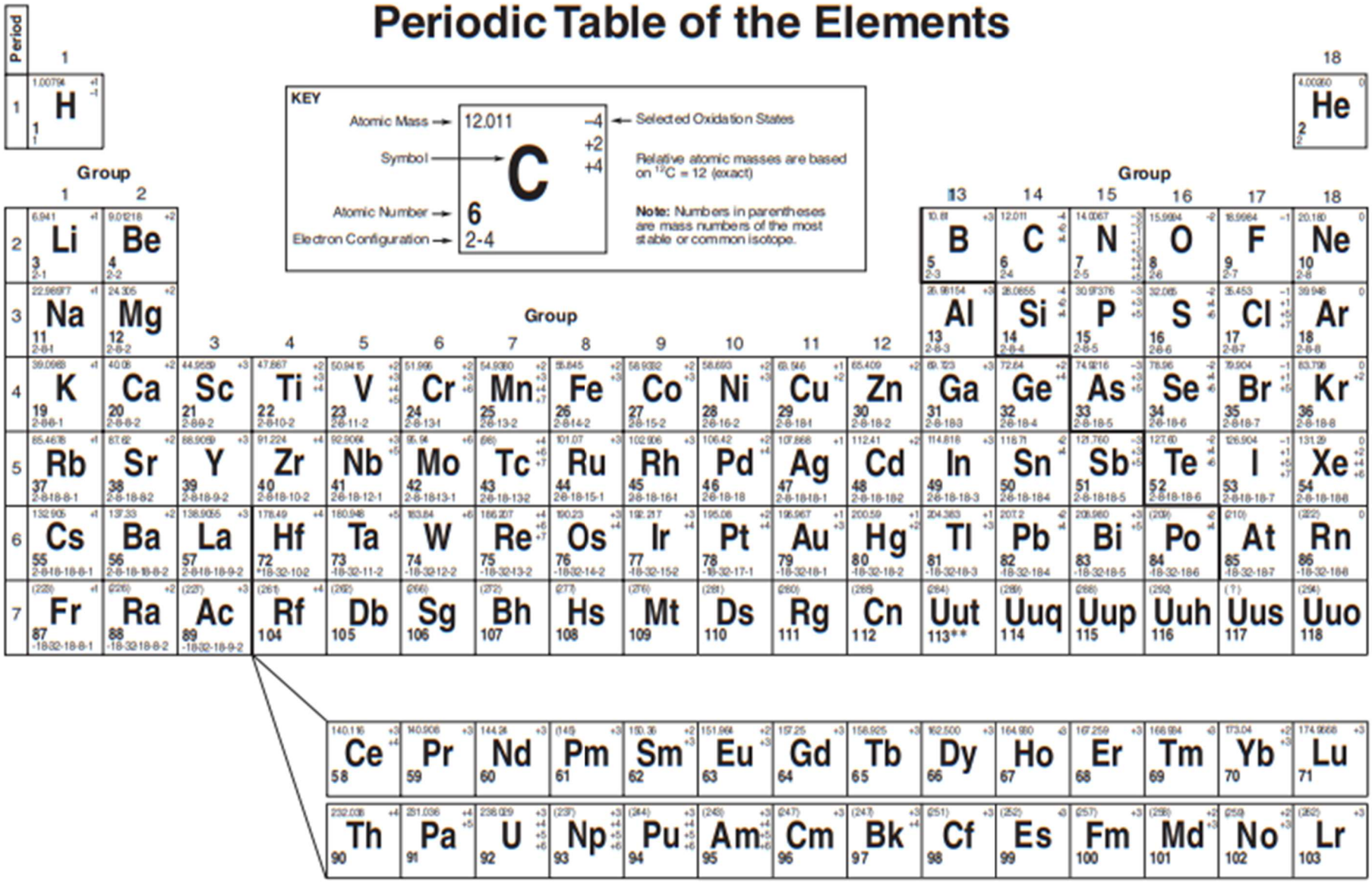
61. How many electrons in a Mg^{+2} cation? (many choose 12 e^-) _____

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		41	Nb	Niobium		81	Tl	Thallium
2	He	Helium		42	Mo	Molybdenum		82	Pb	Lead
3	Li	Lithium		43	Tc	Technetium		83	Bi	Bismuth
4	Be	Beryllium		44	Ru	Ruthenium		84	Po	Polonium
5	B	Boron		45	Rh	Rhodium		85	At	Astatine
6	C	Carbon		46	Pd	Palladium		86	Rn	Radon
7	N	Nitrogen		47	Ag	Silver		87	Fr	Francium
8	O	Oxygen		48	Cd	Cadmium		88	Ra	Radium
9	F	Fluorine		49	In	Indium		89	Ac	Actinium
10	Ne	Neon		50	Sn	Tin		90	Th	Thorium
11	Na	Sodium		51	Sb	Antimony		91	Pa	Protactinium
12	Mg	Magnesium		52	Te	Tellurium		92	U	Uranium
13	Al	Aluminum		53	I	Iodine		93	Np	Neptunium
14	Si	Silicon		54	Xe	Xenon		94	Pu	Plutonium
15	P	Phosphorous		55	Cs	Cesium		95	Am	Americium
16	S	Sulfur		56	Ba	Barium		96	Cm	Curium
17	Cl	Chlorine		57	La	Lanthanum		97	Bk	Berkelium
18	Ar	Argon		58	Ce	Cerium		98	Cf	Californium
19	K	Potassium		59	Pr	Praseodymium		99	Es	Einsteinium
20	Ca	Calcium		60	Nd	Neodymium		100	Fm	Fermium
21	Sc	Scandium		61	Pm	Promethium		101	Md	Mendelevium
22	Ti	Titanium		62	Sm	Samarium		102	No	Nobelium
23	V	Vanadium		63	Eu	Europium		103	Lr	Lawrencium
24	Cr	Chromium		64	Gd	Gadolinium		104	Rf	Rutherfordium
25	Mn	Manganese		65	Tb	Terbium		105	Db	Dubnium
26	Fe	Iron		66	Dy	Dysprosium		106	Sg	Seaborgium
27	Co	Cobalt		67	Ho	Holmium		107	Bh	Bohrium
28	Ni	Nickel		68	Er	Erbium		108	Hs	Hassium
29	Cu	Copper		69	Tm	Thulium		109	Mt	Meitnerium
30	Zn	Zinc		70	Yb	Ytterbium		110	Ds	Darmastadtium
31	Ga	Gallium		71	Lu	Lutetium		111	Rg	Roentgenium
32	Ge	Germanium		72	Hf	Hafnium		112	Cn	Copernicium
33	As	Arsenic		73	Ta	Tantalum		113	Nh	Nihonium
34	Se	Selenium		74	W	Tungsten		114	Fl	Flerovium
35	Br	Bromine		75	Re	Rhenium		115	Mc	Muscovium
36	Kr	Krypton		76	Os	Osmium		116	Lv	Livermorium
37	Rb	Rubidium		77	Ir	Iridium		117	Ts	Tennessine
38	Sr	Strontium		78	Pt	Platinum		118	Og	Organesson
39	Y	Yttrium		79	Au	Gold				
40	Zr	Zirconium		80	Hg	Mercury				

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