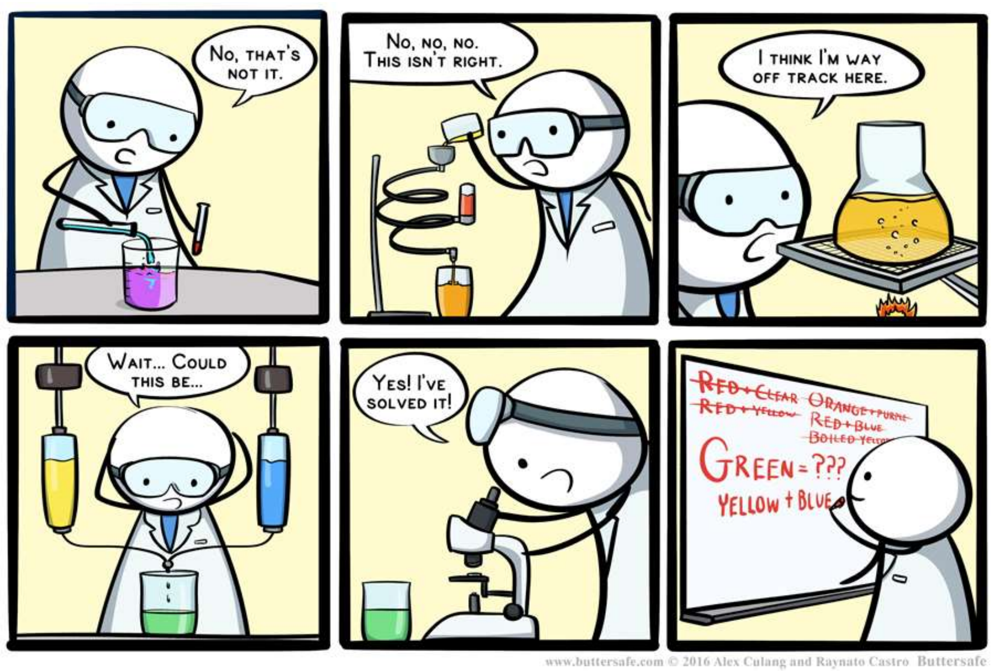
CHEMISTRY 30S

The Alchemist's Notebook

UNIT 2 – CHEMICAL REACTIONS



NAME:____________________________________

LET'S GET STARTED!

By the end of this unit, should be able to:

- ✓ Write balanced formula equations for a variety of types of chemical reactions, including predicting the products.
- ✓ Interpret a balanced equation in terms of mole/volume of gas ratios.
- ✓ Solve stoichiometric problems involving moles and mass, given the reactants and products in a balanced chemical reaction.
- ✓ Use the molar volume of a gas as a conversion factor in stoichiometric problems
- ✓ Determine % yield of a chemical reaction from the actual and theoretical yield.
- ✓ Identify the limiting reactant and calculate the mass of a product, given the reaction equation and reactant data.
- ✓ Perform an experiment to determine the percent yield of a chemical reaction

This unit will take about **15 lessons** to complete and will make up approximately **15% of your mark**.

1. COMMUNICATING CHEMICAL REACTIONS

UNIT 2 CHEMICAL REACTIONS

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1

COMMUNICATING REACTIONS

Methane gas (carbon tetrahydride) combusts with oxygen gas from the air to produce carbon dioxide and water vapour.

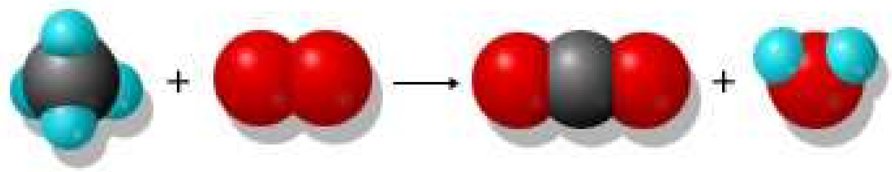
WORD EQUATION:

FORMULA EQUATION:

2

SOMETHING'S NOT RIGHT HERE…

$$CH_4 + O_2 \longrightarrow CO_2 + H_2O$$

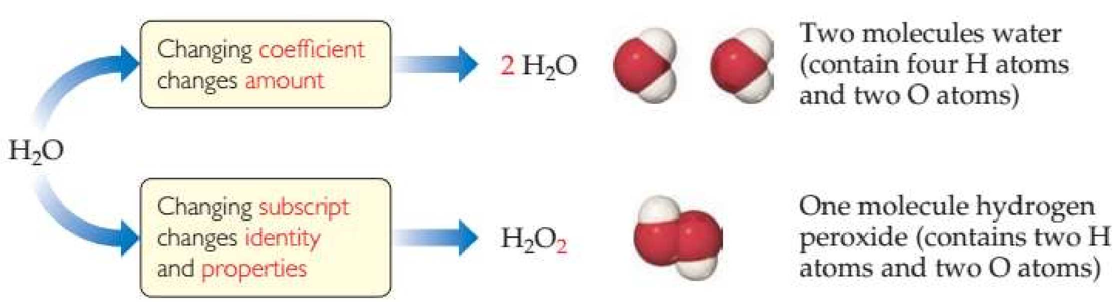


Reactants		Products
1 C atom	=	1 C atom
4 H atoms	≠	2 H atoms
2 O atoms	≠	3 O atoms

3

BALANCING A FORMULA EQUATION

- For a formula equation to be correct, it must be **BALANCED.**
- **MULTIPLIERS** are added in front of each formula. These multipliers are called **COEFFICIENTS**.



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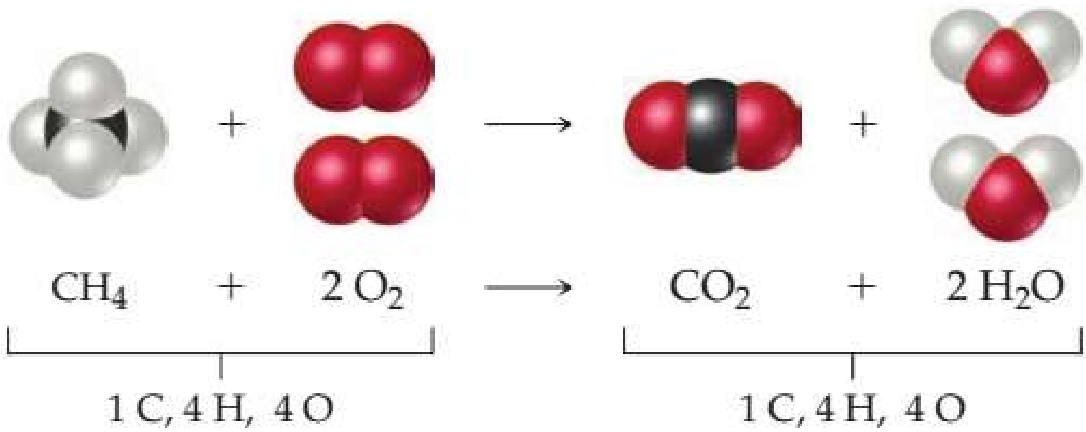
ADJUSTING QUANTITIES



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GENERAL BALANCING PRINCIPLES

___ Al + ___ O_2 → ___ Al_2O_3

___ Na(OH) + ___ $Fe(NO_3)_3$ → ___ $Na(NO_3)$ + ___ $Fe(OH)_3$

___ C_2H_6 + ___ O_2 → ___ CO_2 + ___ H_2O

6

EXAMPLE

A strip of aluminum reacts with copper(II) chloride to produce copper and aluminum chloride.

Words			
Formulas			
Pictures			
Balanced Equation			

7

2. REACTION TYPES

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1

REACTION TYPES

A **synthesis** (or combination) reaction involves two or more simple substances (elements or compounds) combining to form one more complex substance.

A **decomposition** reaction involves a complex compound being broken down or decomposed into two or more simpler substances (elements or compounds).

2

REACTION TYPES

A **combustion** reaction involves the reaction of a hydrocarbon (a compound made up of hydrogen and carbon) or a carbohydrate (a compound made up of hydrogen, carbon and oxygen) with oxygen gas to produce carbon dioxide gas and water.

$$2\,C_8H_{18}(l) + 25\,O_2(g) \rightarrow 16\,CO_2(g) + 18\,H_2O(g)$$

$$C_6H_{12}O_6(s) + 6\,O_2(g) \rightarrow 6\,CO_2(g) + 6\,H_2O(l)$$

3

REACTION TYPES

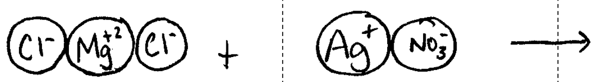
A **single replacement** reaction (also called single displacement) involves a reaction between a compound and an element so that the element replaces an element of the same type in the compound. The result is a new compound and a new element.

A **double replacement** reaction is a chemical reaction between two compounds that trade cations (or anions) with one another.

4

EXAMPLE

A solution of magnesium chloride reacts with a solution of silver nitrate and a reaction occurs.

Words			
Formulas			
Pictures 			
Balanced Equation			

5

3. STOICHIOMETRY

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1

REACTIONS ARE LIKE BAKING!

- 1 cup butter
- 1/2 cup white sugar
- 1 cup packed brown sugar
- 1 teaspoon vanilla extract
- 2 eggs
- 2 1/2 cups all-purpose flour
- 1 teaspoon baking soda
- 1 teaspoon salt
- 2 cups semisweet chocolate chips

Makes 3 dozen

How many eggs are needed to make 3 dozen cookies?

How many eggs would we need to make 9 dozen cookies?

How much brown sugar would I need if I used 1 ½ cups white sugar?

2

THE ANALOGY

BAKING	CHEMICAL REACTIONS
The Recipe	
The Ingredients (butter, sugar, etc)	
The Amounts (cups, teaspoons, etc)	
The Delicious Cookies!	

3

IT'S ALL ABOUT THE MOLE RATIOS!

THE REACTION THAT WILL TAKE PLACE IN OUR ROCKETS:

$$\underline{2}\,H_2 + \underline{1}\,O_2 \rightarrow \underline{2}\,H_2O$$

- What is the ideal mole ratio of reactants for this reaction?
- What are some ways we could write this ratio?

4

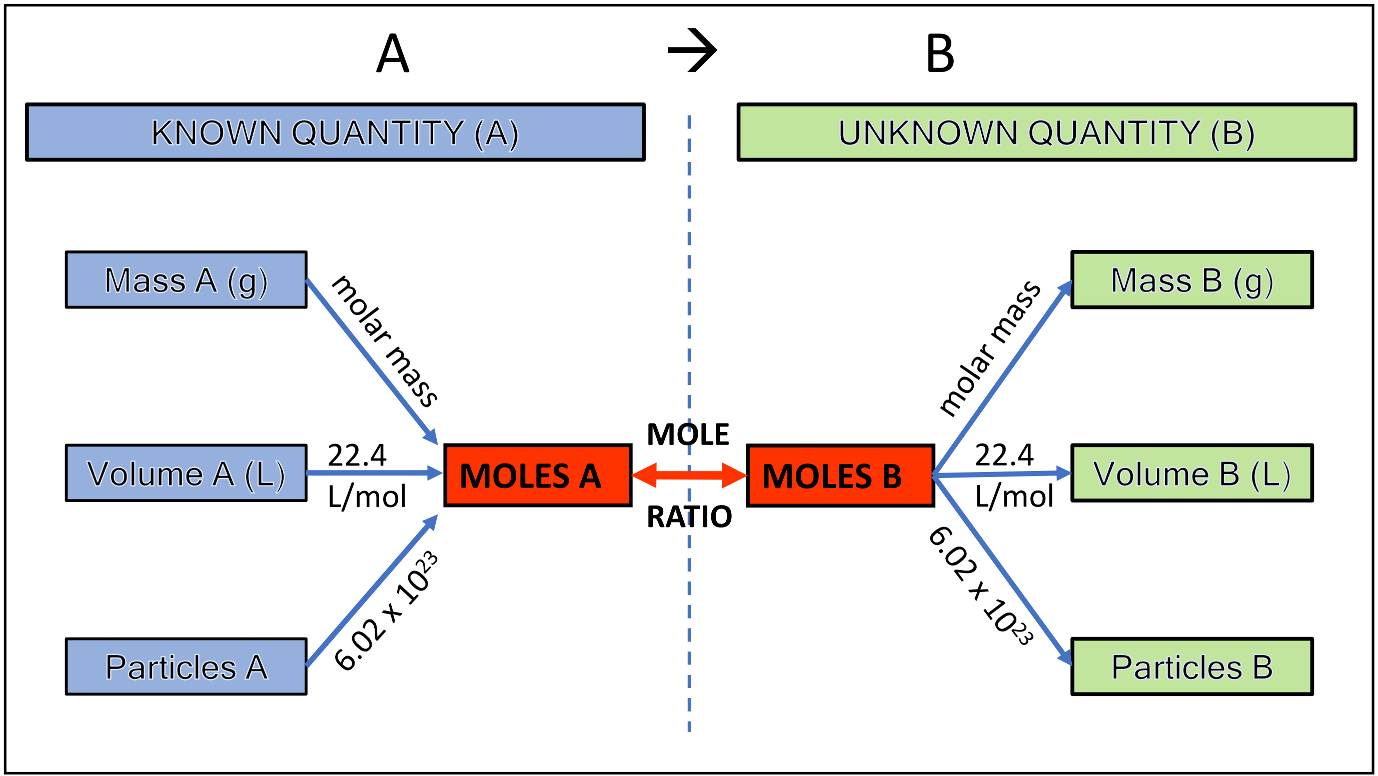
IT'S ALL ABOUT THE MOLE RATIOS!

THE REACTION THAT WILL TAKE PLACE IN OUR ROCKETS:

$\underline{2}\ H_2 + \underline{1}\ O_2 \rightarrow \underline{2}\ H_2O$

If we had 3 moles of oxygen available, how many moles of hydrogen would we need to react with it completely? How many moles of water would be produced?

5



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EXAMPLE #1

A small piece of aluminum foil is placed in a solution of copper(II) chloride. A reaction occurs.

1. What type of reaction will occur?
2. Write the word equation for this reaction.
3. Write the formula equation for this reaction.
4. Balance your formula equation.

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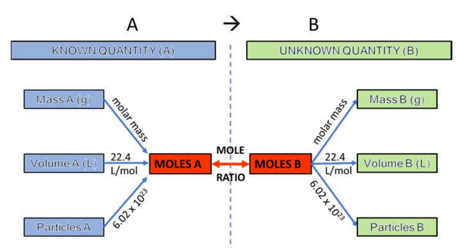
EXAMPLE #1



<u>**Balanced Equation:**</u>

<u>What mass</u> of copper will be produced if <u>5.0 g of aluminum</u> foil is completely reacted?

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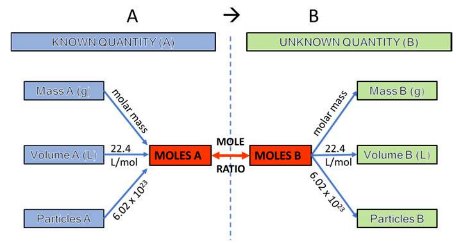
EXAMPLE #1



Balanced Equation:

What mass of aluminum foil is required to react to produce 25.0 g of copper?

9

EXAMPLE #2

A small piece of magnesium is placed in a solution of hydrochloric acid (hydrogen chloride). A reaction occurs.

Balanced Equation:

What volume of hydrogen gas will be produced if 0.50 g of magnesium is completely reacted?

10

EXAMPLE #3

A candle made of paraffin wax ($C_{25}H_{52}$) is combusted.

Balanced Equation:

How many water molecules will be produced if 1.25 g of paraffin wax are combusted?

11

4. PERCENT YIELD

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(A.K.A. "What you got compared to what you shoulda got!")

1

YOU CAN'T ALWAYS GET WHAT YOU WANT!

$$\text{Percentage Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$

Actual Yield is what is experimentally measured in the lab.

Theoretical Yield is what is calculated using stoichiometry.

2

EXAMPLE #1

In an experiment 152. g of $AgNO_3$ is reacted with excess Na_2SO_4. After the reaction is complete, 75.1g of Ag_2SO_4 was collected. Calculate the percentage yield.

$$\underline{2}\ AgNO_{3(aq)} + \underline{1}\ Na_2SO_{4(aq)} \rightarrow \underline{1}\ Ag_2SO_{4(s)} + \underline{2}\ NaNO_{3(aq)}$$

3

EXAMPLE #2

Calculate the theoretical yield in litres at STP of CO_2 in the reaction of 100.0 g of Fe_2O_3. If the actual yield was 19.0 L @ STP, calculate the percentage yield.

$$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$$

4

5. LIMITING REACTANTS

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1

MMMM….CHEMISTRY CAKE!

You have **20 cups** of flour, **8 cups** of sugar, **30 litres** of milk and **48 eggs** in your kitchen. The recipe for chemistry cake is:

3 cups of flour
2 cups of sugar
2 litres of milk
+ 6 eggs

= 1 chemistry cake

2

BE A CHEMISTRY-CAKE BOSS!

You have **20 cups** of flour, **8 cups** of sugar, **30 litres** of milk and **48 eggs** in your kitchen. The recipe for chemistry cake is:

3 cups of flour
2 cups of sugar
2 litres of milk
+6 eggs
= 1 chemistry cake

1. How many cakes can you make?
2. Which ingredient ran out first and limited the number of cakes you could make?
3. What and how much of each ingredient is left over?
4. What does this assignment have to do with chemistry?

3

INTRODUCING…THE ICE TABLE!

You have **20 cups** of flour, **8 cups** of sugar, **30 litres** of milk and **48 eggs** in your kitchen. What is the limiting ingredient? How much of each excess ingredient is left over?

	3F +	2S +	2M +	6E →	1Cake
Initial					
Change					
End					

4

EXAMPLE #1

14.0 mole Ga and 12.0 mole O_2 react. Find the limiting reactant, the mass of excess reactant and product made.

$$\_\_\_Ga \quad + \quad \_\_\_O_2 \quad \rightarrow \quad \_\_\_Ga_2O_3$$

5

EXAMPLE #2

14.0 g of Al reacts with 94.0 g of Br_2. Find the limiting reactant, the mass of the excess reactant and product.

$$\_\_\_Al \quad + \quad \_\_\_Br_2 \quad \rightarrow \quad \_\_\_AlBr_3$$

6

EXAMPLE #3

25.0 g of H_3PO_4 reacts with 94.0 g of $Ca(NO_3)_2$. Find the limiting reactant, the mass of the excess reactant and product.

___H_3PO_4 + ___$Ca(NO_3)_2$ → ___$Ca_3(PO_4)_2$ + ___HNO_3

7

Fundamental Constants

Name	Symbol	Value
Speed of light in a vacuum	c	3.00×10^{8} m/s
Magnitude of charge of electron	e	1.602×10^{-19} C
Planck's constant	h	6.626×10^{-34} J·s
Boltzmann constant	k	1.381×10^{-23} J/K
Avogadro's number	N_A	6.022×10^{23} particles/mol
Gas constant, SI	R	8.314 L·kPa/mol·K
Gas constant	R	0.08206 L·atm/mol·K
Mass of electron	m_e	9.109×10^{-31} kg
Mass of proton	m_p	1.673×10^{-27} kg
Mass of neutron	m_n	1.675×10^{-27} kg
Faraday constant	$\mathfrak{F}$ or F	96 485 C/mol e^-

International System (SI) Units

Physical Quantity	Name of Unit	Symbol
	base units	
Length (l)	Meter	m
Mass (m)	Kilogram	kg
Time (t)	Second	s
Temperature (T)	Kelvin	K
Electric Current (I)	Ampere	A
Luminous Intensity (φ)	Candela	cd
Amount of Substance	Mole	mol
	derived units	
Area (A)	square meter	m^2
Volume (V)	cubic meter	m^3
Frequency (ν)	Hertz	Hz [s^{-1}]
Speed, velocity (v)	meter per second	m/s
Force (F)	Newton	N [kg·m/s^2]
Pressure (P)	Pascal	Pa [N/m^2]

Common SI Prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{12}	tera	T	10^{-2}	centi	c
10^{9}	giga	G	10^{-3}	milli	m
10^{6}	mega	M	10^{-6}	micro	μ
10^{3}	kilo	k	10^{-9}	nano	n
			10^{-12}	pico	p
			10^{-15}	femto	f

e.g. 1 km = 1 x 10^3 m

e.g. 1 μg = 1 x 10^{-6} g

PERIODIC TABLE OF IONS

TABLE OF POLYATOMIC IONS					
acetate	CH_3COO^-	dihydrogen phosphate	$H_2PO_4^-$	oxalate	$C_2O_4^{2-}$
arsenate	AsO_4^{3-}	hydrogen carbonate	HCO_3^-	perchlorate	ClO_4^-
arsenite	AsO_3^{3-}	hydrogen oxalate	$HC_2O_4^-$	periodate	IO_4^-
benzoate	$C_6H_5COO^-$	hydrogen sulfate	HSO_4^-	permanganate	MnO_4^-
borate	BO_3^{3-}	hydrogen sulfide	HS^-	peroxide	O_2^{2-}
bromate	BrO_3^-	hydrogen sulfite	HSO_3^-	phosphate	PO_4^{3-}
carbonate	CO_3^{2-}	hydroxide	OH^-	pyrophosphate	$P_2O_7^{4-}$
chlorate	ClO_3^-	hypochlorite	ClO^-	sulfate	SO_4^{2-}
chlorite	ClO_2^-	iodate	IO_3^-	sulfite	SO_3^{2-}
chromate	CrO_4^{2-}	monohydrogen phosphate	HPO_4^{2-}	thiocyanate	SCN^-
cyanate	CNO^-	nitrate	NO_3^-	thiosulfate	$S_2O_3^{2-}$
cyanide	CN^-	nitrite	NO_2^-	POSITIVE POLYATOMIC IONS	
dichromate	$Cr_2O_7^{2-}$	orthosilicate	SiO_4^{4-}	ammonium	NH_4^+
				hydronium	H_3O^+

KEY

atomic number
symbol
26
Fe^{3+}
iron (III)
Fe^{2+}
iron (II)
ion charge
ion name (IUPAC)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H^+ hydrogen																1 H^- hydride	2 He helium
3 Li^+ lithium	4 Be^{2+} beryllium											5 B boron	6 C carbon	7 N^{3-} nitride	8 O^{2-} oxide	9 F^- fluoride	10 Ne neon
11 Na^+ sodium	12 Mg^{2+} magnesium											13 Al^{3+} aluminum	14 Si silicon	15 P^{3-} phosphide	16 S^{2-} sulfide	17 Cl^- chloride	18 Ar argon
19 K^+ potassium	20 Ca^{2+} calcium	21 Sc^{3+} scandium	22 Ti^{4+} titanium (IV) / Ti^{3+} titanium (III)	23 V^{3+} vanadium(III) / V^{5+} vanadium (V)	24 Cr^{3+} chromium (III) / Cr^{2+} chromium (II)	25 Mn^{2+} manganese(II) / Mn^{4+} manganese(IV)	26 Fe^{3+} iron (III) / Fe^{2+} iron (II)	27 Co^{2+} cobalt (II) / Co^{3+} cobalt (III)	28 Ni^{2+} nickel (II) / Ni^{3+} nickel (III)	29 Cu^{2+} copper (II) / Cu^+ copper (I)	30 Zn^{2+} zinc	31 Ga^{3+} gallium	32 Ge^{4+} germanium	33 As^{3-} arsenide	34 Se^{2-} selenide	35 Br^- bromide	36 Kr krypton
37 Rb^+ rubidium	38 Sr^{2+} strontium	39 Y^{3+} yttrium	40 Zr^{4+} zirconium	41 Nb^{5+} niobium (V) / Nb^{3+} niobium(III)	42 Mo^{6+} molybdenum	43 Tc^{7+} technitium	44 Ru^{3+} ruthenium(III) / Ru^{4+} ruthenium(IV)	45 Rh^{3+} rhodium	46 Pd^{2+} paladium(II) / Pd^{4+} paladium(IV)	47 Ag^+ silver	48 Cd^{2+} cadmium	49 In^{3+} indium	50 Sn^{4+} tin (IV) / Sn^{2+} tin (II)	51 Sb^{3+} antimony(III) / Sb^{5+} antimony(V)	52 Te^{2-} telluride	53 I^- iodide	54 Xe xenon
55 Cs^+ cesium	56 Ba^{2+} barium	57 La^{3+} lanthanum	72 Hf^{4+} hafnium	73 Ta^{5+} tantalum	74 W^{6+} tungsten	75 Re^{7+} rhenium	76 Os^{4+} osmium	77 Ir^{4+} iridium	78 Pt^{4+} platinum(IV) / Pt^{2+} platinum(II)	79 Au^{3+} gold (III) / Au^+ gold (I)	80 Hg^{2+} mercury (II) / Hg_2^{2+} mercury (I)	81 Tl^+ thallium (I) / Tl^{3+} thallium(III)	82 Pb^{2+} lead (II) / Pb^{4+} lead (IV)	83 Bi^{3+} bismuth(III) / Bi^{5+} bismuth(V)	84 Po^{2+} polonium(II) / Po^{4+} polonium(IV)	85 At^- astatide	86 Rn radon
87 Fr^+ francium	88 Ra^{2+} radium	89 Ac^{3+} actinium															

58 Ce^{3+} cerium	59 Pr^{3+} praseodymium	60 Nd^{3+} neodymium	61 Pm^{3+} promethium	62 Sm^{3+} samarium(III) / Sm^{2+} samarium(II)	63 Eu^{3+} europium (III) / Eu^{2+} europium (II)	64 Gd^{3+} gadolinium	65 Tb^{3+} terbium	66 Dy^{3+} dysprosium	67 Ho^{3+} holmium	68 Er^{3+} erbium	69 Tm^{3+} thulium	70 Yb^{3+} ytterbium(III) / Yb^{2+} ytterbium(II)	71 Lu^{3+} lutetium
90 Th^{4+} thorium	91 Pa^{5+} protactinium(V) / Pa^{4+} protactinium(IV)	92 U^{6+} uranium (VI) / U^{4+} uranium (IV)	93 Np^{5+} neptunium	94 Pu^{4+} plutonium(IV) / Pu^{6+} plutonium(VI)	95 Am^{3+} americium(III) / Am^{4+} americium(IV)	96 Cm^{3+} curium	97 Bk^{3+} berkelium(III) / Bk^{4+} berkelium(IV)	98 Cf^{3+} californium	99 Es^{3+} einsteinium	100 Fm^{3+} fermium	101 Md^{2+} mendelevium (II) / Md^{3+} mendelevium (III)	102 No^{2+} nobelium(II) / No^{3+} nobelium(III)	103 Lr^{3+} lawrencium

The Periodic Table of the Elements

Average relative masses are rounded to two decimal places.

Element name → Mercury
80 ← Atomic #
Symbol → Hg
200.59 ← Avg. Mass

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Hydrogen 1 **H** 1.01																		Helium 2 **He** 4.00
Lithium 3 **Li** 6.94	Beryllium 4 **Be** 9.01												Boron 5 **B** 10.81	Carbon 6 **C** 12.01	Nitrogen 7 **N** 14.01	Oxygen 8 **O** 16.00	Fluorine 9 **F** 19.00	Neon 10 **Ne** 20.18
Sodium 11 **Na** 22.99	Magnesium 12 **Mg** 24.31												Aluminum 13 **Al** 26.98	Silicon 14 **Si** 28.09	Phosphorus 15 **P** 30.97	Sulfur 16 **S** 32.07	Chlorine 17 **Cl** 35.45	Argon 18 **Ar** 39.95
Potassium 19 **K** 39.10	Calcium 20 **Ca** 40.08		Scandium 21 **Sc** 44.96	Titanium 22 **Ti** 47.88	Vanadium 23 **V** 50.94	Chromium 24 **Cr** 52.00	Manganese 25 **Mn** 54.94	Iron 26 **Fe** 55.85	Cobalt 27 **Co** 58.93	Nickel 28 **Ni** 58.69	Copper 29 **Cu** 63.55	Zinc 30 **Zn** 65.39	Gallium 31 **Ga** 69.72	Germanium 32 **Ge** 72.61	Arsenic 33 **As** 74.92	Selenium 34 **Se** 78.96	Bromine 35 **Br** 79.90	Krypton 36 **Kr** 83.80
Rubidium 37 **Rb** 85.47	Strontium 38 **Sr** 87.62		Yttrium 39 **Y** 88.91	Zirconium 40 **Zr** 91.22	Niobium 41 **Nb** 92.91	Molybdenum 42 **Mo** 95.94	Technetium 43 **Tc** (97.91)	Ruthenium 44 **Ru** 101.07	Rhodium 45 **Rh** 102.91	Palladium 46 **Pd** 106.42	Silver 47 **Ag** 107.87	Cadmium 48 **Cd** 112.41	Indium 49 **In** 114.82	Tin 50 **Sn** 118.71	Antimony 51 **Sb** 121.76	Tellurium 52 **Te** 127.60	Iodine 53 **I** 126.90	Xenon 54 **Xe** 131.29
Cesium 55 **Cs** 132.91	Barium 56 **Ba** 137.33	57-70 *	Lutetium 71 **Lu** 174.97	Hafnium 72 **Hf** 178.49	Tantalum 73 **Ta** 180.95	Tungsten 74 **W** 183.84	Rhenium 75 **Re** 186.21	Osmium 76 **Os** 190.23	Iridium 77 **Ir** 192.22	Platinum 78 **Pt** 195.08	Gold 79 **Au** 196.97	Mercury 80 **Hg** 200.59	Thallium 81 **Tl** 204.38	Lead 82 **Pb** 207.20	Bismuth 83 **Bi** 208.98	Polonium 84 **Po** (208.98)	Astatine 85 **At** (209.99)	Radon 86 **Rn** (222.02)
Francium 87 **Fr** (223.02)	Radium 88 **Ra** (226.03)	89-102 **	Lawrencium 103 **Lr** (262.11)	Rutherfordium 104 **Rf** (265.12)	Dubnium 105 **Db** (268.13)	Seaborgium 106 **Sg** (271.13)	Bohrium 107 **Bh** (270)	Hassium 108 **Hs** (277.15)	Meitnerium 109 **Mt** (276.15)	Darmstadtium 110 **Ds** (281.16)	Roegentium 111 **Rg** (280.16)	Copernicium 112 **Cn** (285.17)	Nihonium 113 **Nh** (284.18)	Flerovium 114 **Fl** (289.19)	Moscovium 115 **Mc** (288.19)	Livermorium 116 **Lv** (293)	Tennessine 117 **Ts** (294)	Oganesson 118 **Og** (294)

*lanthanides	Lanthanum 57 **La** 138.91	Cerium 58 **Ce** 140.12	Praseodymium 59 **Pr** 140.91	Neodymium 60 **Nd** 144.24	Promethium 61 **Pm** (145)	Samarium 62 **Sm** 150.36	Europium 63 **Eu** 151.97	Gadolinium 64 **Gd** 157.25	Terbium 65 **Tb** 158.93	Dysprosium 66 **Dy** 162.50	Holmium 67 **Ho** 164.93	Erbium 68 **Er** 167.26	Thulium 69 **Tm** 168.93	Ytterbium 70 **Yb** 173.05
**actinides	Actinium 89 **Ac** (227.03)	Thorium 90 **Th** 232.04	Protactinium 91 **Pa** 231.04	Uranium 92 **U** 238.03	Neptunium 93 **Np** (237.05)	Plutonium 94 **Pu** (244.06)	Americium 95 **Am** (243.06)	Curium 96 **Cm** (247.07)	Berkelium 97 **Bk** (247.07)	Californium 98 **Cf** (251.08)	Einsteinium 99 **Es** (252.08)	Fermium 100 **Fm** (257.10)	Mendelevium 101 **Md** (258.10)	Nobelium 102 **No** (259.10)