

AP Chemistry Summer Assignment Packet

2025-2026

Welcome to AP Chemistry. Summer review work is meant to get us off to a running start when fall arrives. You should already know most of the material in this packet from your first year chemistry class. Nonetheless, **START NOW** to make your way leisurely through this review. Do **NOT** think you should wait until the very end of the summer so the concepts are "fresh in your mind." The **LONGER** this review swirls around in your gray cells, the better the concepts will stick.

This packet is also available in several separate pdf documents on the website. Each group of topics and MC practice has an associated video with answers and explanations, so if there is something you forget from honors or seems new be sure to utilize the videos. There are direct links to the videos on the summer assignment website hyperlinked in the chart (also shown below and continued on the next page). You do **NOT** have to print this document, you can answer the questions on a separate piece of paper. Please be sure to label them with the topic and question numbers.

There are due dates posted in the AP Summer Google Classroom, but **don't worry if you miss a due date**, do the work late rather than not at all. Always better late than never. The ultimate due date is the first day of school. **On the first day of school you will be expected to submit the packet with work shown, NOT just answers.** Yes, this includes work needed to answer multiple choice questions. Please email if you have questions or comments. While we are all on vacation, I will be looking at email, maybe not daily, but often. You can expect a response.

There will be a quiz on this review material in the first week of each unit. PLEASE work on this review material so you are prepared and can start your year in AP on the right track.

The topics covered in this packet are (almost) all reviews from first year chemistry, and are labeled and aligned with topics in the AP Chemistry curriculum (CB = college board). The chart below will outline the pages in the packet, unit it will be in class, and the college board alignment. It also includes where the topic can be found in your Tro textbook*, which will be helpful when preparing for the review quiz later.

Have a great summer!

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Google Classroom Code: hoxeoyi7

*You do not have your textbook yet, you will receive it on the first day of class.

Pages in Packet	CB Unit	Description	Class Unit	Tro Chapter and Section
<u>CB Topics 1.1 - 1.3</u>				
<u>5</u>	1.1	Moles and Molar Mass	A	2.9, 3.8, 3.9
<u>6</u>	1.2	Mass Spectrum and Isotopes, Protons and Neutrons	A	2.6, 2.8
<u>7</u>	1.3	Pure Substances, Percent Composition, Empirical and Molecular Formula, Combustion Analysis, Hydrate, Heating to a Constant Mass	A	1.3, 2.3, 3.3, 3.4, 3.9
<u>11</u>	—	<u>MC Practice for Topics 1.1 - 1.3</u> (8 Questions)		

<u>CB Topics 1.4 - 1.5</u> (1.6 is NOT included, it will be covered in class. Stop the Video at 47:43)				
12	1.4	Composition of Mixtures: Percent of compounds or elements in a mixture, percent high or low, what other compound?, using precipitation to determine percent of compound in mixture	A	1.3, 3.9, 3.10
13	1.5	Atomic Structure, Electron Configuration of atoms and ions	B	2.5, 2.6. 8.2-8.7
17	—	MC Practice for Topics 1.4 - 1.5 (6 Questions)		
<u>CB Topics 1.7 - 1.8</u>				
17	1.7	Periodic Trends (Will Review the Anomalies of Groups 3 and 6 again in class)	B	8.4-8.9, 9.6
23	1.8	Valence Electrons and Ionic Bonds (Nomenclature)	B	4.5, 8.4, 8.5, 9.2-9.4
25	—	MC Practice for Topics 1.7 - 1.8 (9 Questions)		
<u>CB Topics 3.2-3.4</u>				
26	3.2	Solids, Liquids, and Vapor Pressure (Particulates, VP equilibrium, VP graph, Network Covalent Solids)	C	9.2, 9.11, 11.2 - 11.5, 11.12, 11.13, 23.4
32	3.3	Solids, Liquids, and especially Gases	C	5.2, 5.3, 11.2, 11.12
33	3.4	The Ideal Gas Law	C	5.3-5.6
39	—	MC Practice for Topics 3.2 - 3.4 (7 Questions)		
<u>CB Topics 4.1-4.4</u>				
40	4.1 & 4.4	Introduction for Reactions, Chemical and Physical Changes	D	1.4, 1.5, 12.2, 12.3
43	4.2	Net Ionic Equations	D	1.4, 4.2, 4.7, 4.9
49	4.3	Representation of Reactions	D	3.2 - 3.3, 4.2, 4.6 - 4.9
51	—	MC Practice for Topics 4.1 - 4.4 (9 Questions)		
<u>CB Topics 4.5</u> (4.6 is NOT included, it will be covered in class. Stop the video 28:26.)				
52	4.5	Stoichiometry	A	4.3, 4.4, 4.8 - 4.9, 5.4
55	—	MC Practice for Topic 4.5 (4 Questions) Stop Video at 15:38		
Pre - <u>CB Topics 4.9</u> (Only 38:44 to 58:55 will apply to this assignment. The rest will be covered in class later.)				
56	Pre 4.9	Assigning Oxidation States	D	4.7 - 4.9

PERIODIC TABLE OF THE ELEMENTS

18

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.008	2 He 4.00	3 Li 6.94	4 Be 9.01	5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18	11 Na 22.99	12 Mg 24.30	13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.97	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc	44 Ru 101.07	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 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57-71 Lanthanoids	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	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	85 At	86 Rn
87 Fr	88 Ra	89-103 Actinoids	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	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
89 Ac	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

*Lanthanoids

†Actinoids

AP® CHEMISTRY EQUATIONS AND CONSTANTS, EFFECTIVE 2025

UNIT SYMBOLS	UNIT CONVERSIONS	METRIC PREFIXES
gram, g		Factor Prefix Symbol
mole, mol	1 hertz = 1 s ⁻¹	10 ⁹ giga G
liter, L	1 atm = 760 mm Hg = 760 torr	10 ⁶ mega M
meter, m		10 ³ kilo k
second, s	K = °C + 273.15	10 ⁻² centi c
hertz, Hz		10 ⁻³ milli m
atmosphere, atm	1 volt = $\frac{1 \text{ joule}}{1 \text{ coulomb}}$	10 ⁻⁶ micro μ
millimeter of mercury, mm Hg	1 ampere = $\frac{1 \text{ coulomb}}{1 \text{ second}}$	10 ⁻⁹ nano n
degree Celsius, °C		10 ⁻¹² pico p
Kelvin, K		
joule, J		
volt, V		
coulomb, C		
ampere, A		

ATOMIC STRUCTURE

$$E = h\nu$$

$$c = \lambda\nu$$

$$F_{\text{coulombic}} \propto \frac{q_1q_2}{r^2}$$

E = energy

ν = frequency

λ = wavelength

F = force

q = charge

r = separation

Planck's constant, $h = 6.626 \times 10^{-34}$ J s

Speed of light, $c = 2.998 \times 10^8$ m s⁻¹

Avogadro's number = 6.022×10^{23} mol⁻¹

GASES, LIQUIDS, AND SOLUTIONS

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$PV = nRT$$

$$P_A = P_{\text{total}} \times X_A, \text{ where } X_A = \frac{\text{moles } A}{\text{total moles}}$$

$$P_{\text{total}} = P_A + P_B + P_C + \dots$$

$$n = \frac{m}{M}$$

$$D = \frac{m}{V}$$

$$KE = \frac{1}{2}mv^2$$

$$M = \frac{n_{\text{solite}}}{L_{\text{solution}}}$$

$$A = \epsilon bc$$

P = pressure

V = volume

T = temperature

n = number of moles

X = mole fraction

m = mass

M = molar mass

D = density

KE = kinetic energy

v = velocity

M = molarity

A = absorbance

ϵ = molar absorptivity

b = path length

c = concentration

Gas constant, $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$

$= 0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1}$

STP = 273.15 K and 1.0 atm

Ideal gas at STP = 22.4 L mol⁻¹

KINETICS

$$[A]_t - [A]_0 = -kt$$

$$\ln[A]_t - \ln[A]_0 = -kt$$

$$\frac{1}{[A]_t} - \frac{1}{[A]_0} = kt$$

$$t_{1/2} = \frac{0.693}{k}$$

k = rate constant
 t = time
 $t_{1/2}$ = half-life

EQUILIBRIUM

$$K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}, \text{ where } A + bB \rightleftharpoons cC + dD$$

$$K_p = \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$$

$$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14} \text{ at } 25^\circ\text{C}$$

$$pK_w = 14 = \text{pH} + \text{pOH at } 25^\circ\text{C}$$

$$\text{pH} = -\log[\text{H}_3\text{O}^+], \quad \text{pOH} = -\log[\text{OH}^-]$$

$$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}, \quad K_b = \frac{[\text{OH}^-][\text{HB}^*]}{[\text{B}]}$$

$$pK_a = -\log K_a, \quad pK_b = -\log K_b$$

$$K_w = K_a \times K_b, \quad pK_w = \text{p}K_a + \text{p}K_b$$

$$\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$$

Equilibrium Constants

K_c (molar concentrations)

K_p (gas pressures)

K_w (water)

K_a (acid)

K_b (base)

THERMODYNAMICS/ELECTROCHEMISTRY

$$q = mc\Delta T$$

$$\Delta H^\circ_{\text{reaction}} = \sum \Delta H^\circ_{f, \text{products}} - \sum \Delta H^\circ_{f, \text{reactants}}$$

$$\Delta S^\circ_{\text{reaction}} = \sum S^\circ_{\text{products}} - \sum S^\circ_{\text{reactants}}$$

$$\Delta G^\circ_{\text{reaction}} = \sum \Delta G^\circ_{f, \text{products}} - \sum \Delta G^\circ_{f, \text{reactants}}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$= -RT \ln K$$

$$= -nFE^\circ$$

$$I = \frac{q}{t}$$

$$E_{\text{cell}} = E^\circ_{\text{cell}} - \frac{RT}{nF} \ln Q$$

Faraday's constant, $F = 96,485 \text{ coulombs / } 1 \text{ mol } e^-$

q = heat

m = mass

c = specific heat capacity

T = temperature

S° = standard entropy

H° = standard enthalpy

G° = standard Gibbs free energy

R = gas constant

K = equilibrium constant

n = number of moles of electrons

E° = standard potential

I = current (amperes)

q = charge (coulombs)

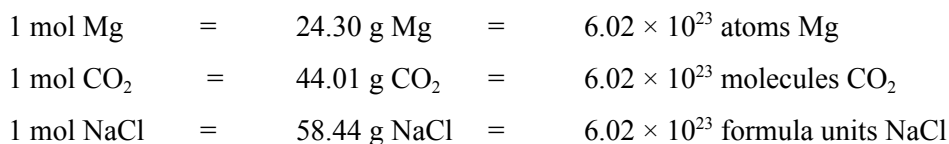
t = time (seconds)

Q = reaction quotient

Essential knowledge statements from the AP Chemistry CED:

- One cannot count particles directly while performing laboratory work. Thus, there must be a connection between the masses of substances reacting and the actual number of particles undergoing chemical changes.
- Avogadro's number ($N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$) provides the connection between the number of moles in a pure sample of a substance and the number of constituent particles (or formula units) of that substance.
- Expressing the mass of an individual atom or molecule in atomic mass units (amu) is useful because the average mass in amu of one particle (atom or molecule) or formula unit of a substance will always be numerically equal to the molar mass of that substance in grams. Thus, there is a quantitative connection between the mass of a substance and the number of particles that the substance contains.

The particles of a substance can be described as atoms, molecules, or formula units, as shown in the following examples. The molar mass of a substance can be determined or calculated from the atomic mass values on the periodic table.

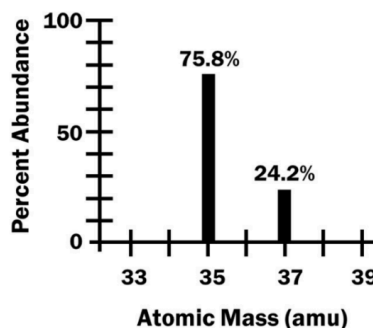


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1. Calculate the mass, in grams, of 0.0850 mol Ba(OH)₂.
 2. Calculate the number of moles of C₄H₁₀ present in 2.00 g C₄H₁₀.
 3. Calculate the number of atoms of Si present in 35.0 mol Si.
 4. Calculate the number of moles of O₃ present in 4.3×10^{24} molecules of O₃.
 5. Calculate the mass, in grams, of 8.2×10^{22} molecules of CHCl₃.
 6. Calculate the number of formula units of Na₂SO₄ present in 0.248 g Na₂SO₄.

Essential knowledge statements from the AP Chemistry CED:

- The mass spectrum of a sample containing a single element can be used to determine the identity of the isotopes of that element and the relative abundance of each isotope in nature.
- The average atomic mass of an element can be estimated from the weighted average of the isotopic masses using the mass of each isotope and its relative abundance.

Isotope	Abundance
Cl-35	75.8%
Cl-37	24.2%

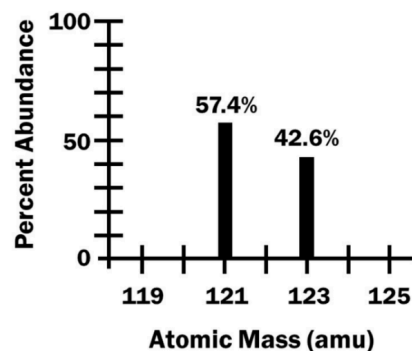


7. Based on the information shown above,
 (a) calculate the average atomic mass of Cl.

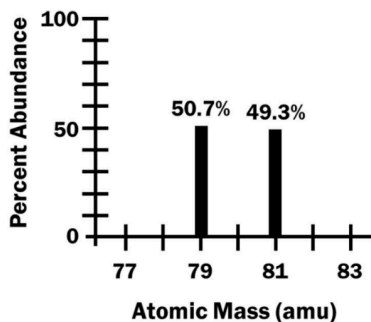
(b) Fill in the table below.

Isotope	Protons	Neutrons
Cl-35		
Cl-37		

8. Based on the information shown to the right,
 (a) calculate the average atomic mass of the element.



(b) What is the most likely identity of this element?



9. Based on the information shown to the left,
 (a) What is the most likely identity of this element?
 (b) Fill in the table below.

Mass Number	Protons	Neutrons
79		
81		

10. A certain element has two naturally occurring isotopes with mass numbers of 63 and 65.

(a) What is the most likely identity of this element?

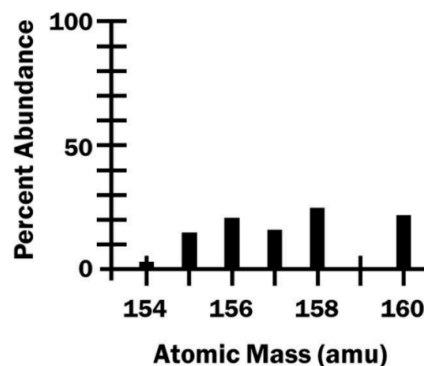
(b) Fill in the table below.

Mass Number	Protons	Neutrons
63		
65		

(c) Which isotope of this element, mass number = 63 or mass number = 65, is more abundant in nature? Justify your answer.

11. If an element has several naturally occurring isotopes, the calculation of the average atomic mass of the element can be a bit more complicated.

Mass Number	Abundance
154	2.18%
155	14.80%
156	20.47%
157	15.65%
158	24.84%
160	22.06%



(a) Based on the information above, estimate the average atomic mass of the element to the nearest whole number. Then use a calculator to determine the average atomic mass.

(b) What is the most likely identity of this element?

CB Topic 1.3 Elemental Composition of Pure Substances Video: <https://www.youtube.com/watch?v=WpDHbWSms0o>

Essential knowledge statements from the AP Chemistry CED:

- Some pure substances are composed of individual molecules, while others consist of atoms or ions held together in fixed proportions as described by a formula unit.
- According to the law of definite proportions, the ratio of the masses of the constituent elements in any pure sample of that compound is always the same.
- The chemical formula that lists the lowest whole number ratio of atoms of the elements in a compound is the empirical formula.

12. Calculate the percent composition by mass of each element in glucose ($C_6H_{12}O_6$).
13. Calculate the percent composition by mass of each element in erythrose ($C_4H_8O_4$).
14. What is the empirical formula of glucose?

What is the empirical formula of erythrose?

***Two different compounds with the same empirical formula
have the same percent composition by mass.***

15. A certain compound has the following percent composition by mass.

43.64% P 56.36% O

Determine the empirical formula of this compound.

If you are given mass data for a certain compound, the following procedure will help you to determine the empirical formula of the compound.

- Convert the mass of each element into moles.
- Divide each value of moles by the lowest number.
- At this point, you may already have whole numbers for the moles of each element. If not, then you may need to multiply each value by 2 or by 3 in order to get whole numbers.
- Use the whole number values of moles to write the empirical formula.

16. A certain compound has the following percent composition by mass.

52.14% C 13.13% H 34.73% O

Determine the empirical formula of this compound.

17. A pure sample of tin (Sn) with a mass of 6.18 g is burned in air until the tin is completely converted into tin oxide. The mass of the tin oxide is equal to 7.85 g. Determine the empirical formula of the tin oxide compound.
18. Compound X consists of the elements C, H, and N. A 15.00-g sample of compound X contains
- 9.81 g C 1.37 g H 3.82 g N.
- (a) Determine the empirical formula of compound X.
- (b) It is determined that a 25.0-gram sample of compound X contains 9.11×10^{22} molecules. Calculate the molar mass of compound X, in units of g/mol.
- (c) Based on your answers to parts (a) and (b), determine the molecular formula of compound X.

Another way to determine the empirical formula of a compound is to use data from a combustion experiment. If a compound that contains carbon and hydrogen is burned in the presence of excess oxygen gas, the carbon will be converted into CO₂ and the hydrogen will be converted into H₂O. If the compound contains other elements such as nitrogen or sulfur, other gases may be formed.

Mass of sample that is burned	5.00 g
Mass of CO ₂ produced	10.99 g
Mass of H ₂ O produced	6.00 g

19. A sample of a compound that contains carbon, hydrogen, and oxygen is burned completely in O₂. Data from the combustion experiment is shown in the table above.
- (a) Determine the mass of carbon (C) present in 5.00 g of the compound.
- (b) Determine the mass of hydrogen (H) present in 5.00 g of the compound.
- (c) Determine the mass of oxygen (O) present in 5.00 g of the compound.
- (d) Determine the empirical formula of the compound.

Another type of situation that involves mass and mole ratios involves a substance known as a hydrate. A hydrate is a substance in which water molecules are included in the chemical formula. These substances are often ionic compounds in which water molecules are bonded to the ions in the crystal structure. A hydrate salt can be heated to remove the water through evaporation, forming an anhydrous salt. Two examples of anhydrous salts and hydrates are listed in the table below.

Anhydrous Salt	Hydrate Salt
copper(II) sulfate, CuSO_4	copper(II) sulfate pentahydrate, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$
calcium chloride, CaCl_2	calcium chloride dihydrate, $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$

20. A sample of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ has a mass of 25.00 g.

(a) Calculate the mass of CuSO_4 present in this 25.00-g sample.

(b) Calculate the mass of H_2O present in this 25.00-g sample.

21. Calculate the percentage of H_2O by mass in $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$.

22. In a certain experiment, a sample of a hydrate of magnesium sulfate, $\text{MgSO}_4 \cdot n\text{H}_2\text{O}$, is heated in order to remove all of the water from the sample. Experimental data is shown in the table below.

mass of empty container	25.356 g
mass of container and hydrate salt, before heating	28.418 g
mass of container and sample after 1 st heating	26.931 g
mass of container and sample after 2 nd heating	26.853 g
mass of container and sample after 3 rd heating	26.852 g

(a) Explain how the data indicates that all of the water has been removed from the hydrate salt in this experiment.

(b) Calculate the mass of the hydrate salt used in this experiment.

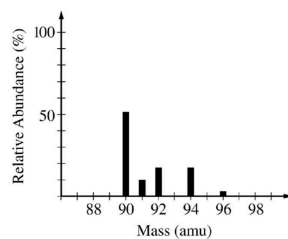
(c) Calculate the mass of water that was removed from the hydrate sample in this experiment.

(d) Determine the value of n in the formula $\text{MgSO}_4 \cdot n\text{H}_2\text{O}$.

1. Which of the following contains the greatest mass of oxygen?

A. 1.00 g Na_2O
 B. 1.00 g MgO
 C. 1.00 g K_2O
 D. 1.00 g CaO

2. The mass spectrum of element X is presented in the diagram to the right. Based on the spectrum, which of the following can be concluded about element X?

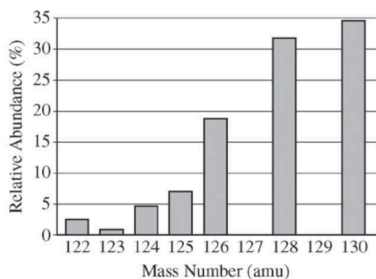


A. X is a transition metal, and each peak represents an oxidation state of the metal.
 B. X contains five electron sublevels.
 C. The atomic mass of X is 90.
 D. The atomic mass of X is between 90 and 92.

3. A 23.0 g sample of a compound contains 12.0 g of C, 3.0 g of H, and 8.0 g of O. Which of the following is the empirical formula of the compound?

A. CH_3O
 B. $\text{C}_2\text{H}_3\text{O}$
 C. $\text{C}_2\text{H}_6\text{O}$
 D. $\text{C}_4\text{H}_6\text{O}$

4. The elements I and Te have similar average atomic masses. A sample that was believed to



be a mixture of I and Te was run through a mass spectrometer, resulting in the data above. All of the following statements are true. Which one would be the best basis for concluding that the sample was pure Te?

A. Te forms ions with a -2 charge, whereas I forms ions with a -1 charge.
 B. Te is more abundant than I in the universe.
 C. I consists of only one naturally occurring isotope with 74 neutrons, whereas Te has more than one isotope.
 D. I has a higher first ionization energy than Te does.

5. A sample of a compound that contains only the elements C, H, and N is completely burned in O_2 to produce 44.0 g of CO_2 , 45.0 g of H_2O , and some NO_2 . A possible empirical formula of the compound is

A. CH_2N
 B. CH_5N
 C. $\text{C}_2\text{H}_5\text{N}$
 D. $\text{C}_3\text{H}_3\text{N}_2$

6. M^+ is an unknown metal cation with a $+1$ charge. A student dissolves the chloride of the unknown metal, MCl , in enough water to make 100.0 mL of solution. The student then mixes the solution with excess AgNO_3 solution, causing AgCl to precipitate. The student collects the precipitate by filtration, dries it, and records the data shown below. (*The molar mass of AgCl is 143 g/mol.*)

Mass of unknown chloride, MCl , 0.74 g

Mass of filter paper, 0.80 g

Mass of filter paper plus AgCl precipitate, 2.23 g

What is the identity of the metal chloride?

A. NaCl
 B. KCl
 C. CuCl
 D. LiCl

7. Complete combustion of a sample of a hydrocarbon in excess oxygen produces equimolar quantities of carbon dioxide and water. Which of the following could be the molecular formula of the compound?

A. C_2H_2
 B. C_2H_6
 C. C_4H_8
 D. C_6H_6

8. After completing an experiment to determine gravimetrically the percentage of water in a hydrate, a student reported a value of 38 percent. The correct value for the percentage of water in the hydrate is 51 percent. Which of the following is the most likely explanation for this difference?

A. The anhydrous salt had absorbed moisture from the air before its mass was recorded.
 B. Strong initial heating of the solid hydrate caused some of the sample to spatter out of the crucible.
 C. The crucible had not been heated to constant mass before it was used in the experiment.
 D. Excessive heating caused the anhydrous salt to undergo a decomposition reaction.

CB Topic 1.4 Composition of MixturesVideo: https://youtu.be/FPdhwLE0Pdo?si=ldEXHbrYD_LTcZlaEssential knowledge statements from the AP Chemistry CED:

- While pure substances contain molecules or formula units of a single type, mixtures contain molecules or formula units of two or more types, whose relative proportions can vary.
 - Elemental analysis can be used to determine the relative numbers of atoms in a substance and to determine its purity.
-

Mass of NaCl	Mass of MgCl ₂	Total Mass of Mixture
2.75 g	3.42 g	6.17 g

1. Answer the following questions about the mixture whose composition is listed in the table above.

(a) Calculate the percentage of NaCl by mass in this mixture.

(b) Calculate the percentage of Na by mass in this mixture.

(c) Calculate the percentage of Cl by mass in this mixture.

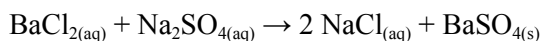
2. A sample of a solid labeled as AgNO₃ may be impure. A student analyzes the sample, and determines that it contains 68% Ag by mass.

(a) Calculate the percentage of Ag by mass in a pure sample of AgNO₃.

(b) Which of the following is more likely to represent the solid sample that was analyzed by the student? Justify your answer.

a mixture of AgNO ₃ and AgCl	a mixture of AgNO ₃ and AgBr
---	---

3. A student needs to analyze a mixture that contains BaCl_2 and NaCl . The student dissolves a 6.75-g sample of this mixture completely into water and adds an excess amount of $\text{Na}_2\text{SO}_4(\text{aq})$. A white precipitate of $\text{BaSO}_4(\text{s})$ is formed, based on the following chemical equation.



The solid precipitate is filtered, dried, and weighed, and its mass is recorded as 2.36 g.

(a) Calculate the number of moles of $\text{BaSO}_4(\text{s})$ that is recovered in this experiment.

(b) Calculate the percentage of BaCl_2 by mass in this mixture.

4. A mixture of CaCO_3 and Na_2CO_3 is found to contain 35.00% Na by mass. Calculate the percentage of Na_2CO_3 by mass in this mixture.

CB Topic 1.5 Atomic Structure and Electron Configuration

Video: https://youtu.be/FPdhwLE0Pdo?si=ldEXHbrYD_LTcZla

Essential knowledge statements from the AP Chemistry CED:

- The atom is composed of negatively charged electrons and a positively charged nucleus that is made of protons and neutrons.
- Coulomb's law is used to calculate the force between two charged particles.

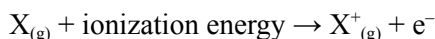
$$F_{\text{coulombic}} \propto \frac{q_1 q_2}{r^2}$$

- In atoms and ions, the electrons can be thought of as being in “shells (energy levels)” and “subshells (sublevels),” as described by the electron configuration. Inner electrons are called core electrons, and outer electrons are called valence electrons. The electron configuration is explained by quantum mechanics, as delineated in the Aufbau principle and exemplified in the periodic table of the elements.
- The relative energy required to remove an electron from different subshells of an atom or ion or from the same subshell in different atoms or ions (ionization energy) can be estimated through a qualitative application of Coulomb's law. This energy is related to the distance from the nucleus and the effective (shield) charge of the nucleus.

5. The valence electrons of both Na and Mg are located in the 3rd energy level. Which atom, Na or Mg, experiences a greater attractive force between the nucleus and the valence electrons? Justify your answer in terms of Coulomb's law.

6. The valence electron of Na is located in the 3rd energy level, whereas the valence electron of K is located in the 4th energy level. Which atom, Na or K, experiences a greater attractive force between the nucleus and the valence electron? Justify your answer in terms of Coulomb's law.

7. Ionization energy is normally expressed in units of kilojoules per mole, and is defined as the energy required to remove one mole of electrons from one mole of gaseous atoms (or ions) in their ground states. This process is represented by the equation below.



Based on your answers to Questions #5 and #6, arrange the atoms Na, Mg, and K in order of increasing ionization energy value.

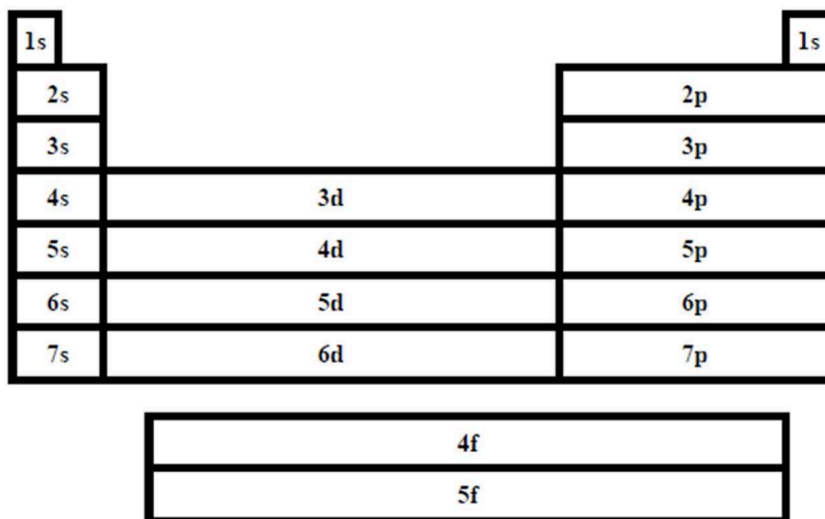
lowest ionization energy value	----->	highest ionization energy value

The Bohr Model of the Hydrogen Atom (1913)

- Electrons travel in orbits around the nucleus. Only orbits of certain radii, corresponding to certain specific energy values, are permitted for the electron.
- An electron absorbs energy when it moves farther away from the nucleus from a lower energy level to a higher energy level. An electron releases energy when it moves closer to the nucleus from a higher energy level to a lower energy level.
- The letter “n” refers to the principal quantum number or the electronic energy level. The lowest energy level (n = 1) for a hydrogen atom is called the ground state. The higher energy levels (n = 2 or higher) are called excited states.

The Bohr model of the hydrogen atom is a primitive, inaccurate model. Today we do not think of electrons as moving in orbits around the nucleus. Instead, we use the term atomic orbital, which is a mathematical function used to indicate the probability of finding an electron. We can visualize atomic orbitals as “electron clouds.”

The **electron configuration** is the distribution of the electrons in an atom or an ion among the various orbitals. There are patterns on the periodic table that help you write the electron configuration of an atom or an ion.



8. Fill in the missing information in the table below.

Element Symbol	Atomic Number	Complete Electron Configuration	Noble Gas Abbreviated Electron Configuration
O	8	$1s^2 2s^2 2p^4$	[He] $2s^2 2p^4$
			[Ne] $3s^2 3p^1$
Ca		$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$	
	26		
As			
Cd			

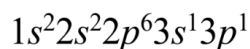
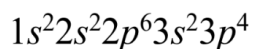
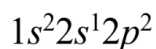
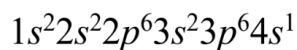
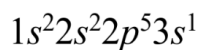
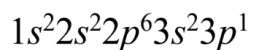
An **orbital diagram** is another way to represent the electron configuration. Each box represents an orbital. Each electron is represented by an arrow. Electrons that have opposite spins are represented by a pair of arrows pointing in opposite directions. Electrons are paired when they occupy the same orbital. An unpaired electron is an electron in an orbital without another electron of opposite spin.

9. Fill in the missing information in the table below.

Element Symbol	Atomic Number	Orbital Diagram for the Electron Configuration
Be	4	 $1s$ $2s$ $2p$ $3s$
N	7	 $1s$ $2s$ $2p$ $3s$
O	8	 $1s$ $2s$ $2p$ $3s$
Na	11	 $1s$ $2s$ $2p$ $3s$

The **ground state** electron configuration refers to the arrangement of the electrons in the lowest available energy levels. An **excited state** electron configuration refers to a situation in which at least one of the electrons has moved up to a higher energy level.

10. Circle all of the following that represent an excited state electron configuration.



Electron Configurations of Ions

- When electrons are removed from an atom to form a cation, they are always removed first from the occupied orbitals having the largest principal quantum number n (energy level).
- When electrons are added to an atom to form an anion, they are added to the empty or partially filled orbital that has the lowest value of n .
- When an atom of a transition metal (e.g., elements #21 – #30 and #39 – #48) loses electrons to become a cation, the electrons are first removed from the valence s orbitals. If additional electrons are lost, they are removed from the valence d orbitals.

11. Write the ground state electron configuration for the following ions.

Ca^{2+} _____

Fe^{2+} _____

O^{2-} _____

Fe^{3+} _____

Stop the Video at 46:51. NO need to continue to topic 1.6. We will cover this topic together in class.

CB Topics 1.4 - 1.5 MC PracticeVideo: https://www.youtube.com/watch?v=kU_Rj7mQgbs

1. A student performed a gravimetric analysis experiment to determine the percentage of Ag by mass in an alloy containing a mixture of Ag and Cu. A sample of the alloy is dissolved completely in a solution of $\text{HNO}_{3(aq)}$, forming the aqueous ions $\text{Ag}^+_{(aq)}$ and $\text{Cu}^{2+}_{(aq)}$. An excess amount of $\text{NaCl}_{(aq)}$ is added to this solution, causing the formation of a precipitate, $\text{AgCl}_{(s)}$. The student collects the precipitate by filtration, dries it, and records its mass. Data from the experiment is shown below.

Mass of Ag/Cu alloy	2.00 g
Mass of $\text{AgCl}_{(s)}$ precipitate	0.72 g

Based on the information in the data table, which of the following best represents the percent of Ag by mass in the alloy?

- A. 27%
 B. 36%
 C. 54%
 D. 75%
2. The mass percent of potassium in pure K_2SO_4 is 45%. A chemist analyzes an impure sample of K_2SO_4 and determines that the mass percent of potassium is 50%. Which of the following impurities could account for the high mass percent of potassium in the sample?
- a. KBr
 b. KI
 c. KCN
 d. KMnO_4

3. A mixture of LiCl and NaCl is analyzed and found to contain 5.00 percent Li by mass. Which of the following best represents the mass percent of LiCl in this mixture?
- a. 11.8%
 b. 30.5%
 c. 2.0%
 d. 81.9%
4. Which of the following represents the ground state electron configuration for an atom of tin (Sn)?
- a. $[\text{Kr}] 5s^2 5p^2$
 b. $[\text{Kr}] 4d^{10} 5s^2 5p^2$
 c. $[\text{Kr}] 5d^{10} 5s^2 5p^2$
 d. $[\text{Kr}] 4d^{10} 5p^2$
5. Which of the following choices correctly identifies the number of unpaired electrons in the ground state electron configuration for an atom of that element?

	Element	Number of Unpaired Electrons
(A)	S	1
(B)	Mg	2
(C)	Co	3
(D)	Ti	4

6. Which of the following represents the ground state electron configuration for the Mn^{3+} ion?
- a. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$
 b. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^2$
 c. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^1$
 d. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^4$

CB Topic 1.7 Periodic TrendsVideo: <https://youtu.be/QWNlmABCavQ?si=Vrvpxk6w1V3No8kC>

Essential knowledge statements from the AP Chemistry CED:

- The organization of the periodic table is based on the recurring properties of the elements and explained by the pattern of electron configurations and the presence of completely or partially filled shells (and subshells) of electrons in atoms.
- Trends in atomic properties within the periodic table (periodicity) can be qualitatively understood through the position of the element in the periodic table, Coulomb's law, the shell model, and the concept of shielding/effective nuclear charge. These properties include the following.
 - atomic and ionic radii
 - ionization energy
 - Electronegativity
 - electron affinity
- Periodicity is useful to predict /estimate values of properties in the absence of data.

Coulomb's law describes the force between two charged particles. This equation is useful when studying periodic trends.

$$F_{\text{coulombic}} \propto \frac{q_1 q_2}{r^2}$$

When comparing the atoms of two different elements that are located in the same period,

- The valence electrons of each atom are located in the same energy level.
- The element with more protons has a greater nuclear charge, and there is a stronger attraction between the nucleus and the valence electrons.
- According to Coulomb's law, the greater the magnitude of charge, the stronger the attractive force between oppositely charged particles.

When comparing the atoms of two different elements that are located in the same group,

- The valence electrons of each atom are located in different energy levels.
- Electrons located in a higher energy level are farther away from the nucleus.
- Electrons located in a lower energy level are closer to the nucleus.
- According to Coulomb's law, the smaller the distance between oppositely charged particles, the greater the attractive force between them.

1. Which element, Li or Be, has a smaller atomic radius? Justify your answer in terms of atomic structure and Coulomb's law.

2. Which element, Li or Na, has a smaller atomic radius? Justify your answer in terms of atomic structure and Coulomb's law.

3. Based on your answers to Questions #1 and #2, arrange the atoms Li, Be, and Na in order of increasing atomic radius.

smallest atomic radius	----->	largest atomic radius

4. The atomic radius of the Na atom is different than the ionic radius of the Na⁺ ion.

(a) Write the complete ground state electron configuration for Na and for Na⁺.

Na:

Na⁺ :

(b) Which particle, Na or Na⁺, has a larger radius? Justify your answer in terms of atomic structure.

Ion	Ionic Radius (pm)
Fe ²⁺	92
Fe ³⁺	79

5. The ionic radii of two different ions are shown in the table above.

(a) Write the ground state electron configuration for Fe²⁺ and for Fe³⁺.

Fe²⁺:

Fe³⁺:

(b) In terms of atomic structure, explain why the ionic radius of Fe²⁺ is larger than that of Fe³⁺.

6. The atomic radius of the F atom is different than the ionic radius of the F⁻ ion.

(a) Write the complete ground state electron configuration for F and for F⁻.

F:

F⁻:

(b) Which particle, F or F⁻, has a larger radius? Justify your answer in terms of atomic structure.

K ⁺	Ca ²⁺	S ²⁻	Cl ⁻
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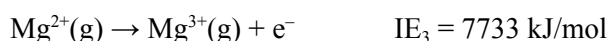
7. Each of the ions shown in the table above are members of an isoelectronic series. This means that each ion has the same number of electrons.

(a) Arrange these ions in order of increasing ionic radius.

smallest ionic radius	----->	----->	largest ionic radius

(b) Justify your answer.

Ionization energy is normally expressed in units of kilojoules per mole, and is defined as the energy required to remove one mole of electrons from one mole of gaseous atoms (or ions) in their ground states. Removing the outermost electron from a neutral atom is called the first ionization energy (IE₁). Removing the outermost electron from a +1 ion is called the second ionization energy (IE₂), etc.



8. As you move from left to right across a horizontal row (period) on the periodic table, atomic radius values tend to _____ from left to right, and first ionization energy values tend to _____ from left to right.

9. As you move from top to bottom down a vertical column (group) on the periodic table, atomic radius values tend to _____ from top to bottom, and first ionization energy values tend to _____ from top to bottom.

On the AP Exam:

- you will NOT earn credit for simply referring to the relative position of the elements on the periodic table without an explanation.
- you will NOT earn credit for using one trend to explain another trend.

<i>Explain why the first ionization energy value of Mg (738 kJ/mol) is greater than the first ionization energy value of Na (496 kJ/mol).</i>	
Ionization energy increases from left to right across a period. Therefore it requires more energy to remove a valence electron from a Mg atom than it does to remove a valence electron from a Na atom.	Unacceptable response because there is no explanation.
Mg has a smaller atomic radius than Na. Therefore it requires more energy to remove a valence electron from a Mg atom than it does to remove a valence electron from a Na atom.	Unacceptable response because it uses one trend to explain another trend.
The valence electrons in Na and Mg are located in the same energy level ($n = 3$). Na has 11 protons, and Mg has 12 protons. Since Mg has a greater nuclear charge than Na, there is a stronger attraction between the nucleus and the valence electrons. Therefore it requires more energy to remove a valence electron from a Mg atom than it does to remove a valence electron from a Na atom.	Acceptable response because it uses principles of atomic structure to explain the data.

<i>Explain why the first ionization energy value of K (419 kJ/mol) is less than the first ionization energy value of Na (496 kJ/mol).</i>	
Ionization energy decreases from top to bottom down a group. Therefore it requires less energy to remove a valence electron from a K atom than it does to remove a valence electron from a Na atom.	Unacceptable response because there is no explanation.
K has a larger atomic radius than Na. Therefore it requires less energy to remove a valence electron from a K atom than it does to remove a valence electron from a Na atom.	Unacceptable response because it uses one trend to explain another trend.
Na has three occupied energy shells, and K has four occupied energy shells. The valence electron in Na is located in a 3s orbital, whereas the valence electron in K is located in a 4s orbital. Since the valence electron in K is farther away from the nucleus than the valence electron in Na, there is a weaker attraction between the nucleus and the valence electron. Therefore it requires less energy to remove a valence electron from a K atom than it does to remove a valence electron from a Na atom.	Acceptable response because it uses principles of atomic structure to explain the data.

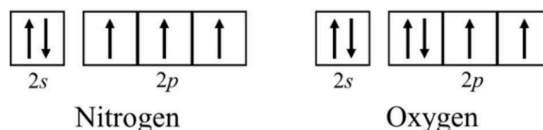
These two anomalies are NEW for you! We will also review them in class.

Two Anomalies in the Horizontal Trend for First Ionization Energy

Element	Li	Be	B	C
Electron Configuration	$1s^2 2s^1$	$1s^2 2s^2$	$1s^2 2s^2 2p^1$	$1s^2 2s^2 2p^2$
Ionization Energy (kJ/mol)	520	899	801	1086

Although B has one more proton than Be, the ionization energy of B is slightly less than that of Be. This decrease in ionization energy can be explained as follows. The outermost electron for B is located in the 2p subshell, whereas the outermost electron for Be is located in the 2s subshell. The 2p subshell is slightly higher in energy than the 2s subshell. It requires slightly less energy to remove an electron from the 2p subshell than it does to remove an electron from the 2s subshell.

Element	C	N	O	F
Electron Configuration	$1s^2 2s^2 2p^2$	$1s^2 2s^2 2p^3$	$1s^2 2s^2 2p^4$	$1s^2 2s^2 2p^5$
Ionization Energy (kJ/mol)	1086	1402	1314	1681



Although O has one more proton than N, the ionization energy of O is slightly less than that of N. This decrease in ionization energy can be explained as follows. There is slightly more electron-electron repulsion between the paired electrons in the p^4 configuration of O as compared to the p^3 configuration of N. This electron repulsion in the p^4 configuration explains why it requires slightly less energy to remove an electron from an atom of O than it does to remove an electron from an atom of N.

Element	1 st IE	2 nd IE	3 rd IE	4 th IE	5 th IE	6 th IE	7 th IE
Na	496	4562	6910	9543	13,354	16,613	20,117
Mg	738	1451	7733	10,543	13,630	18,020	21,711
Al	578	1817	2745	11,577	14,842	18,379	23,326
Si	786	1577	3232	4356	16,091	19,805	23,780
P	1012	1907	2914	4964	6274	21,267	25,431
S	1000	2252	3357	4556	7004	8496	27,107
Cl	1251	2298	3822	5159	6542	9362	11,018

10. Consider the data for successive ionization energy in the table above.

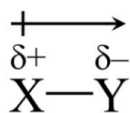
(a) In terms of atomic structure and Coulomb's law, explain why the ionization energy values increase as successive electrons are removed from an atom.

(b) In terms of atomic structure and Coulomb's law, explain why the 2nd IE for Na is much higher than the 2nd IE for Mg.

Element	1 st IE	2 nd IE	3 rd IE	4 th IE	5 th IE
X	1087	2353	4621	6223	37,831

11. Based on the information in the table above, how many valence electrons does element X have? Justify your answer.

Electronegativity is defined as the tendency of an atom to attract electrons to itself in a chemical bond. The higher the electronegativity value is, the greater the attraction for electrons. Electronegativity values are used when determining if a particular chemical bond is classified as nonpolar covalent, polar covalent, or ionic. The greater the difference in electronegativity between two atoms, the more polar the bond is. Suppose that a polar covalent bond is formed between two atoms X and Y as shown below.



If atom X is less electronegative than atom Y, there is a partial positive charge ($\delta+$) on atom X and a partial negative charge ($\delta-$) on atom Y. The arrow above the polar covalent bond represents the dipole, which is generated whenever two electrical charges of opposite sign are separated by a distance. The arrow always points toward the atom that has the higher electronegativity value. The measure of the magnitude of the dipole is called the dipole moment. In general, the greater the difference in electronegativity, the greater the magnitude of the dipole moment.

Electronegativity Values

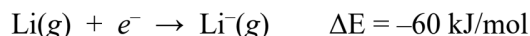
H 2.1						
Li 1.0	Be 1.5	B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.2	Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0
K 0.8	Ca 1.0	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8
Rb 0.8	Sr 1.0	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5

Notice that the noble gases (He, Ne, Ar, etc.) are not included in the data table above. This is because the atoms of the noble gases ordinarily do not form chemical bonds or share electrons with other atoms.

12. As you move from left to right across a horizontal row (period) on the periodic table, electronegativity values tend to _____ from left to right. As you move from top to bottom down a vertical column (group) on the periodic table, electronegativity values tend to _____ from top to bottom.

13. The smaller the atomic radius is, the the electronegativity value is _____. The larger the atomic radius is, the _____ the electronegativity value is. The most electronegative element on the periodic table is _____.

Electron affinity is a periodic trend that is a bit confusing to understand. Electron affinity is defined as the energy change that occurs when an electron is added to a gaseous atom to form a negatively charged anion. Consider the following examples.



If ΔE is negative, energy is released. If ΔE is positive, energy is absorbed. The greater the attraction is between an atom and an added electron, the more negative the value of ΔE is. The more negative the value of ΔE is, the greater the electron affinity is. As you can see in the table below, the trends in electron affinity are not necessarily clear and predictable.

In general, more energy is released when a nonmetal atom gains an electron than when a metal atom gains an electron. For the noble gases, the electron affinity has a positive value. This indicates that the $\text{X}^{-}(g)$ ion is less stable than the $\text{X}(g)$ atom.

Electron Affinity (kJ/mol)

H -73							He +48
Li -60	Be +48	B -27	C -122	N +7	O -141	F -328	Ne +116
Na -53	Mg +40	Al -42	Si -134	P -72	S -200	Cl -349	Ar +96
K -48	Ca -2	Ga -29	Ge -119	As -78	Se -195	Br -325	Kr +96

CB Topic 1.8 Valence Electrons and Ionic Compounds Video: <https://youtu.be/QWNlmABCavO?si=Vrvpxk6w1V3No8kC>

Essential knowledge statements from the AP Chemistry CED:

- The likelihood that two elements will form a chemical bond is determined by the interactions between the valence electrons and nuclei of elements.
- Elements in the same column of the periodic table tend to form analogous compounds.
- Typical charges of atoms in ionic compounds are governed by their location on the periodic table and the number of valence electrons.

14. Write the correct number of valence electrons for each of the following elements.

Element	Li	Be	B	C	N	O	F	Ne
Valence Electrons								

15. Write the correct charge (e.g., 1+, 2+, 1-, 2-, etc.) that each of the following elements has when it forms a stable monoatomic ion.

Element	Li	Be	B	C	N	O	F	Ne
Charge				N/A				

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	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi			Rn

metal	nonmetal	metalloid
-------	----------	-----------

Binary ionic compounds (e.g., NaCl) normally consist of a metal and a nonmetal. The chemical formula of a binary ionic compound can be determined by examining the charges on each ion. The formula is written as an empirical formula, and should have an overall charge of zero.

16. Write the correct chemical formula for the binary ionic compound that is formed from the combination of each of the following pairs of elements.

Elements	Chemical Formula of the Binary Ionic Compound
Li and F	
Na and S	
Mg and Cl	
Al and O	
Ca and P	

Elements in the same group (column) of the periodic table have the same number of valence electrons. This explains why elements in the same group tend to form analogous compounds.

CB Topics 1.7 - 1.8 MC Practice

Video: <https://www.youtube.com/watch?v=k3FsdRWpapE>

Element	Atomic Radius	First Ionization Energy
Calcium	194 pm	590 kJ/mol
Potassium	–	–

1. Based on periodic trends and the data in the table above, which of the following are the most probable values of the atomic radius and the first ionization energy for potassium, respectively?

- A. 242 pm, 633 kJ/mol
- B. 242 pm, 419 kJ/mol
- C. 120 pm, 633 kJ/mol
- D. 120 pm, 419 kJ/mol

2. Which of the following correctly identifies which has the higher first-ionization energy, Cl or Ar, and supplies the best justification?

- A. Cl, because of its higher electronegativity
- B. Cl, because of its higher electron affinity
- C. Ar, because of its completely filled valence shell
- D. Ar, because of its higher effective nuclear charge

3. Which of the following correctly compares periodic properties of two elements and provides an accurate explanation for that difference?

- A. The first ionization energy of Si is greater than that of C because Si has a greater number of protons in its nucleus than C has.
- B. The first ionization energy of Cl is greater than that of S because S has a higher electronegativity than Cl has.
- C. The atomic radius of Br is larger than that of Cl because Br has one more occupied electron shell, which increases the distance between the valence electrons and the nucleus.
- D. The atomic radius of Ca is smaller than that of Mg because Ca has a larger nuclear charge than Mg does.

	Ionization Energy (kJ/mol)
First	738
Second	1,451
Third	7,733
Fourth	10,543
Fifth	13,630

4. The table to the right shows the first ionization energy and atomic radius of several elements.

Which of the following best helps to explain the deviation of the first ionization energy of oxygen from the overall trend?

Element	First Ionization Energy (kJ/mol)	Atomic Radius (pm)
B	801	85
C	1086	77
N	1400	75
O	1314	73
F	1680	72
Ne	2080	70

- A. The atomic radius of oxygen is greater than the atomic radius of fluorine.
- B. The atomic radius of oxygen is less than the atomic radius of nitrogen.
- C. There is repulsion between paired electrons in oxygen's $2p$ orbitals.
- D. There is attraction between paired electrons in oxygen's $2p$ orbitals.

5. The first five ionization energies of a second-period element are listed in the table to the right.

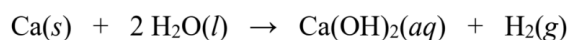
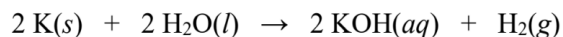
Which of the following correctly identifies the element and best explains the data in the table?

	Ionization Energy (kJ/mol)
First	801
Second	2,430
Third	3,660
Fourth	25,000
Fifth	32,820

- A. B, because it has five core electrons
- B. B, because it has three valence electrons
- C. N, because it has five valence electrons
- D. N, because it has three electrons in the p sublevel

6. Based on the ionization energies of element X given in the table to the left, which of the following is most likely to be the empirical formula of an oxide of element X?

- A. XO
- B. XO₂
- C. X₂O
- D. X₂O₃



7. Both K(s) and Ca(s) react with water according to the equations shown above. Which of the following identifies the element that reacts more vigorously with water and provides the correct justification?

	Element that reacts more vigorously with water	Justification
(A)	K	The first ionization energy of K is less than that of Ca.
(B)	K	In aqueous solution, the attraction between $\text{K}^+(aq)$ and H_2O molecules is stronger than the attraction between $\text{Ca}^{2+}(aq)$ and H_2O molecules.
(C)	Ca	The first ionization energy of K is less than that of Ca.
(D)	Ca	In aqueous solution, the attraction between $\text{Ca}^{2+}(aq)$ and H_2O molecules is stronger than the attraction between $\text{K}^+(aq)$ and H_2O molecules.

8. Properties of the compound CaCl_2 are listed in the table below. On the basis of periodic properties, which of the following compounds should have properties that are most similar to those of CaCl_2 ?

- A. SCl_2
 B. BaCl_2
 C. BCl_3
 D. CCl_4

Appearance	white powder
Solubility	75 g CaCl_2 per 100 mL H_2O
Melting point	772°C

9. Based on the positions of elements in the periodic table, which of the following pairs contains compounds that are most likely to have similar chemical properties?

- A. SeO_2 and TiO_2
 B. CaC_2 and CaF_2
 C. MgCl_2 and MgBr_2
 D. ScCl_3 and PCl_3

CB Topic 3.2 Composition of Mixtures

Video: https://youtu.be/bFYtg63Pn1A?si=UU9vvknGpTtNg_tZ

Essential knowledge statements from the AP Chemistry CED:

- Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present. Because intermolecular interactions are broken when a substance vaporizes, the vapor pressure and boiling point are directly related to the strength of those interactions. Melting points also tend to correlate with interaction strength, but because the interactions are only rearranged, in melting, the relations can be more subtle.
- Particulate-level representations, showing multiple interacting chemical species, are a useful means to communicate or understand how intermolecular interactions help to establish macroscopic properties.
- Due to strong interactions between ions, ionic solids tend to have low vapor pressures, high melting points, and high boiling points. They tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. They conduct electricity only when the ions are mobile, as when the ionic solid is melted or dissolved in water or another solvent.
- In covalent network solids, the atoms are covalently bonded together into a three-dimensional network (e.g., diamond) or layers of two-dimensional networks (e.g., graphite). These are only formed from nonmetals: elemental (e.g., diamond, graphite) or binary compounds of two nonmetals (e.g., silicon dioxide and silicon carbide). Due to the strong covalent interactions, covalent solids have high melting

points. Three-dimensional network solids are also rigid and hard, because the covalent bond angles are fixed. However, graphite is soft because adjacent layers can slide past each other relatively easily.

- Molecular solids are composed of distinct, individual units of covalently-bonded molecules attracted to each other through relatively weak intermolecular forces. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. They do not conduct electricity because their valence electrons are tightly held within the covalent bonds and the lone pairs of each constituent molecule. Molecular solids are sometimes composed of very large molecules or polymers.
- Metallic solids are good conductors of electricity and heat, due to the presence of free valence electrons. They also tend to be malleable and ductile, due to the ease with which the metal cores can rearrange their structure. In an interstitial alloy, interstitial atoms tend to make the lattice more rigid, decreasing malleability and ductility. Alloys typically retain a sea of mobile electrons and so remain conducting.
- In large biomolecules or polymers, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule. The functionality and properties of such molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions.

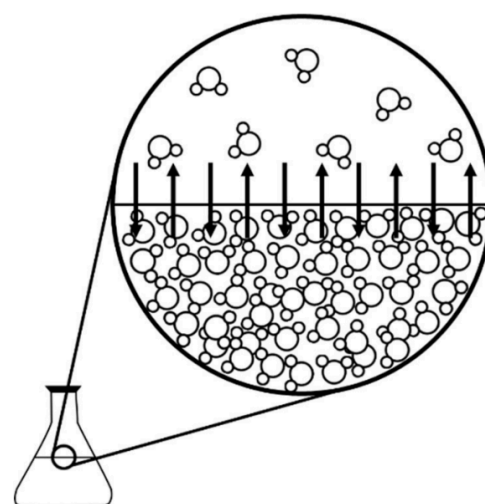
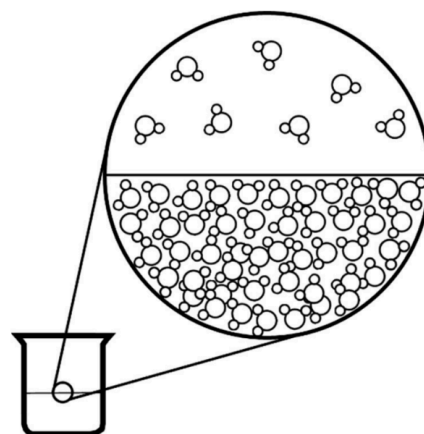
The first diagram shown at right represents a sample of pure water in a beaker at room temperature. The close-up view shows a particulate model of H₂O molecules near the surface of the liquid. The molecules in the liquid phase are moving at different speeds and have a range of values for kinetic energy.

Some of the molecules near the surface have sufficient energy to overcome the intermolecular forces between them. They can escape from the liquid phase and enter the space above the liquid surface.

Eventually the beaker will become dry when the sample of water evaporates completely.

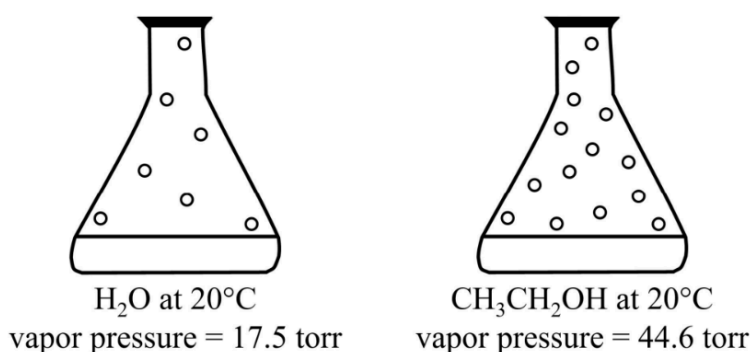
The second diagram shown at right represents a sample of pure water in a sealed flask at room temperature. The arrows in the close-up view indicate that molecules undergo both evaporation and condensation. A point is reached in this sealed container in which the rate of evaporation is equal to the rate of condensation. This is a state of dynamic equilibrium. As long as the temperature remains constant, the number of water molecules in the gas phase remains constant.

The **vapor pressure** of a liquid is defined as the pressure exerted by a gas in equilibrium with its liquid phase at a given temperature.



Temp. (°C)	VP (torr)	Temp. (°C)	VP (torr)	Temp. (°C)	VP (torr)
10	9.21	40	55.3	70	233.7
20	17.54	50	92.5	80	355.1
30	31.82	60	149.4	90	525.8

1. The table above shows the vapor pressure of H₂O at various temperatures. Explain why the vapor pressure of water (or any liquid, for that matter) will increase when the temperature of the liquid increases. Discuss the kinetic energy of the particles in your answer.



The diagram above shows two sealed flasks at 20°C. The flask on the left contains a sample of pure H₂O, and the flask on the right contains a sample of pure ethanol (CH₃CH₂OH).

2. Answer the following questions based on the information in the diagram.

(a) Which substance, water or ethanol, appears to evaporate more easily at 20°C?

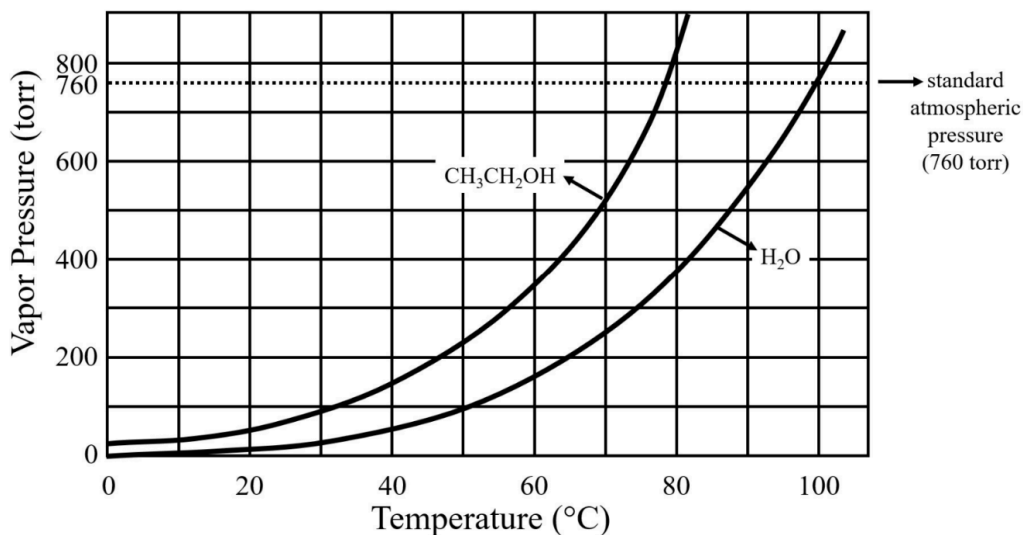
(b) Which substance, water or ethanol, is more likely to experience stronger intermolecular attractive forces in the liquid phase?

(c) Which substance, water or ethanol, is more likely to have the higher boiling point?

3. When comparing two different liquids at the same temperature, the liquid that has a (lower / higher) vapor pressure should also be the liquid that has a (lower / higher) boiling point.

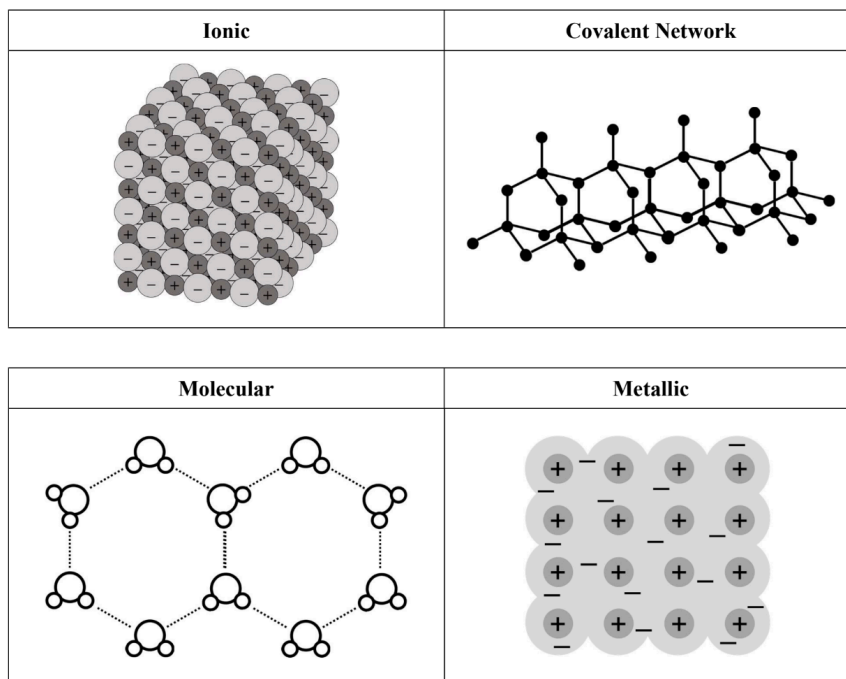
The **boiling point** of a liquid is defined as the temperature at which the vapor pressure of the liquid is equal to the external pressure surrounding the liquid.

The **normal boiling point** of a liquid refers to the situation in which the vapor pressure of the liquid is equal to standard atmospheric pressure at sea level, which is usually defined as 1 atmosphere (1 atm) or 760 torr.



4. The diagram above is a graph of vapor pressure versus temperature for water and ethanol. The normal boiling point of water is 100°C. Use the information in the diagram to estimate the normal boiling point of ethanol.

Particulate-level Representations of Four Different Types of Solid



There are four different types of solids that you should be familiar with in AP Chemistry. Descriptions of each type of solid are shown in the table below.

Type	Ionic	Covalent Network	Molecular	Metallic
Particles	positive and negative ions	atoms	molecules	positive metal cations (nucleus plus core electrons) and valence electrons
Attractions Between Particles	electrostatic attractions between oppositely charged ions	covalent bonds between atoms in a large, extended network	intermolecular attractions between molecules	attractions between positive metal cations and a "sea" of delocalized, mobile valence electrons
Electrical Conductivity	does not conduct as a solid because ions cannot move freely; conducts when melted or dissolved in a solvent because ions can move freely	does not conduct because valence electrons are localized in covalent bonds	does not conduct because the electrons are localized in covalent bonds; the particles are neutral molecules	conducts electricity as a solid because of the mobile valence electrons
Melting Point	relatively high	relatively high	relatively low	varies over a wide range
Other Properties	hard, brittle solid	hard, rigid solid	soft solid	malleable and ductile
Examples	LiBr NaNO ₃ MgO KCl CuSO ₄ PbI ₂	diamond (C) graphite (C) silicon (Si) quartz (SiO ₂) silicon carbide (SiC) boron nitride (BN)	I ₂ CO ₂ CH ₂ Cl ₂ H ₂ O C ₁₀ H ₈ C ₆ H ₁₂ O ₆	Na Mg Al Ni Cu Zn

5. When a sample of solid diamond (C) melts, covalent bonds are broken. However, when a sample of solid H₂O melts, covalent bonds are not broken. Explain.

6. The following information was collected for four different solids, labeled A through D.

Solid	Physical Appearance	Melting Point	Conductivity	Solubility
A	white solid	80°C	nonelectrolyte	slightly soluble in H ₂ O (30 mg/L)
B	gray solid	1414°C	nonelectrolyte	insoluble in H ₂ O
C	white solid	770°C	conducts electricity when dissolved in water	very soluble in H ₂ O (344 g/L)
D	silvery-white solid	1455°C	conducts electricity as a solid	insoluble in H ₂ O

(a) Based on this information, classify each of the four solids into one of the following types: metallic, ionic, covalent network, and molecular

A _____ C _____

B _____ D _____

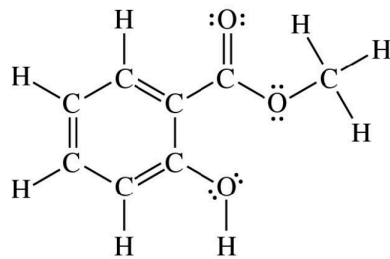
(b) The identity of the four solids are (in no particular order): silicon (Si), nickel (Ni), naphthalene (C₁₀H₈), and potassium chloride (KCl). Make a prediction for the most likely identity of each solid.

A _____ C _____

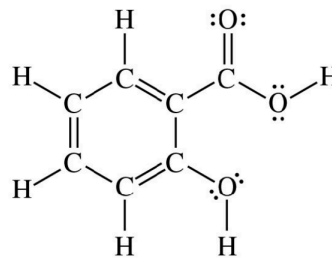
B _____ D _____

Substance	Melting Point (K)	Boiling Point (K)
SiH ₄	88	161
SiO ₂	1986	3220

7. Use principles of interparticle forces to explain the difference in the properties of the two substances shown in the table above.



Methyl Salicylate
Melting Point: -9°C



Salicylic Acid
Melting Point: 159°C

8. The structures and melting points for methyl salicylate and salicylic acid are shown above. The same three types of intermolecular forces (London dispersion forces, dipole-dipole interactions, and hydrogen bonding) exist among molecules of each substance. Explain why the melting point of salicylic acid is higher than that of methyl salicylate.

CB Topic 3.3 Solids, Liquids, and Gases

Video: https://youtu.be/bFYtg63Pn1A?si=UU9vvknGpTtNg_tZ

Essential knowledge statements from the AP Chemistry CED:

- Solids can be crystalline, where the particles are arranged in a regular three-dimensional structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both cases, the motion of the individual particles is limited, and the particles do not undergo overall translation with respect to each other. The structure of the solid is influenced by interparticle interactions and the ability of the particles to pack together.
- The constituent particles in liquids are in close contact with each other, and they are continually moving and colliding. The arrangement and movement of particles are influenced by the nature and strength of the forces (e.g., polarity, hydrogen bonding, and temperature) between the particles.
- The solid and liquid phases for a particular substance typically have similar molar volume because, in both phases, the constituent particles are in close contact at all times.
- In the gas phase, the particles are in constant motion. Their frequencies of collision and the average spacing between them are dependent on temperature, pressure, and volume. Because of this constant motion, and minimal effects of forces between particles, a gas has neither a definite volume nor a definite shape.

Essential knowledge statements from the AP Chemistry CED:

- The macroscopic properties of ideal gases are related through the ideal gas law.
 - Equation: $PV = nRT$
- In a sample containing a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the total pressure of the sample is the sum of the partial pressures.
 - Equation: $P_A = P_{\text{total}} \times X_A$ where $X_A = \text{moles}_A / \text{moles}_{\text{Total}}$
 - Equation: $P_{\text{total}} = P_A + P_B + P_C + \dots$
- Graphical representations of the relationships between P , V , T , and n are useful to describe gas behavior.

Properties of an Ideal Gas

- Gas particles are in constant random, rapid motion.
- Gases expand to fill their container completely.
- Two or more gases will form a homogeneous mixture when they are combined together.
- Gases are highly compressible.
- The volume of the gas particles themselves is negligible compared to the volume occupied by the gas.
- Collisions of gas particles are perfectly elastic, meaning that energy is transferred but not lost during collisions.
- There are no attractive or repulsive forces between the gas particles.

Here is a portion of the AP Chemistry Equations and Constants Sheet that includes information about gases. Note this was updated for Fall of 2024. Below shows what you will have.

GASES, LIQUIDS, AND SOLUTIONS

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$PV = nRT$$

$$P_A = P_{\text{total}} \times X_A, \text{ where } X_A = \frac{\text{moles } A}{\text{total moles}}$$

$$P_{\text{total}} = P_A + P_B + P_C + \dots$$

$$n = \frac{m}{M}$$

$$D = \frac{m}{V}$$

$$KE = \frac{1}{2}mv^2$$

$$M = \frac{n_{\text{solute}}}{L_{\text{solution}}}$$

$$A = \epsilon bc$$

P = pressure

V = volume

T = temperature

n = number of moles

X = mole fraction

m = mass

M = molar mass

D = density

KE = kinetic energy

v = velocity

M = molarity

A = absorbance

ϵ = molar absorptivity

b = path length

c = concentration

Gas constant, $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$

$= 0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1}$

STP = 273.15 K and 1.0 atm

Ideal gas at STP = 22.4 L mol^{-1}

Relationships Between Gas Variables (P, V, n, and T)

Variable #1	Relationship	Variable #2	Constant Variables	Equation
P	is inversely proportional to	V	n, T	$P_1V_1 = P_2V_2$
P	is directly proportional to	T	n, V	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
P	is directly proportional to	n	V, T	$\frac{P_1}{n_1} = \frac{P_2}{n_2}$
V	is directly proportional to	n	P, T	$\frac{V_1}{n_1} = \frac{V_2}{n_2}$
V	is directly proportional to	T	n, P	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

9. A student was assigned the task of determining the molar mass of an unknown gas. The student measured the mass of a sealed 843 mL rigid flask that contained dry air. The student then flushed the flask with the unknown gas, resealed it, and measured the mass again. Both the air and the unknown gas were at 23.0°C and 750. torr. The data for the experiment are shown in the table below.

Volume of sealed flask	843 mL
Mass of sealed flask and dry air	157.70 g
Mass of sealed flask and unknown gas	158.08 g

- (a) Calculate the mass, in grams, of the dry air that was in the sealed flask.
(The density of dry air is 1.18 g L⁻¹ at 23.0°C and 750. torr.)
- (b) Calculate the mass, in grams, of the sealed flask itself (i.e., if it had no air in it.)
- (c) Calculate the mass, in grams, of the unknown gas that was added to the sealed flask.
- (d) Using the information above, calculate the value of the molar mass of the unknown gas.
- (e) After the experiment was completed, the instructor informed the student that the unknown gas was carbon dioxide (44.0 g/mol). Calculate the percent error in the value of the molar mass calculated in part (d).

9. (continued)

(f) For each of the following two possible occurrences, indicate whether it by itself could have been responsible for the error in the student's experimental result. You need not include any calculations with your answer. For each of the possible occurrences, justify your answer.

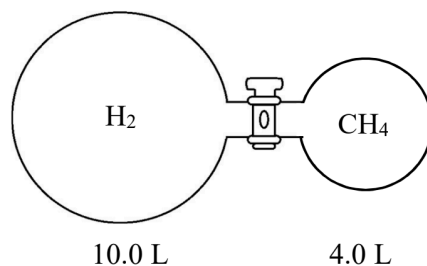
Occurrence 1: The flask was incompletely flushed with $\text{CO}_2(g)$, resulting in some dry air remaining in the flask.

Occurrence 2: The temperature of the air was 23.0°C , but the temperature of the $\text{CO}_2(g)$ was lower than the reported 23.0°C .

(g) Describe the steps of a laboratory method that the student could use to verify that the volume of the rigid flask is 843 mL at 23.0°C . You need not include any calculations in your answer.

10. A pure sample of a gas has a density of 1.31 g/L at 1.00 atm and 25.0°C . What is the molar mass of this gas? Propose a possible identity of this gas.

11. A gas mixture contains 14.0 g $\text{N}_2(g)$ and 32.0 g $\text{O}_2(g)$. The total pressure of the gas mixture is equal to 1200 torr. Calculate the partial pressure of each gas in the mixture.

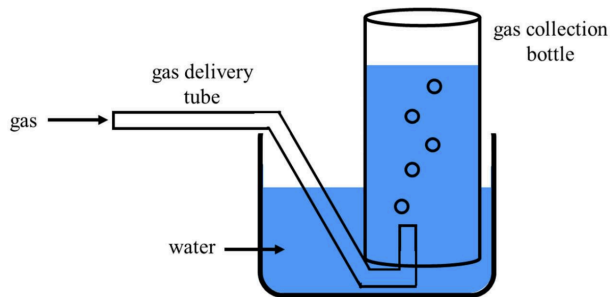


12. In the diagram above, two flasks are connected by a valve that is closed. The flask on the left contains 10.0 L of $\text{H}_2(\text{g})$ at a pressure of 3.0 atm. The flask on the right contains 4.0 L of $\text{CH}_4(\text{g})$ at a pressure of 2.0 atm.

- (a) Calculate the total pressure of the system after the valve is opened and the two gases are mixed completely. Assume that the temperature remains constant and that the total volume of the gas mixture is equal to 14.0 L.

$$\text{mole fraction of A } (X_A) = \frac{\text{moles of A}}{\text{total moles in mixture}}$$

- (b) The definition of mole fraction (X) is shown above. Calculate the mole fraction of H_2 and CH_4 in this gas mixture.



In the laboratory, water displacement can be used to collect a sample of gas. This technique is appropriate to collect a gas that does not react with water or dissolve (very much) in water. A collection bottle is prepared that is initially filled with water and inverted in a container of water. Once the gas has been collected, the collection bottle is raised or lowered so that the water level inside the bottle is the same as the water level outside the bottle. This ensures that the gas pressure inside the bottle is equal to the atmospheric pressure outside the bottle. The total pressure inside the collection bottle is equal to the sum of the partial pressure of the gas collected (P_{gas}) and the vapor pressure of the water ($P_{\text{H}_2\text{O}}$). Values for the vapor pressure of water at various temperatures can be found in a reference table.

$$P_{\text{total}} = P_{\text{atmosphere}} = P_{\text{gas}} + P_{\text{H}_2\text{O}}$$

13. A sample of butane gas was collected by the method of water displacement. The initial mass of a butane lighter is recorded as 22.24 g. The temperature of the water bath is 22°C. The barometric pressure in the laboratory is 755.0 torr. After the gas is collected, the mass of the butane lighter is recorded as 22.02 g. At the end of the experiment, the height of the collection tube is adjusted so that the water levels inside and outside the tube are the same.

Vapor Pressure of Water at Different Temperatures (torr)				
Temperature (°C)	20	21	22	23
Vapor Pressure (torr)	17.54	18.65	19.83	21.07

(a) Based on the information in the table above, what is the value of the vapor pressure of water under the conditions of this experiment?

(b) Calculate the partial pressure of the dry butane gas that is collected in this experiment.

(c) The volume of butane gas collected in this experiment is recorded as 100.0 mL. Calculate the number of moles of butane gas collected in this experiment. Assume that the temperature of the butane gas is the same as the temperature of the water bath.

(d) Calculate the mass of butane gas collected in this experiment.

(e) Calculate the experimental value for the molar mass of butane.

(f) Calculate the percent error for the molar mass value obtained in this experiment. The chemical formula for butane is C_4H_{10} .

14. A sample of a pure, gaseous hydrocarbon is introduced into a previously evacuated rigid 1.00 L vessel. The pressure of the gas is 0.200 atm at a temperature of 127°C.

(a) Calculate the number of moles of the hydrocarbon in the vessel.

14. (continued)

(b) $O_{2(g)}$ is introduced into the same vessel containing the hydrocarbon. After the addition of the $O_{2(g)}$, the total pressure of the gas mixture in the vessel is 1.40 atm at $127^{\circ}C$. Calculate the partial pressure of $O_{2(g)}$ in the vessel.

The mixture of the hydrocarbon and $O_{2(g)}$ is sparked so that a combustion reaction occurs, producing $CO_{2(g)}$ and $H_2O(g)$. The reaction proceeds to completion so that all of the hydrocarbon is consumed. There is some $O_{2(g)}$ remaining in the reaction vessel after the reaction is complete. The temperature inside the reaction vessel is returned to $127^{\circ}C$, and the partial pressure of each gas in the reaction vessel at the end of the reaction are shown in the table below.

Gas	Partial Pressure (atm) at $127^{\circ}C$
$CO_2(g)$	0.600
$H_2O(g)$	0.800
$O_2(g)$	0.200

(c) Calculate each of the following quantities.

$$\frac{\text{moles of } CO_2(g) \text{ produced}}{\text{moles of hydrocarbon consumed}}$$

$$\frac{\text{moles of } H_2O(g) \text{ produced}}{\text{moles of hydrocarbon consumed}}$$

(d) Determine the chemical formula of the hydrocarbon and write the balanced chemical equation for the combustion reaction that occurred in this experiment.

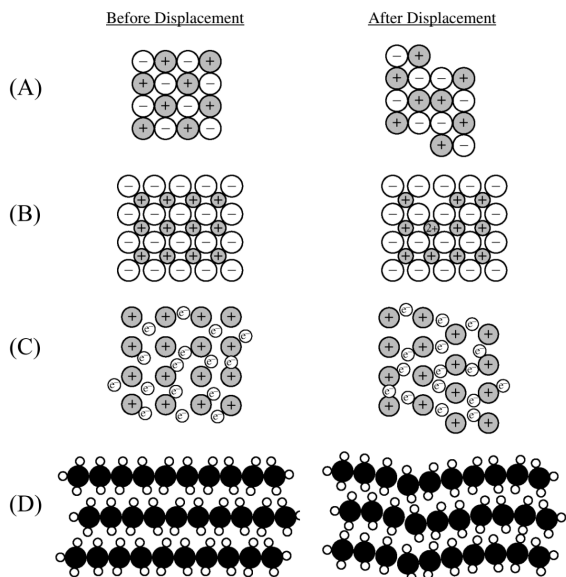
(e) Calculate the mass of the hydrocarbon that was consumed in this experiment.

1. Which of the following could be the identity of a white crystalline solid that exhibits the following properties?

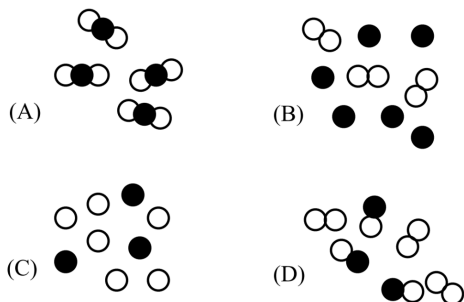
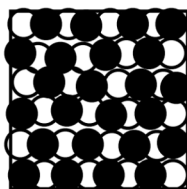
- It melts at 110°C
- It does not conduct electricity as a solid.
- It conducts electricity in an aqueous solution.

- A. $C_{12}H_{22}O_{11(s)}$
- B. $Zn(NO_3)_2(s)$
- C. $SiO_{2(s)}$
- D. $Al_{(s)}$

2. Which of the following diagrams best illustrates how a displacement in an ionic crystal results in cleavage and brittleness?



3. The diagram to the right represents solid carbon dioxide, better known as dry ice. Which diagram below best represents some of the dry ice after it sublimates into a gas?



4. The table below contains data for mercury and water under normal air pressure conditions

substance	Melting Point (°C)	Boiling Point (°C)
mercury	-39	357
water	0.0	100

Based on the data in the table, which of the following pairs of substances could exist at the same temperature?

- A. liquid water and mercury vapor
- B. liquid water and solid mercury
- C. solid water and liquid mercury
- D. water vapor and solid mercury

5. When 4.0 moles of oxygen are confined in a 24-liter vessel at 176°C, the pressure is 6.0 atm. If the oxygen is allowed to expand isothermally (without changing temp) until the gas occupies 36 liters, what will be the new pressure?

- A. 3 atm
- B. 4 atm
- C. 8 atm
- D. 9 atm

6. A 7.0 Liter container will hold about 12 g of which of the following gases at 0°C and 1 atm?

- A. F_2
- B. Cl_2
- C. Br_2
- D. N_2

7. A sealed flask at 20°C contains 1 molecule of carbon dioxide, CO_2 for every 3 atoms of helium, He. If the total pressure is 800 mmHg, the partial pressure of helium is

- A. 200 mmHg
- B. 300 mmHg
- C. 400 mmHg
- D. 600 mmHg

4.4 Chemical and Physical Changes

Essential knowledge statements from the AP Chemistry CED:

- A physical change occurs when a substance undergoes a change in properties but not a change in composition. Changes in the phase of a substance (solid, liquid, gas) or formation/separation of mixtures of substances are common physical changes.
- A chemical change occurs when substances are transformed into new substances, typically with different compositions. Production of heat or light, formation of a gas, formation of a precipitate, and/or color change provide possible evidence that a chemical change has occurred.
- Processes that involve the breaking and/or formation of chemical bonds are typically classified as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes.
- Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.

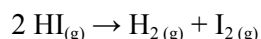
Examples of Physical Changes	Examples of Chemical Changes
<ul style="list-style-type: none"> • a change of phase occurs when a pure substance is heated or cooled • a change in particle size, texture, or shape occurs when the form of a substance changes, without changing its chemical composition • a mixture is formed by combining two or more substances; no new substances are formed • a mixture is separated into simpler substances based on a technique such as distillation, chromatography, or filtration; no new substances are formed 	<ul style="list-style-type: none"> • a change in energy occurs, especially involving heat or light • a new substance is formed with a different chemical composition than any of the original substances • a solid precipitate is formed when aqueous solutions are combined • a gas is formed that is not the result of a simple phase change for a pure substance • an odor is produced, associated with the formation of a new gaseous substance • a change in color occurs that is not the result of a physical change*

*Note that a change in color is not necessarily an indicator of a chemical change. Mixing a sample of blue dye and yellow dye can produce a new green color. However, this is still classified as a physical change because it is simply the formation of a mixture. There is no change in the chemical composition of either dye. On the other hand, if an acid-base indicator changes color from yellow to blue, this event is likely the result of a change in the chemical structure of the indicator.

What Happens at the Particle Level During a Physical Change?	What Happens at the Particle Level During a Chemical Change?
<ul style="list-style-type: none"> • attractive forces between molecules of a pure substance are broken or formed during a phase change • attractive forces between particles of solute and solvent are broken or formed during the separation or the formation of a mixture 	<ul style="list-style-type: none"> • chemical bonds are broken or formed during a process in which a new chemical substances with different chemical compositions are produced

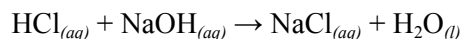
1. A pure sample of liquid water is added to a previously evacuated, rigid flask. The pressure inside the flask increases, eventually reaching a constant value of 20 torr after 30 seconds. The temperature inside the flask is kept at 300 K, and liquid water is observed to remain present at the bottom of the container. Which of the following best describes the change that occurs immediately after the sample of liquid water is added to the flask and gives a correct justification?

	Type of Change	Justification
(A)	Physical	Covalent bonds are broken.
(B)	Physical	Intermolecular attractions are overcome.
(C)	Chemical	Covalent bonds are broken.
(D)	Chemical	Intermolecular attractions are overcome.



2. Which of the following describes the change represented by the equation above and gives a correct justification?

	Type of Change	Justification
(A)	Physical	A mixture of hydrogen and iodine is separated into simpler substances.
(B)	Physical	Covalent bonds are broken and new covalent bonds are formed.
(C)	Chemical	A mixture of hydrogen and iodine is separated into simpler substances.
(D)	Chemical	Covalent bonds are broken and new covalent bonds are formed.



3. A student had two dilute, colorless solutions, $\text{HCl}_{(aq)}$ and $\text{NaOH}_{(aq)}$, which were at the same temperature. The student combined the solutions, and the process represented by the equation above occurred. Which of the following results would be evidence that a chemical reaction took place?

- A. The resulting solution is colorless.
- B. The temperature of the reaction mixture increases.
- C. The total volume of the mixture is approximately equal to the sum of the initial volumes.
- D. The resulting solution conducts electricity.

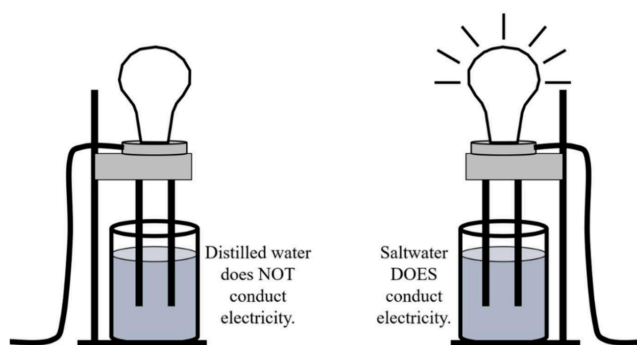
4. A student places a 5.00-gram sample of a dark grey solid into a crucible. The crucible and solid are heated strongly in air for several minutes. The student makes the claim that a chemical reaction has taken place between the dark grey solid and a substance present in the air. Which of the following observations is most likely to support the claim that a chemical reaction has occurred?

- A. The final mass of the solid in the crucible is equal to 5.00 grams after heating.
- B. The final mass of the solid in the crucible is equal to 8.00 grams after heating.
- C. The solid present in the crucible after heating is dark grey in appearance.
- D. The solid present in the crucible after heating is not soluble in water.

Essential knowledge statements from the AP Chemistry CED:

- All physical and chemical processes can be represented symbolically by balanced equations.
- Chemical equations represent chemical changes. These changes are the result of a rearrangement of atoms into new combinations; thus, any representation of a chemical change must contain equal numbers of atoms of every element before and after the change occurred. Equations thus demonstrate that mass is conserved in chemical reactions.
- Balanced molecular, complete ionic, and net ionic equations are differing symbolic forms used to represent a chemical reaction. The form used to represent the reaction depends on the context in which it is to be used.

In order to master the skill of writing a net ionic equation, it is important to understand why substances behave as electrolytes or nonelectrolytes.



Distilled water, H_2O , is an example of a **nonelectrolyte**. It is a covalent molecular substance that consists of neutral molecules. The absence of charged particles explains why a sample of pure H_2O does not conduct electricity.

Saltwater, $\text{NaCl}_{(aq)}$, is an example of an **electrolyte**. NaCl is an ionic substance. When NaCl dissolves in water, the Na^+ and Cl^- ions break away from the solid crystal lattice. A solution of $\text{NaCl}_{(aq)}$ contains positive and negative ions that can move freely throughout the solution. The movement of ions allows electricity to flow through the solution.

5. A substance can conduct electricity when there are mobile charged particles. Explain each of the following observations related to conductivity. Each of your explanations should refer to the presence or absence of charged particles in the sample and whether or not the charged particles can move or flow freely.

- (a) A piece of solid silver metal, $\text{Ag}_{(s)}$, does conduct electricity.
- (b) A sample of solid crystals of sodium chloride, $\text{NaCl}_{(s)}$, does not conduct electricity.
- (c) A sample of molten (i.e., melted) sodium chloride, $\text{NaCl}_{(l)}$, does conduct electricity.
- (d) A sample of aqueous sucrose, $\text{C}_{12}\text{H}_{22}\text{O}_{11(aq)}$, does not conduct electricity.

5. (continued)

(e) A sample of aqueous methanol, $\text{CH}_3\text{OH}_{(aq)}$, does not conduct electricity.

(f) A sample of aqueous potassium hydroxide, $\text{KOH}_{(aq)}$, does conduct electricity.

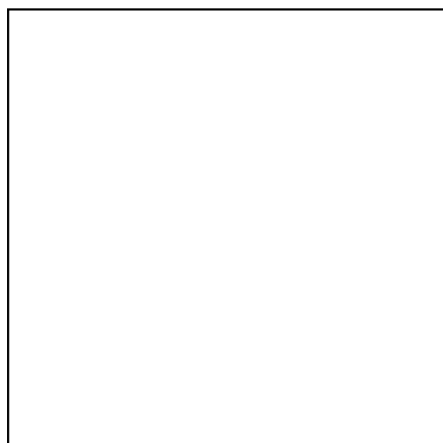
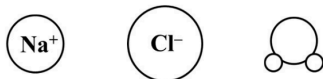
6. Each of the following solutes can be dissolved in water to form an aqueous solution. Write a balanced chemical equation that represents what happens to the solute particles when the solute is dissolved in water.

Solute	Equation for the Dissolution of the Solute in Water
copper(II) chloride, CuCl_2	
glucose, $\text{C}_6\text{H}_{12}\text{O}_6$	
sodium sulfate, Na_2SO_4	
ammonium nitrate, NH_4NO_3	
ethanol, $\text{CH}_3\text{CH}_2\text{OH}$	
barium hydroxide, $\text{Ba}(\text{OH})_2$	

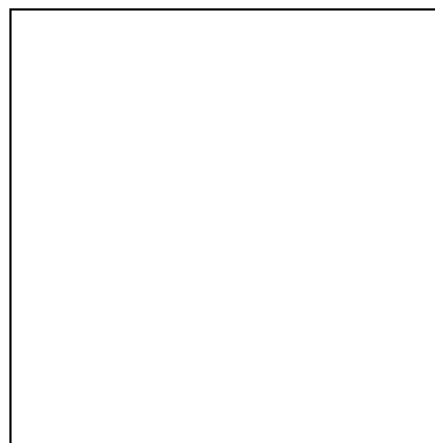
7. Students were asked to write an equation that represents what happens to the solute particles when solid calcium nitrate, $\text{Ca}(\text{NO}_3)_2$, is dissolved in water. Give a reason to explain why each of the following responses is incorrect.

Student Response	Why is This Response Incorrect?
$\text{Ca}(\text{NO}_3)_2(s) \rightarrow \text{Ca}(\text{NO}_3)_2(aq)$	
$\text{Ca}(\text{NO}_3)_2(s) \rightarrow \text{Ca}(aq) + \text{N}_2(aq) + 3 \text{O}_2(aq)$	
$\text{Ca}(\text{NO}_3)_2(s) \rightarrow \text{Ca}(aq) + 2 \text{NO}_3(aq)$	
$\text{Ca}(\text{NO}_3)_2(s) \rightarrow \text{Ca}^+(aq) + 2 \text{NO}_3^-(aq)$	
$\text{Ca}(\text{NO}_3)_2(s) \rightarrow \text{Ca}^{2+}(aq) + 2 \text{N}^{3-}(aq) + 6 \text{O}^{2-}(aq)$	
$\text{Ca}(\text{NO}_3)_2(s) \rightarrow \text{Ca}^{2+}(aq) + \text{NO}_3^-(aq)$	
$\text{Ca}(\text{NO}_3)_2(s) + \text{H}_2\text{O}(l) \rightarrow \text{Ca}^{2+}(aq) + 2 \text{NO}_3^-(aq) + \text{H}_2\text{O}(l)$	

8. Draw two different particle diagrams below. On the left, represent solid sodium chloride, $\text{NaCl}_{(s)}$. On the right, represent aqueous sodium chloride, $\text{NaCl}_{(aq)}$. Use the following symbols to create your particle diagrams.

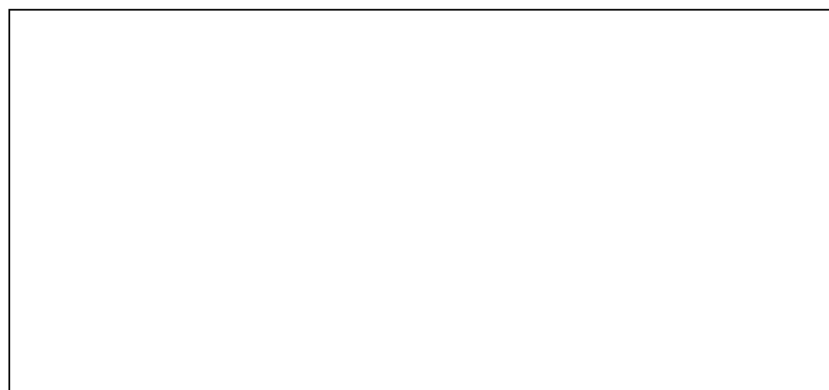


$\text{NaCl}_{(s)}$



$\text{NaCl}_{(aq)}$

9. Draw a particle diagram to represent aqueous magnesium chloride. Use the following symbols to create your particle diagram.



10. A student combines a clear, colorless solution of potassium iodide, $\text{KI}_{(aq)}$, with a clear, colorless solution of lead(II) nitrate, $\text{Pb}(\text{NO}_3)_2_{(aq)}$. You can watch a video of this experiment by scanning the QR code shown at right. Describe what you observe in the video when solutions of $\text{KI}_{(aq)}$ and $\text{Pb}(\text{NO}_3)_2_{(aq)}$ are combined.



- A **precipitation reaction** occurs when two different aqueous solutions containing ions are combined, resulting in the formation of an insoluble (or slightly soluble) solid ionic compound. The solid product is called the **precipitate** (abbreviated ppt).
- There are three different ways to write a balanced equation for a precipitation reaction: a molecular equation, a complete ionic equation, and a net ionic equation
 - **molecular equation** – each reactant and product is written as a neutral compound
 - **complete ionic equation** – any substance that ionizes completely is broken up into separate ions; any substance that does not ionize (or is only partially ionized) is written as a neutral compound
 - **spectator ions** – ions that appear in identical forms on both sides of a complete ionic equation
 - **net ionic equation** – the balanced equation that describes the actual reaction that occurs in aqueous solution; it is obtained after the spectator ions are eliminated from the complete ionic equation

11. The experiment described in Question #10 involves the chemical reaction between aqueous solutions of potassium iodide and lead(II) nitrate. The yellow solid precipitate formed in this experiment is lead(II) iodide.

(a) Write the balanced molecular equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

(b) Write the balanced complete ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

(c) Write the balanced net ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

Here is a list of ions that are commonly encountered in chemistry.

Monoatomic Ions					
1+	2+	3+	3-	2-	1-
lithium, Li ⁺ sodium, Na ⁺ potassium, K ⁺ rubidium, Rb ⁺ cesium, Cs ⁺ copper(I), Cu ⁺ silver, Ag ⁺	magnesium, Mg ²⁺ calcium, Ca ²⁺ strontium, Sr ²⁺ barium, Ba ²⁺ manganese(II), Mn ²⁺ iron(II), Fe ²⁺ cobalt(II), Co ²⁺ nickel(II), Ni ²⁺ copper(II), Cu ²⁺ zinc, Zn ²⁺ lead(II), Pb ²⁺ tin(II), Sn ²⁺	aluminum, Al ³⁺ chromium(III), Cr ³⁺ iron(III), Fe ³⁺	nitride, N ³⁻ phosphide, P ³⁻	oxide, O ²⁻ sulfide, S ²⁻	fluoride, F ⁻ chloride, Cl ⁻ bromide, Br ⁻ iodide, I ⁻

Polyatomic Ions			
1+	1-	2-	3-
ammonium, NH_4^+	hydroxide, OH^- nitrate, NO_3^- hydrogen carbonate, HCO_3^- cyanide, CN^- acetate, $\text{C}_2\text{H}_3\text{O}_2^-$ permanganate, MnO_4^- hypochlorite, ClO^- chlorite, ClO_2^- chlorate, ClO_3^- perchlorate, ClO_4^-	carbonate, CO_3^{2-} sulfate, SO_4^{2-} chromate, CrO_4^{2-}	phosphate, PO_4^{3-}

Writing a net ionic equation is a very important skill that requires practice. When you study Topic 4.7 (Types of Chemical Reactions), you will learn the following information from the AP Chemistry Course and Exam Description (CED).

- Precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound.
- All sodium (Na^+), potassium (K^+), ammonium (NH_4^+), and nitrate (NO_3^-) salts are soluble in water.
 - One way to remember these four soluble ions is to think of them as “SNAP” (or “SNAK”) (S = sodium, N = nitrate, A = ammonium, and P = potassium)

12. A student combines solutions of ammonium nitrate, $\text{NH}_4\text{NO}_3(aq)$, and sodium sulfate, $\text{Na}_2\text{SO}_4(aq)$.

(a) Write the chemical formulas for the two compounds that are formed as a result of the chemical reaction between $\text{NH}_4\text{NO}_3(aq)$ and $\text{Na}_2\text{SO}_4(aq)$.

(b) Do you predict that a precipitate will be formed when solutions of $\text{NH}_4\text{NO}_3(aq)$ and $\text{Na}_2\text{SO}_4(aq)$ are combined? Justify your answer based on the solubility rules for the “SNAP” ions.

13. A student combines solutions of silver nitrate, $\text{AgNO}_3(aq)$, and ammonium chloride, $\text{NH}_4\text{Cl}(aq)$, and a precipitate is formed.

(a) Write the balanced molecular equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

(b) Write the balanced complete ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

(c) Write the balanced net ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

14. A student combines solutions of barium chloride, $\text{BaCl}_{2(aq)}$, and potassium sulfate, $\text{K}_2\text{SO}_{4(aq)}$, and a precipitate is formed.

(a) Write the balanced molecular equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

(b) Write the balanced complete ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

(c) Write the balanced net ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

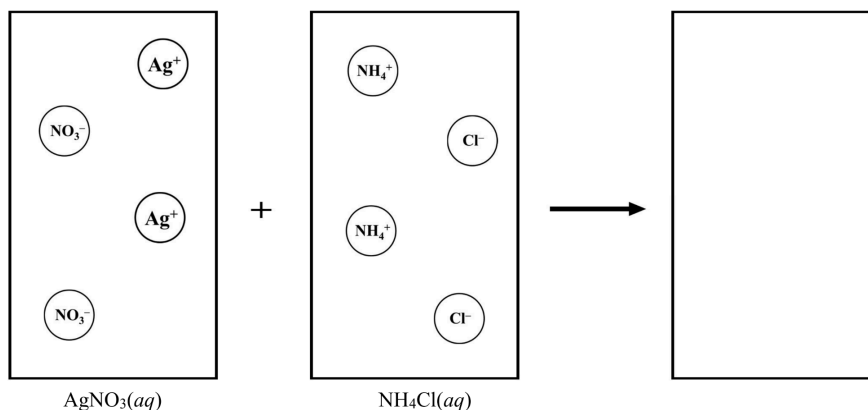
15. A student combines solutions of copper(II) chloride, $\text{CuCl}_{2(aq)}$, and sodium hydroxide, $\text{NaOH}_{(aq)}$, and a precipitate is formed.

(a) Write the balanced molecular equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

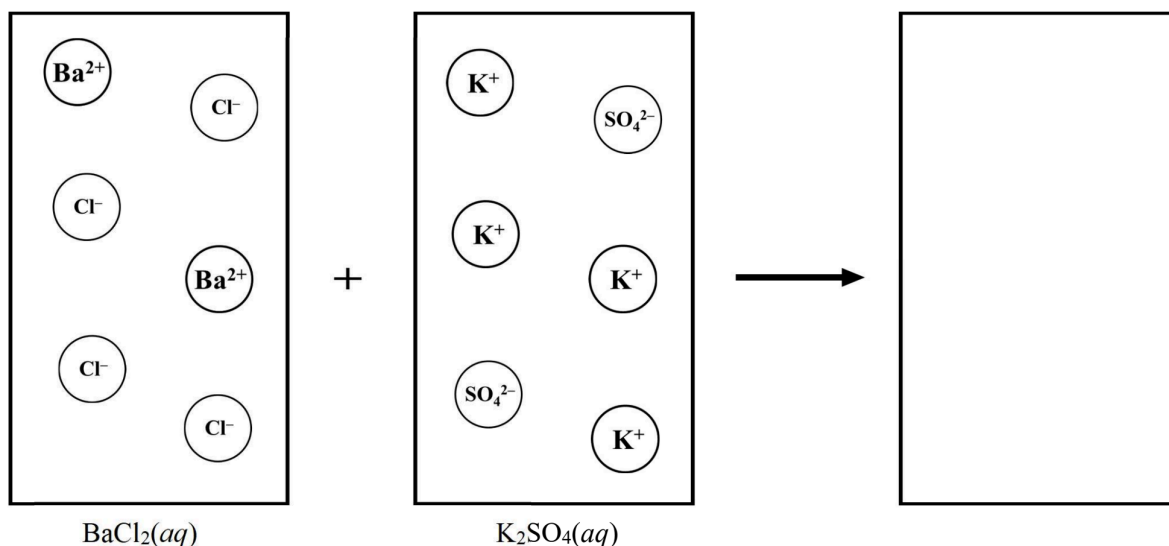
(b) Write the balanced complete ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

(c) Write the balanced net ionic equation for the reaction. Include the phases of matter symbols (*aq*) or (*s*) for each reactant and product.

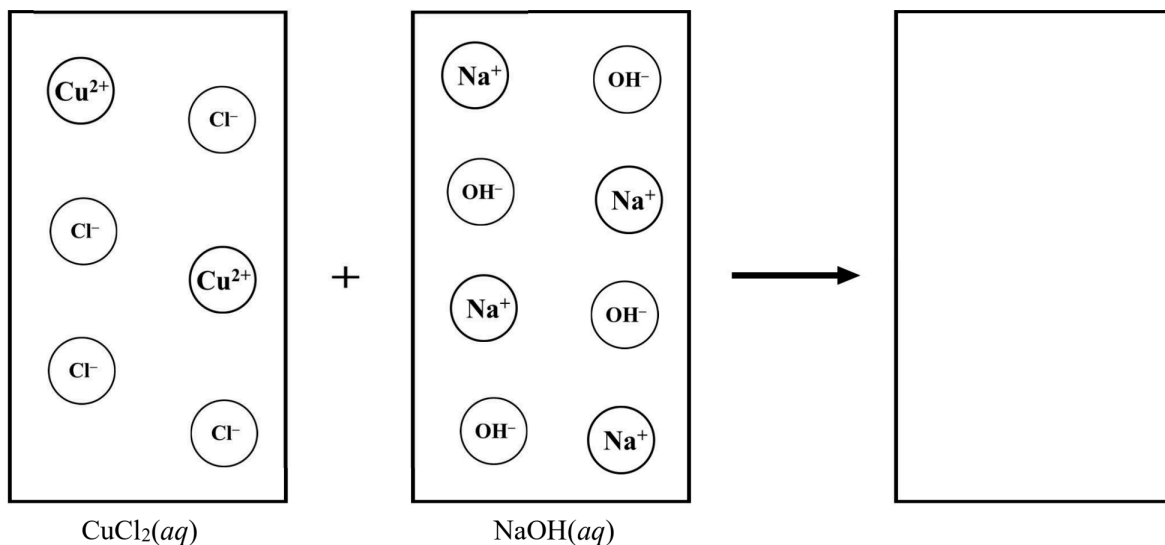
16. Based on the information shown in the particle diagrams below, draw a particle diagram in the box on the far right that represents both the aqueous ions and the solid precipitate. Pay attention to the conservation of mass. You do not need to include any water molecules in your diagram.



17. Based on the information shown in the particle diagrams below, draw a particle diagram in the box on the far right that represents both the aqueous ions and the solid precipitate. Pay attention to the conservation of mass. You do not need to include any water molecules in your diagram.



18. Based on the information shown in the particle diagrams below, draw a particle diagram in the box on the far right that represents both the aqueous ions and the solid precipitate. Pay attention to the conservation of mass. You do not need to include any water molecules in your diagram.

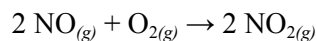


CB Topic 4.3 Representation of Reactions

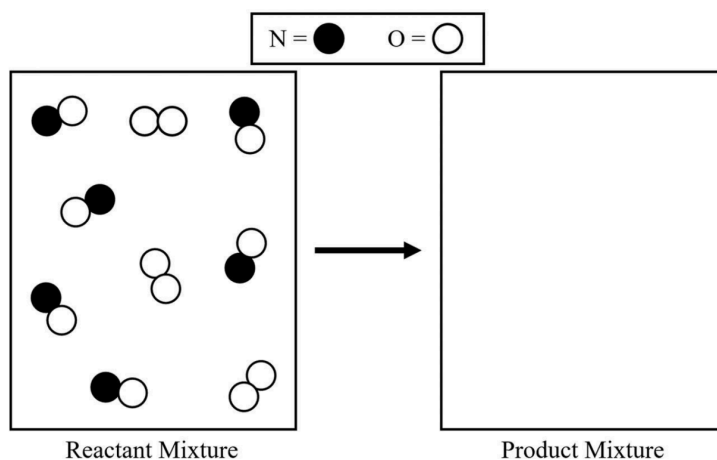
Video: <https://www.youtube.com/watch?v=2nPVFBo-sKU>

Essential knowledge statements from the AP Chemistry CED:

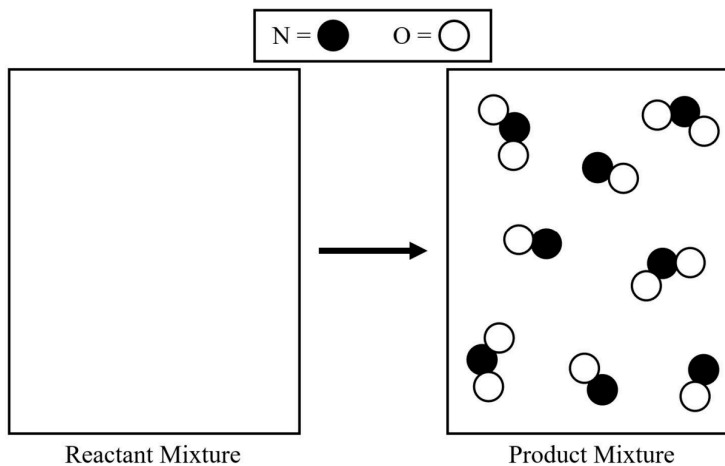
- Balanced chemical equations in their various forms can be translated into symbolic particulate representations.

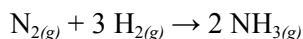


19. A particle diagram representing a mixture of $\text{NO}_{(g)}$ and $\text{O}_{2(g)}$ in a reaction vessel is shown below in the box on the left. A chemical reaction takes place according to the equation above until one of the reactants is completely consumed. In the box below on the right, draw a particle diagram representing the contents of the reaction vessel at the completion of the reaction. Represent nitrogen atoms and oxygen atoms as indicated below.

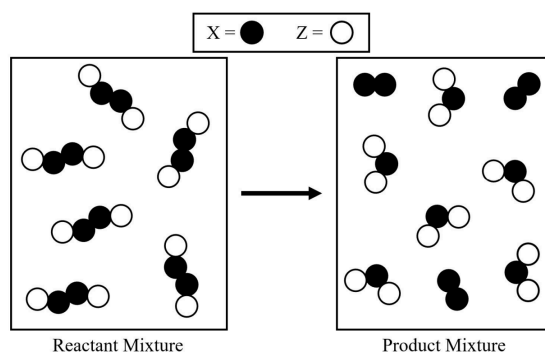
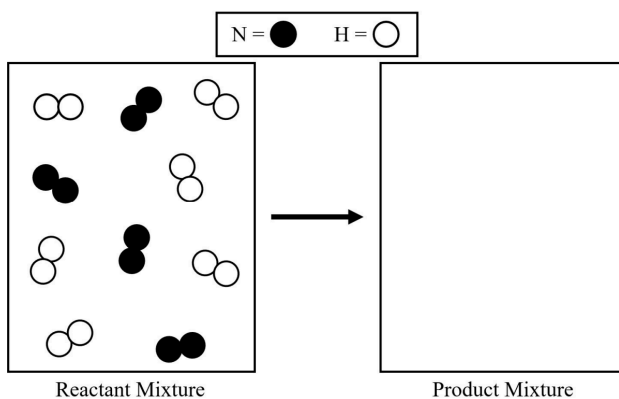


20. A particle diagram representing a mixture of $\text{NO}_{(g)}$ and $\text{NO}_{2(g)}$ in a reaction vessel is shown below in the box on the right. A chemical reaction has already taken place according to the equation shown in Question #19 until one of the reactants was completely consumed. In the box below on the left, draw a particle diagram representing the reaction mixture of $\text{NO}_{(g)}$ and $\text{O}_{2(g)}$ in the reaction vessel at the beginning of the reaction. Represent nitrogen atoms and oxygen atoms as indicated below.





21. A particle diagram representing a mixture of $\text{N}_{2(g)}$ and $\text{H}_{2(g)}$ in a reaction vessel is shown below in the box on the left. A chemical reaction takes place according to the equation above until one of the reactants is completely consumed. In the box below on the right, draw a particle diagram representing the contents of the reaction vessel at the completion of the reaction. Represent nitrogen atoms and hydrogen atoms as indicated below.



22. Based on the information in the particle diagrams shown above, write a balanced chemical equation for the decomposition of X_2Z_2 .

CB Topics 4.1 - 4.4 MC Practice

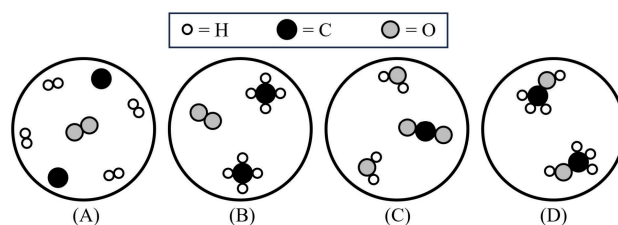
Video: https://www.youtube.com/watch?v=gP3rX_3-DGU

1. A beaker contains 50 mL of a clear, colorless liquid. A student added a small amount of 1.0 M $\text{NaCl}_{(aq)}$ to liquid in a beaker. Which of the following is most likely to support the claim that a chemical reaction occurred in this experiment?

- A. The final volume of the mixture is 51 mL.
- B. The appearance of the mixture is cloudy.
- C. The mixture conducts electricity.
- D. The concentration of $\text{C}^{1-}_{(aq)}$ in the mixture is less than 1.0 M.

2. A sample of pure liquid methanol, $\text{CH}_3\text{OH}_{(l)}$, was added to a beaker and placed on a hot plate. The

temperature of the liquid increased gradually. Eventually the liquid began to produce bubbles vigorously. Four diagrams are shown below to indicate a particulate representation of the gas produced above the surface of the liquid in this experiment. Which diagram best supports the claim that this experiment is a physical change?

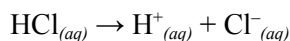


3. A sample of solid sodium metal, $\text{Na}_{(s)}$, is added to a sample of liquid water, $\text{H}_2\text{O}_{(l)}$. A chemical reaction occurs, and bubbles of hydrogen gas, $\text{H}_{2(g)}$, are produced. After the reaction has gone to completion, the reaction mixture appears clear and colorless. Which of the following is the balanced net-ionic equation that best represents the reaction that occurs in this experiment?

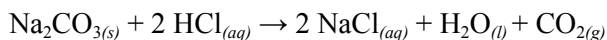
- A. $\text{Na}_{(s)} + 2 \text{H}^+_{(aq)} \rightarrow \text{Na}^+_{(aq)} + \text{H}_{2(g)}$
- B. $2 \text{Na}_{(s)} + 2 \text{H}_2\text{O}_{(l)} \rightarrow 2 \text{NaOH}_{(s)} + \text{H}_{2(g)}$
- C. $2 \text{Na}_{(s)} + 2 \text{H}_2\text{O}_{(l)} \rightarrow 2 \text{Na}^+_{(aq)} + 2 \text{OH}^-_{(aq)} + \text{H}_{2(g)}$
- D. $2 \text{Na}^+_{(s)} + 2 \text{H}_2\text{O}_{(l)} \rightarrow 2 \text{NaOH}_{(aq)} + \text{H}_{2(g)}$

4. When solutions of barium nitrate, $\text{Ba}(\text{NO}_3)_{2(aq)}$, and potassium carbonate, $\text{K}_2\text{CO}_{3(aq)}$, are combined, a solid precipitate is formed. Which of the following is the balanced net-ionic equation for the reaction that occurs when these two solutions are combined?

- A. $\text{Ba}(\text{NO}_3)_{2(aq)} + \text{K}_2\text{CO}_{3(aq)} \rightarrow \text{BaCO}_{3(s)} + 2 \text{KNO}_{3(s)}$
- B. $\text{Ba}(\text{NO}_3)_{2(aq)} + \text{K}_2\text{CO}_{3(aq)} \rightarrow \text{BaCO}_{3(s)} + 2 \text{KNO}_{3(aq)}$
- C. $\text{K}^+_{(aq)} + \text{NO}_3^-_{(aq)} \rightarrow \text{KNO}_{3(s)}$
- D. $\text{Ba}^{2+}_{(aq)} + \text{CO}_3^{2-}_{(aq)} \rightarrow \text{BaCO}_{3(s)}$

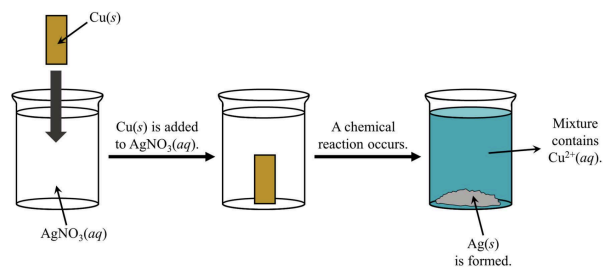


5. Hydrochloric acid (HCl) is an example of a strong acid that completely ionizes in aqueous solution according to the equation shown above. A student adds an excess amount of $\text{HCl}_{(aq)}$ to a sample of solid sodium carbonate, $\text{Na}_2\text{CO}_{3(s)}$. A chemical reaction occurs according to the equation shown below.



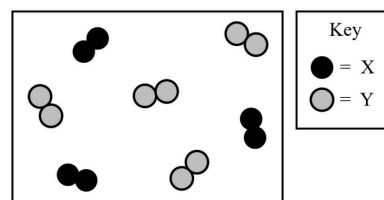
Which of the following is the balanced net-ionic equation for the reaction that occurred in this experiment?

- A. $\text{Na}_2\text{CO}_{3(s)} + 2 \text{H}^+_{(aq)} \rightarrow 2 \text{Na}^+_{(aq)} + \text{H}_2\text{O}_{(l)} + \text{CO}_{2(g)}$
- B. $\text{Na}_2\text{CO}_{3(s)} \rightarrow 2 \text{Na}^+_{(aq)} + \text{CO}_{2(g)}$
- C. $\text{Na}^+_{(aq)} + \text{Cl}^-_{(aq)} \rightarrow \text{NaCl}_{(aq)}$
- D. $\text{CO}_3^{2-}_{(aq)} + 2 \text{H}^+_{(aq)} \rightarrow \text{H}_2\text{O}_{(l)} + \text{CO}_{2(g)}$

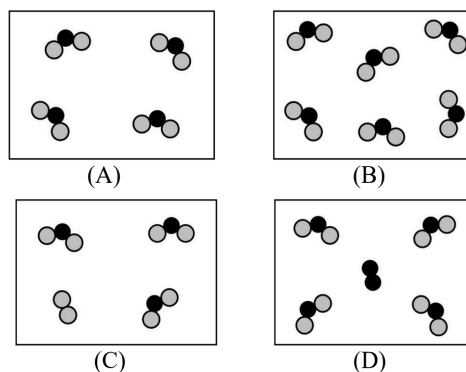


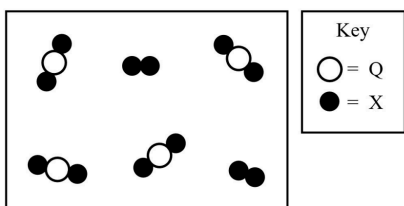
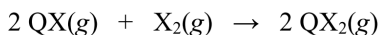
6. A sample of $\text{Cu}_{(s)}$ is added to a sample of $\text{AgNO}_{3(aq)}$ as shown in the diagram above. A chemical reaction occurs, resulting in the formation of $\text{Ag}_{(s)}$. At the end of the experiment, the reaction mixture contains $\text{Cu}^{2+}_{(aq)}$. Which of the following is a balanced equation that represents only the species that react and the species that are produced in this experiment?

- A. $\text{Cu}_{(s)} + \text{Ag}^+_{(aq)} \rightarrow \text{Ag}_{(s)} + \text{Cu}^{2+}_{(aq)}$
- B. $\text{Cu}_{(s)} + 2 \text{AgNO}_{3(aq)} \rightarrow 2 \text{Ag}_{(s)} + \text{Cu}(\text{NO}_3)_{2(aq)}$
- C. $\text{Cu}_{(s)} + 2 \text{Ag}^+_{(aq)} \rightarrow 2 \text{Ag}_{(s)} + \text{Cu}^{2+}_{(aq)}$
- D. $\text{Cu}^{2+}_{(s)} + 2 \text{Ag}_{(aq)} \rightarrow 2 \text{Ag}^+_{(s)} + \text{Cu}_{(aq)}$

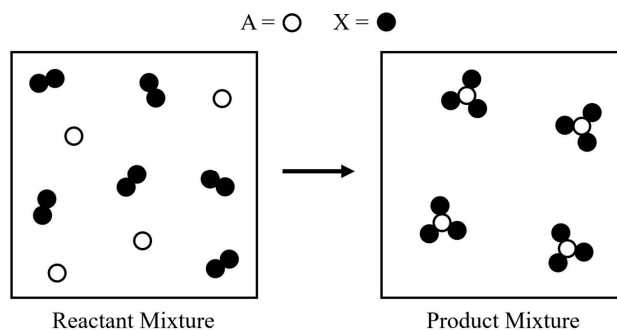
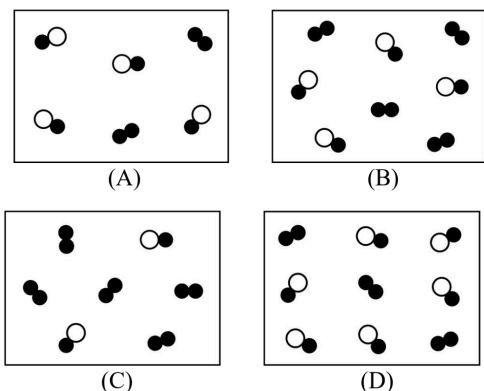


7. A mixture of $\text{X}_{2(g)}$ and $\text{Y}_{2(g)}$ is placed in a reaction vessel as shown above. A reaction between $\text{X}_{2(g)}$ and $\text{Y}_{2(g)}$ occurs, forming $\text{XY}_{2(g)}$. Which of the following best represents the contents of the reaction vessel after the reaction has proceeded as completely as possible?





8. The particle-level diagram shown above is a representation of the substances present in a reaction vessel at the completion of a reaction between $\text{QX}_{(g)}$ and $\text{X}_{2(g)}$. Which of the following diagrams represents the reaction mixture that would yield the product mixture shown above?



9. Based on the information in the particle diagrams above, which of the following represents the correct balanced chemical equation for the reaction that occurred?

- A. $2 \text{A}_{(g)} + 6 \text{X}_{(g)} \rightarrow 2 \text{AX}_{3(g)}$
 B. $2 \text{A}_{(g)} + 3 \text{X}_{2(g)} \rightarrow 2 \text{AX}_{3(g)}$
 C. $\text{A}_{2(g)} + 6 \text{X}_{(g)} \rightarrow 2 \text{AX}_{3(g)}$
 D. $\text{A}_{2(g)} + 3 \text{X}_{2(g)} \rightarrow 2 \text{AX}_{3(g)}$

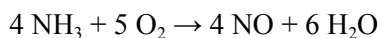
CB Topic 4.5 Stoichiometry

Video: <https://www.youtube.com/watch?v=b7QLZEQuv3o>

STOP at 28:26 (4.6 and 3.7 not in SW)

Essential knowledge statements from the AP Chemistry CED:

- Because atoms must be conserved during a chemical process, it is possible to calculate product amounts by using known reactant amounts, or to calculate reactant amounts given known product amounts.
- Coefficients of balanced chemical equations contain information regarding the proportionality of the amounts of substances involved in the reaction. These values can be used in chemical calculations involving the mole concept.
- Stoichiometric calculations can be combined with the ideal gas law and calculations involving molarity to quantitatively study gases and solutions.



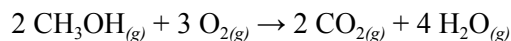
1. Ammonia, NH_3 , reacts with oxygen gas, O_2 , to produce nitrogen monoxide and water vapor, according to the chemical equation shown above.

- (a) Calculate the number of moles of O_2 that is required to react completely with 28.3 moles of NH_3 in this chemical reaction.

(b) Calculate the mass, in grams, of NH_3 that is required to react completely with 175 grams of O_2 .

The **limiting reactant** in a chemical reaction is the reactant that

- is completely consumed when the chemical reaction is completed
- determines the maximum amount of product that can be produced, which is known as the **theoretical yield**

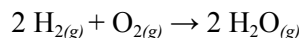


2. Equimolar amounts of $\text{CH}_3\text{OH}_{(g)}$ and $\text{O}_{2(g)}$ are introduced into a rigid, previously evacuated reaction vessel. The mixture is sparked and a chemical reaction occurs according to the equation shown above until one of the reactants is completely consumed. Which substance, $\text{CH}_3\text{OH}_{(g)}$ or $\text{O}_{2(g)}$, is used up completely in this experiment? Justify your answer.

There are two strategies summarized below to determine the identity of the limiting reactant.

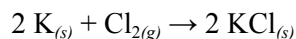
Compare How Much Reactant is Needed with How Much Reactant is Available
Use stoichiometry calculations to convert the available amount of each reactant into the amount of the other reactant that is needed to react completely with it. <ul style="list-style-type: none">• If the amount of a reactant that is needed is greater than the amount that is available, then that reactant is the limiting reactant.• If the amount of a reactant that is needed is less than the amount that is available, then that reactant is the excess reactant.

Calculate the Theoretical Yield of Product, Starting from Each Reactant
Use stoichiometry calculations to convert the available amount of each reactant into the amount of the product that could be produced from it. <ul style="list-style-type: none">• The reactant that leads to the smaller amount of product is the limiting reactant.• The reactant that leads to the larger amount of product is the excess reactant.



3. Hydrogen gas reacts with oxygen gas to form water vapor according to the equation above. For each of the following experiments, identify the limiting reactant and calculate the theoretical yield of H_2O that would be produced, in units of moles or grams as shown in the table. Use the space below the table for scratch work and calculations.

Experiment	Amount of H ₂ Available	Amount of O ₂ Available	Identity of the Limiting Reactant	Theoretical Yield of H ₂ O
1	5.4 mol	2.5 mol		mol H ₂ O
2	13.2 mol	6.8 mol		mol H ₂ O
3	24.5 g	201 g		g H ₂ O
4	31.8 g	237 g		g H ₂ O



4. The elements potassium and chlorine react to form potassium chloride according to the equation shown above. In a certain experiment, a reaction occurred between 100.0 g of K_(s) and 100.0 g of Cl_{2(g)} until one of the reactants was completely consumed.

(a) Identify the limiting reactant in this experiment. Justify your choice with both an explanation in words and supporting calculations.

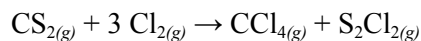
(b) Determine the theoretical yield, in grams, of KCl_(s) in this experiment.

(c) Determine the mass, in grams, of the reactant that is leftover (unreacted) at the end of this experiment.

(d) When this experiment was performed in the laboratory, the actual yield of KCl_(s) recovered was equal to 162.1 g. Calculate the percent yield of KCl_(s).

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%$$

CB Topic 4.5 MC Practice



1. In a certain experiment, a 48.0 g sample of $\text{CS}_{2(g)}$ reacts completely with $\text{Cl}_{2(g)}$ in a chemical reaction according to the equation shown above. What is the minimum mass of $\text{Cl}_{2(g)}$ consumed in this experiment?

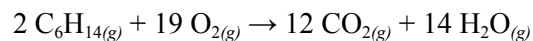
- A. 44.7 g $\text{Cl}_{2(g)}$
- B. 134 g $\text{Cl}_{2(g)}$
- C. 144 g $\text{Cl}_{2(g)}$
- D. 213 g $\text{Cl}_{2(g)}$

2. Which of the following will produce the greatest mass of $\text{CO}_{2(g)}$ when it undergoes complete combustion with $\text{O}_{2(g)}$?

- A. 100 g of CH_4
- B. 200 g of C_2H_6
- C. 300 g of C_3H_8
- D. 400 g of $\text{C}_4\text{H}_{10}\text{O}_2$

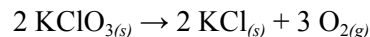
Video: https://www.youtube.com/watch?v=REt_1OYowx4

Stop Video at 15:38



3. Hexane, $\text{C}_6\text{H}_{14(g)}$, undergoes combustion with $\text{O}_{2(g)}$ according to the equation above. In a certain experiment, 12 mol of $\text{C}_6\text{H}_{14(g)}$ reacts with 95 mol of $\text{O}_{2(g)}$ until one of the reactants is completely consumed. Which of the following statements is correct?

- A. C_6H_{14} is the limiting reactant and 70. mol of H_2O is formed.
- B. C_6H_{14} is the limiting reactant and 84 mol of H_2O is formed.
- C. O_2 is the limiting reactant and 70. mol of H_2O is formed.
- D. O_2 is the limiting reactant and 84 mol of H_2O is formed.



4. When 6.00 g of $\text{KClO}_{3(s)}$ undergoes decomposition according to the equation above, 2.00 g of $\text{O}_{2(g)}$ is produced. What is the percent yield of $\text{O}_{2(g)}$ in this experiment?

- A. 33.3%
- B. 42.6%
- C. 78.5%
- D. 85.1%

Rules for Assigning Oxidation Numbers

In a redox reaction, electrons are transferred from the substance that is oxidized to the substance that is reduced. One of the ways to recognize a redox reaction is to look for changes in oxidation numbers. Oxidation numbers are assigned to elements according to the following rules.

Rule	Examples
#1: If an atom is in its elemental form, the oxidation number is zero.	H ₂ = zero C = zero Li = zero Cl ₂ = zero N ₂ = zero Fe = zero
#2: The oxidation number of a monoatomic ion is the charge on that ion.	Na ⁺ = +1 Cl ⁻ = -1 Mg ²⁺ = +2 O ²⁻ = -2 Al ³⁺ = +3 N ³⁻ = -3
#3: The oxidation number of a metal in Group 1 is +1 in all compounds. The oxidation number of a metal in Group 2 is +2 in all compounds.	Na = +1 in compounds such as NaCl, NaNO ₃ , and Na ₂ CO ₃ . Mg = +2 in compounds such as MgBr ₂ , MgSO ₄ , and MgO.
#4: The oxidation number of F is -1 in all compounds.	F = -1 in compounds such as NaF, CH ₃ F, and SF ₂ .
#5: The oxidation number of H is usually +1 when H is bonded to nonmetals and -1 when H is bonded to metals.	H = +1 in compounds such as H ₂ O, CH ₃ OH, NH ₄ Cl, and H ₂ S. H = -1 in compounds such as LiH, NaH, and CaH ₂ .
#6: The oxidation number of O is usually -2 in most ionic and molecular compounds. Two important exceptions to this rule are hydrogen peroxide, H ₂ O ₂ , and oxygen difluoride, OF ₂ .	O = -2 in compounds such as Na ₃ PO ₄ , Mg(NO ₃) ₂ , CO ₂ , H ₂ SO ₃ , N ₂ O, and P ₂ O ₅ . O = -1 in H ₂ O ₂ O = +2 in OF ₂
#7: The oxidation number of the halogens Cl, Br, and I is -1 in most binary compounds that contain only two elements. When atoms Cl, Br, and I are bonded with oxygen or fluorine, they will have a positive oxidation number.	The halogens Cl, Br, or I have an oxidation number of -1 in compounds such as KCl, NaBr, MgI ₂ , CCl ₄ , SBr ₂ , and HI. Cl = +1 in NaClO and HClO Cl = +3 in NaClO ₂ and HClO ₂ Cl = +5 in NaClO ₃ and HClO ₃ Cl = +7 in NaClO ₄ and HClO ₄

- The sum of the oxidation numbers of all atoms in a neutral compound is equal to zero.
- The sum of the oxidation numbers of all atoms in a polyatomic ion is equal to the overall charge on the polyatomic ion.
- The oxidation number is assigned to an individual atom in a chemical formula.
- The oxidation number is NOT assigned to the entire group of atoms in a chemical formula.

Chemical Formula	Correct Oxidation Numbers	Incorrect Oxidation Numbers Be careful NOT to do this!
CH ₄	C = -4 H = +1	H = +4
SO ₂	S = +4 O = -2	O = -4
Na ₂ CO ₃	Na = +1 C = +4 O = -2	Na = +2 O = -6

10. Assign oxidation numbers to each atom.

Substance	Oxidation Numbers
Fe	Fe =
Cl ₂	Cl =
P ₄	P =
NaBr	Na = Br =
Ca ₃ N ₂	Ca = N =
Fe ₂ O ₃	Fe = O =
MgS	Mg = S =
SO ₂	S = O =
CH ₃ F	C = H = F =
CHF ₃	C = H = F =
CO	C = O =
OF ₂	O = F =
H ₂ O ₂	H = O =
KH	K = H =
CaH ₂	Ca = H =

Substance	Oxidation Numbers
HBr	H = Br =
HBrO	H = Br = O =
HBrO ₂	H = Br = O =
HBrO ₃	H = Br = O =
Na ₂ CO ₃	Na = C = O =
BaCrO ₄	Ba = Cr = O =
NH ₄ ⁺	N = H =
OH ⁻	O = H =
NO ₃ ⁻	N = O =
ClO ₄ ⁻	Cl = O =
SO ₃ ²⁻	S = O =
SO ₄ ²⁻	S = O =
Cr ₂ O ₇ ²⁻	Cr = O =
PO ₄ ³⁻	P = O =
H ₃ O ⁺	H = O =