Molecules & Compounds

Writing Formulas and Naming Compounds

Introduction
Writing formulas and naming compounds can be confusing because there are different types of compounds that follow different rules. Additionally, some compounds (H₂O, NH₃, CH₄, etc.) simply have *common names* that must be memorized.

The two types of compounds we will focus on first are ionic compounds (formed from positive and negative ions) and binary nonmetal compounds (molecular compounds). Later we will add acids. So... you must recognize the *type* of compound before you try to name it. [Note: + ion = “cation” and – ion = “anion”.

<table>
<thead>
<tr>
<th>Ionic</th>
<th>Binary Nonmetal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>usually the less electronegative atom is first</td>
</tr>
<tr>
<td>sodium chloride</td>
<td>CÔ</td>
</tr>
<tr>
<td>ammonium sulfate</td>
<td>CO₂</td>
</tr>
<tr>
<td>sulfide</td>
<td>N₂O</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name of cation + name of anion</th>
<th>Name of cation + name of anion</th>
</tr>
</thead>
<tbody>
<tr>
<td>sodium chloride</td>
<td>CÔ</td>
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</tr>
<tr>
<td>sulfide</td>
<td>N₂O</td>
</tr>
</tbody>
</table>

I. Writing Ionic Formulas

<table>
<thead>
<tr>
<th>Cation</th>
<th>Anion</th>
<th>Formula</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>Cl⁻</td>
<td>NaCl</td>
<td>sodium chloride</td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>NO₃⁻</td>
<td>(NH₄)₂SO₄</td>
<td>ammonium sulfate</td>
</tr>
<tr>
<td>Sn²⁺</td>
<td>S²⁻</td>
<td>Al₂S₃</td>
<td>aluminum sulfide</td>
</tr>
</tbody>
</table>

II. Naming Ionic Compounds

<table>
<thead>
<tr>
<th>Cation</th>
<th>Anion</th>
<th>Formula</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu²⁺</td>
<td>OH⁻</td>
<td>CuOH</td>
<td>copper hydroxide</td>
</tr>
<tr>
<td>Ba²⁺</td>
<td>SO₄²⁻</td>
<td>BaSO₄</td>
<td>barium sulfate</td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>Cr₂O₇²⁻</td>
<td>NH₄Cr₂O₇</td>
<td>ammonium chromate</td>
</tr>
<tr>
<td>Ag⁺</td>
<td>C₂H₅O₂⁻</td>
<td>AgC₂H₅O₂</td>
<td>silver acetate</td>
</tr>
<tr>
<td>Fe³⁺</td>
<td>S²⁻</td>
<td>Fe₂S₃</td>
<td>iron sulfide</td>
</tr>
</tbody>
</table>
### III. Writing Formulas of Binary Nonmetal Compounds

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Name</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>nitrogen trifluoride</td>
<td></td>
<td>phosphorus trichloride</td>
<td></td>
</tr>
<tr>
<td>nitrogen monoxide</td>
<td></td>
<td>phosphorus pentachloride</td>
<td></td>
</tr>
<tr>
<td>nitrogen dioxide</td>
<td></td>
<td>sulfur hexafluoride</td>
<td></td>
</tr>
<tr>
<td>dinitrogen tetroxide</td>
<td></td>
<td>disulfur decafluoride</td>
<td></td>
</tr>
<tr>
<td>dinitrogen monoxide</td>
<td></td>
<td>xenon tetrafluoride</td>
<td></td>
</tr>
</tbody>
</table>

### IV. Naming Binary Nonmetal Compounds

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Name</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCl$_4$</td>
<td></td>
<td>HBr</td>
<td></td>
</tr>
<tr>
<td>P$<em>2$O$</em>{10}$</td>
<td></td>
<td>N$_2$F$_4$</td>
<td></td>
</tr>
<tr>
<td>ClF$_3$</td>
<td></td>
<td>XeF$_3$</td>
<td></td>
</tr>
<tr>
<td>BCl$_3$</td>
<td></td>
<td>PI$_3$</td>
<td></td>
</tr>
<tr>
<td>SF$_4$</td>
<td></td>
<td>SCl$_2$</td>
<td></td>
</tr>
</tbody>
</table>

### V. Practice for Both Types of Compounds

<table>
<thead>
<tr>
<th>Formula</th>
<th>Name</th>
<th>Formula</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl</td>
<td>carbon dioxide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCl$_3$</td>
<td>ammonium carbonate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K$_2$S</td>
<td>sulfur dichloride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NiSO$_4$</td>
<td>calcium iodide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ClF$_3$</td>
<td>boron trifluoride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OF$_2$</td>
<td>phosphorus triiodide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al(OH)$_3$</td>
<td>magnesium perchlorate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCl$_3$</td>
<td>potassium permanganate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NH$_4$)$_3$PO$_4$</td>
<td>aluminum phosphate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S$_2$Cl$_2$</td>
<td>dioxygen difluoride</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Molecules and Compounds

Molar Mass & % Composition

I. Molar Masses
Given a periodic table, you should be able to calculate the molecular mass (in u’s) or the molar mass (in grams) for any element or compound.

Examples: (give answers to two decimal places)

<table>
<thead>
<tr>
<th></th>
<th>Cl₂</th>
<th>Ca(OH)₂</th>
<th>HC₂H₃O₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂SO₄</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>N₂O</td>
<td>NaOCl</td>
<td>Al₂S₃</td>
</tr>
</tbody>
</table>

II. Fraction and Percent Composition
It is useful to determine how much of a compound’s mass is made up of each element. Water, H₂O, for example has a molar mass of 18.02 g. The H’s mass is 2(1.0079) = 2.02 g. The O’s mass is 16.00 g.

We can set up fractions for each element: \[ \text{H} = \frac{2.02}{18.02} = 0.112 = 11.2\%. \quad \text{O} = \frac{16.00}{18.02} = 0.888 = 88.8\%. \]

This is called the percent composition. The fraction composition is a good in-between step.

Determine the fraction and percent composition of each element below (answer to one decimal place):

1. H₂SO₄
2. Ca(OH)₂
3. HC₂H₃O₂
4. CO₂
5. N₂O
6. NaOCl
7. Al₂S₃
Problem vs. Exercise

An exercise is a calculation or other task where you know what to do. You are doing repeated examples to build up your skill, your speed, and your experience.

A problem is a situation in which you do not know what to do. So… what do you do when you do not know what to do? Read the problem, read it again, read it again, calculate a few things, read it again, and hopefully things fall into place. You learn to solve problems by solving problems. You add ideas to your “bag of tricks.”

1982 B

Water is added to 4.267 grams of UF₆. The only products are 3.730 grams of a solid containing only uranium, oxygen and fluorine and 0.970 gram of a gas. The gas is 95.0% fluorine, and the remainder is hydrogen.

(a) From these data, determine the empirical formula of the gas.

(b) What fraction of the fluorine of the original compound is in the solid and what fraction in the gas after the reaction?

(c) What is the formula of the solid product?
Chemical Equations and Stoichiometry

Do all of your work on another sheet of paper.

Answers to the numbered problems are located in the back of your textbook.

Chemical Analysis

A mixture of CuSO₄ and CuSO₄ • 5H₂O has a mass of 1.245 g, but, after heating to drive off all the water, the mass is only 0.832 g. What is the weight percent of CuSO₄ • 5H₂O in the mixture?

A 1.25-g sample contains some of the very reactive compound Al(C₆H₅)₃. On treating the compound with aqueous HCl, 0.951 g of C₆H₆ is obtained.

Al(C₆H₅)₃(s) + 3HCl(aq) → AlCl₃(aq) + 3C₆H₆(l)

Assuming that Al(C₆H₅)₃ was converted completely to products, what is the weight percent of Al(C₆H₅)₃ in original 1.25-g sample?

Determination of Empirical Formulas

Styrene, the building block of polystyrene, is a hydrocarbon, a compound consisting only of C and H. If 0.438 g of styrene is burned in oxygen and produces 1.481 g of CO₂ and 0.303 g of H₂O, what is the empirical formula of styrene?

Menthol, from the oil of mint, has a characteristic cool taste. The compound contains only C, H, and O. If 95.6 mg of menthol burns completely in O₂, and gives 269 mg of CO₂ and 110 mg of H₂O, what is the empirical formula of menthol?

Silicon and hydrogen form a series of compounds with the general formula SiₓHₙ. to find the formula of one of them, a 6.22-g sample of the compound is burned in oxygen. On doing so, all of the Si is converted to 11.64 g of SiO₂ and all of the H to 6.980 g of H₂O. What is the empirical formula of the silicon compound?

AP Question
An organic compound was synthesized and found to contain only C, H, N, O, and Cl. It was observed that when a 0.150-g sample of the compound was burned, it produced 0.138 g of CO$_2$ and 0.0566 g of H$_2$O. All the nitrogen in a different 0.200-g sample of the compound was converted to NH$_3$, which was found to have a mass of 0.0238 g. Finally, the chlorine in a 0.125-g sample of the compound was converted to AgCl. The AgCl, when dried, was found to weigh 0.251 g.

(a) Calculate the percent by mass of each element in the compound.
(b) Determine the empirical formula for the compound.

Chemical Equations and Stoichiometry

General Stoichiometry

Several brands of antacid tablets use aluminum hydroxide to neutralize excess acid.

$$\text{Al(OH)}_3(s) + 3 \text{HCl(aq)} \rightarrow \text{AlCl}_3(aq) + 3 \text{H}_2\text{O(l)}$$

[Molar masses: 78.01 36.46 133.4 18.02]

What quantity of HCl, in grams, can a tablet with 0.750 g of Al(OH)$_3$ consume? What quantity of water is produced?

If 10.0 g of carbon is combined with an exact, stoichiometric amount of oxygen (26.6 g) to produce carbon dioxide, what mass, in grams, of CO$_2$ can be obtained? That is, what is the theoretical yield of CO$_2$? [Molar masses: C: 12.011 O$_2$: 32.00 CO$_2$: 44.01]

The equation for one of the reactions in the process of reducing iron ore to the metal is

$$\text{Fe}_2\text{O}_3(s) + 3 \text{CO(g)} \rightarrow 2 \text{Fe(s)} + 3 \text{CO}_2(g)$$

[Molar masses: 159.7 28.01 55.85 44.01]

(a) What is the maximum mass of iron, in grams, that can be obtained from 454 g (1.00 lb) of iron(III) oxide?
(b) What mass of CO is required to reduce the iron(III) oxide to iron metal?

Burning coal and oil in a power plant produces pollutants such as sulfur dioxide, SO$_2$. The sulfur-containing compound can be removed from other waste gases, however, by the following reaction:

$$2 \text{SO}_2(g) + 2 \text{CaCO}_3(s) + \text{O}_2(g) \rightarrow 2 \text{CaSO}_4(s) + 2 \text{CO}_2(g)$$

[Molar masses: 64.07 100.1 32.00 136.2 44.01]

(a) Name the compounds involved in the reaction.
(b) What mass of CaCO$_3$ is required to remove 155 g of SO$_2$?
(c) What mass of CaSO$_4$ is formed when 155 g SO$_2$ is consumed completely?
Your body deals with excess nitrogen by excreting it in the form of urea, \( \text{NH}_2\text{CONH}_2 \). The reaction producing it is the combination of arginine (\( \text{C}_6\text{H}_{14}\text{N}_4\text{O}_2 \)) with water to give urea and ornithine (\( \text{C}_5\text{H}_{12}\text{N}_2\text{O}_2 \)).

\[
\text{C}_6\text{H}_{14}\text{N}_4\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{NH}_2\text{CONH}_2 + \text{C}_5\text{H}_{12}\text{N}_2\text{O}_2
\]

[\text{Molar masses: 174.2 18.02 60.06 132.2}]

If you excrete 95 mg of urea, what quantity of arginine must have been used? What quantity of ornithine must have been produced?
**Limiting Reactants**

The reaction of methane and water is one way to prepare hydrogen:

\[
\text{CH}_4(g) + \text{H}_2\text{O}(g) \rightarrow \text{CO}(g) + 3 \text{H}_2(g)
\]

[Molar masses: 16.04 18.02 28.01 2.02]

If you begin with 995 g of CH\(_4\) and 2510 g of water, what is the maximum possible yield of H\(_2\)?

Disulfur dichloride, S\(_2\)Cl\(_2\), is used to vulcanize rubber. It can be made by treating molten sulfur with gaseous chlorine:

\[
\text{S}_8(l) + 4 \text{Cl}_2(g) \rightarrow 4 \text{S}_2\text{Cl}_2(l)
\]

[Molar masses: 256.6 70.91 135.0]

Starting with a mixture of 32.0 g of sulfur and 71.0 g of Cl\(_2\), which is the limiting reactant? What mass of S\(_2\)Cl\(_2\) (in grams) can be produced? What mass of the excess reactant remains when the limiting reactant is consumed?

Aspirin (C\(_9\)H\(_8\)O\(_4\)) is produced by the reaction of salicylic acid (C\(_7\)H\(_6\)O\(_3\)) and acetic anhydride (C\(_4\)H\(_6\)O\(_3\)) (page 163).

\[
\text{C}_7\text{H}_6\text{O}_3(s) + \text{C}_4\text{H}_6\text{O}_3(l) \rightarrow \text{C}_9\text{H}_8\text{O}_4(s) + \text{CH}_3\text{CO}_2\text{H}(aq)
\]

[Molar masses: 138.1 102.1 180.1 60.05]

If you mix 100. g of each of the reactants, what is the maximum mass of aspirin that can be obtained?

**Percent Yield**

Diborane, B\(_2\)H\(_6\), is a valuable compound in the synthesis of new organic compounds. One of several ways this born compound can be made is by the reaction

\[
2 \text{NaBH}_4(s) + \text{I}_2(s) \rightarrow \text{B}_2\text{H}_6(g) + 2 \text{NaI(s)} + \text{H}_2(g)
\]

[Molar masses: 37.84 253.8 27.67 149.9 2.02]

Suppose you use 1.203 g of NaBH\(_4\) with an excess of iodine and obtain 0.295 g of B\(_2\)H\(_6\). What is the percent yield of B\(_2\)H\(_6\)?

Disulfur dichloride, which has a revolting smell, can be prepared by directly combining S\(_8\) and Cl\(_2\), but it can also be made by the following reaction:

\[
3 \text{SCl}_2(l) + 4 \text{NaF(s)} \rightarrow \text{SF}_4(g) + \text{S}_2\text{Cl}_2(l) + 4 \text{NaCl(s)}
\]

[Molar masses: 103.0 41.99 108.1 135.0 58.46]

Assume you begin with 5.23 g of SCl\(_2\) and excess NaF. What is the theoretical yield of S\(_2\)Cl\(_2\)? If only 1.19 g of S\(_2\)Cl\(_2\) is obtained, what is the percent yield of the compound?
Chemical Equations and Stoichiometry

**Combustion Equations**

For burning to occur, you need a fuel, an oxidizer, and heat. When hydrocarbons are the fuel and O\(_2\) in the air is the oxidizer, then CO\(_2\) and H\(_2\)O are the products.

**Example:** Write the balanced equation for the complete combustion of propane, C\(_3\)H\(_8\), in air.

**Solution:** First, set up the basic equation. You memorize the “+ O\(_2\) → CO\(_2\) + H\(_2\)O” part.

C\(_3\)H\(_8\) + O\(_2\) → CO\(_2\) + H\(_2\)O

Next, balance. 3 C’s in C\(_3\)H\(_8\) result in 3 CO\(_2\)’s; 8 H’s in C\(_3\)H\(_8\) result in 4 H\(_2\)O’s;

C\(_3\)H\(_8\) + ___ O\(_2\) → 3 CO\(_2\) + 4 H\(_2\)O

Total O’s on the product side = 10 [(3 x 2) + (4 x 1)] = total O’s on the reactant side.

This would mean that 5 O\(_2\)’s were involved.

**Tip:** If an UNEVEN number of O’s need to be represented, a fraction should be used. 7 O’s = \(\frac{7}{2}\) O\(_2\)

**Tip:** Take into account fuels that contain oxygen. Subtract the O’s from that represented as O\(_2\)’s

**Practice:** Write the balanced combustion equations for the following substances.

1. CH\(_4\)
2. C\(_5\)H\(_{12}\)
3. C\(_9\)H\(_{20}\)
4. C\(_2\)H\(_6\)
5. C\(_8\)H\(_{18}\)

Chemical Equations and Stoichiometry

**Balancing Equations**

1. ___ZnS + ___HCl → ___ZnCl\(_2\) + ___H\(_2\)S
2. ___HCl + ___Cr → ___CrCl\(_2\) + ___H\(_2\)
3. ___Al + ___Fe\(_3\)O\(_4\) → ___Al\(_2\)O\(_3\) + ___Fe
4. ___H\(_2\) + ___Br\(_2\) → ___HBr
5. \( \text{Na}_2\text{S}_2\text{O}_3 + \text{I}_2 \rightarrow \text{NaI} + \text{Na}_2\text{S}_4\text{O}_6 \)
6. \( \text{LaCl}_3 + \text{Na}_2\text{CO}_3 \rightarrow \text{La}_2(\text{CO}_3)_3 + \text{NaCl} \)
7. \( \text{NH}_4\text{Cl} + \text{Ba(OH)}_2 \rightarrow \text{BaCl}_2 + \text{NH}_3 + \text{H}_2\text{O} \)
8. \( \text{Ca(OH)}_2 + \text{H}_3\text{PO}_4 \rightarrow \text{Ca}_3(\text{PO}_4)_2 + \text{H}_2\text{O} \)
9. \( \text{La}_2(\text{CO}_3)_3 + \text{H}_2\text{SO}_4 \rightarrow \text{La}_2(\text{SO}_4)_3 + \text{H}_2\text{O} + \text{CO}_2 \)

Chemical Equations & Stoichiometry

1991 B

The molecular formula of a hydrocarbon is to be determined by analyzing its combustion products and investigating its colligative properties.

(a) The hydrocarbon burns completely, producing 7.2 grams of water and 7.2 liters of \( \text{CO}_2 \) at standard conditions. What is the empirical formula of the hydrocarbon?

2000 B

Answer the following questions about \( \text{BeC}_2\text{O}_4(s) \) and its hydrate.

(a) Calculate the mass percent of carbon in the hydrated form of the solid that has the formula \( \text{BeC}_2\text{O}_4\cdot3\text{H}_2\text{O} \).

(b) When heated to 220°C, \( \text{BeC}_2\text{O}_4\cdot3\text{H}_2\text{O}(s) \) dehydrates completely as represented below.

\[
\text{BeC}_2\text{O}_4\cdot3\text{H}_2\text{O}(s) \rightarrow \text{BeC}_2\text{O}_4(s) + 3 \text{H}_2\text{O}(g)
\]

If 3.21 g of \( \text{BeC}_2\text{O}_4\cdot3\text{H}_2\text{O}(s) \) is heated to 220°C calculate

(i) the mass of \( \text{BeC}_2\text{O}_4(s) \) formed, and,

(ii) the volume of the \( \text{H}_2\text{O}(g) \) released, measured at STP.

2001 B

Answer the following questions about acetylsalicylic acid, the active ingredient in aspirin.

(a) The amount of acetylsalicylic acid in a single aspirin tablet is 325 mg, yet the tablet has a mass of 2.00 g. Calculate the mass percent of acetylsalicylic acid in the tablet.

(b) The elements contained in acetylsalicylic acid are hydrogen, carbon, and oxygen. The combustion of 3.000 g of the pure compound yields 1.200 g of water and 3.36 L of dry carbon dioxide, measured at STP. Determine the mass, in g, of each element in the 3.000 g sample of the compound.
Reactions in Aqueous Solution

Precipitate Practice #1

Write balanced molecular and detailed ionic equations. Strike out any spectator ions.

1. Solutions of lead nitrate and potassium chloride are mixed.

2. Solutions of sodium sulfate and calcium bromide are mixed.

3. Solutions of aluminum acetate and lithium hydroxide are mixed.

4. Solutions of iron(III) sulfate and sodium sulfide are mixed.

5. Solutions of aluminum sulfate and calcium hydroxide are mixed.

6. Solutions of potassium chromate and lead acetate are mixed.
7. Solutions of silver nitrate and ammonium sulfide are mixed.

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**Reactions in Aqueous Solution**

*Acid-Base & Gas Forming Equations*

Write balanced molecular and detailed ionic equations. Strike out any spectator ions.

**Solutions of Strong Acids & Strong Bases**

1. Solutions of hydrochloric acid and barium hydroxide are mixed.

2. Solutions of sulfuric acid and potassium hydroxide are mixed.

**Solutions containing Weak Acids and/or Weak Bases**

3. Solutions of aluminum hydroxide and carbonic acid are mixed.

4. Solutions of hydrobromic acids and ammonium hydroxide are mixed.

**Solutions reacting with Solids**

5. Solid potassium hydroxide is added to a solution of sulfuric acid.

6. A solution of hydrochloric acid is added to solid copper(II) hydroxide.
**Gas Forming Reactions**
7. A solution of ammonium sulfate is added to solid lead hydroxide.

8. Solid iron (III) sulfide is added to a dilute solution of sulfuric acid.

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**Reactions in Aqueous Solution**

**PRECIPITATE LAB**

1. For each compound, write the two ions that make it up. (Ex: $\text{K}_2\text{CrO}_4 = \text{K}^+ \text{ CrO}_4^{2-}$)
2. In each square, write the two new compounds that will form.
3. Cross out any compounds that you KNOW will be soluble in water and therefore will NOT be precipitates.

<table>
<thead>
<tr>
<th></th>
<th>① AgNO₃</th>
<th>② (NH₄)₂SO₄</th>
<th>③ KCl</th>
<th>④ Na₂CO₃</th>
<th>⑤ Pb(NO₃)₂</th>
<th>⑥ Ba(OH)₂</th>
<th>⑦ CuSO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>①</td>
<td>Ag₂CrO₄</td>
<td>KNO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>②</td>
<td>(NH₄)₂SO₄</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>③</td>
<td>KCl</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>④</td>
<td>Na₂CO₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>⑤</td>
<td>Pb(NO₃)₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>⑥</td>
<td>Ba(OH)₂</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>⑦</td>
<td>CuSO₄</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
$\text{CuSO}_4$
Reactions in Aqueous Solution

Determine the oxidation number of each element in the following ions or compounds:

a) $\text{BrO}_3^-$   d) $\text{CaH}_2$

b) $\text{C}_2\text{O}_4^{2-}$   e) $\text{H}_2\text{SiO}_4$

c) $\text{F}_2$   f) $\text{SO}_4^{2-}$

Determine the oxidation number of each element in the following ions or compounds:

a) $\text{SF}_6$   d) $\text{N}_2\text{O}_4$

b) $\text{H}_2\text{AsO}_4^-$   e) $\text{PCl}_4^+$

c) $\text{UO}_2^+$   f) $\text{XeO}_4^{2-}$

Which of the following reactions is (are) oxidation-reduction reactions? Explain your answer briefly. Classify the remaining reactions.

a) $\text{Zn(s)} + 2 \text{NO}_3^-(\text{aq}) + 4 \text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2 \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O(l)}$

b) $\text{Zn(OH)}_2(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{ZnSO}_4(\text{aq}) + 2 \text{H}_2\text{O(l)}$

c) $\text{Ca(s)} + 2 \text{H}_2\text{O(l)} \rightarrow \text{Ca(OH)}_2(\text{s}) + \text{H}_2(\text{g})$

Which of the following reactions is (are) oxidation-reduction reactions? Explain your answer briefly. Classify the remaining reactions.

a) $\text{CdCl}_2(\text{aq}) + \text{Na}_2\text{S(aq)} \rightarrow \text{CdS(s)} + 2 \text{NaCl(aq)}$

b) $2 \text{Ca(s)} + \text{O}_2(\text{g}) \rightarrow 2 \text{CaO(s)}$

c) $\text{Ca(OH)}_2(\text{s}) + 2 \text{HCl(aq)} \rightarrow \text{CaCl}_2(\text{aq}) + 2 \text{H}_2\text{O(l)}$

In each of the following reactions, decide which reactant is oxidized and which is reduced. Designate the oxidizing agent and reducing agent.

a) $2 \text{Mg(s)} + \text{O}_2(\text{g}) \rightarrow 2 \text{MgO(s)}$

b) $\text{C}_2\text{H}_4(\text{g}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g}) + 2 \text{H}_2\text{O(g)}$

c) $\text{Si(s)} + 2 \text{Cl}_2(\text{g}) \rightarrow \text{SiCl}_4(\text{l})$

In each of the following reactions, decide which reactant is oxidized and which is reduced. Designate the oxidizing agent and reducing agent.

a) $\text{Ca(s)} + 2 \text{HCl(aq)} \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2(\text{g})$

b) $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 3 \text{Sn}^{2+}(\text{aq}) + 14 \text{H}^+(\text{aq}) \rightarrow 2 \text{Cr}^{3+}(\text{aq}) + 3 \text{Sn}^{4+}(\text{aq}) + 7 \text{H}_2\text{O(l)}$

c) $\text{FeS(s)} + 3 \text{NO}_3^-(\text{aq}) + 4 \text{H}^+(\text{aq}) \rightarrow 3 \text{NO(g)} + \text{SO}_4^{2-}(\text{aq}) + \text{Fe}^{3+}(\text{aq}) + 2 \text{H}_2\text{O(l)}$
Reactions in Aqueous Solution

Solution Concentration

If 6.73 g of Na₂CO₃ is dissolved in enough water to make 250. mL of solution, what is the molarity of the sodium carbonate? What are the molar concentrations of the Na⁺ and CO₃²⁻ ions?

Some potassium dichromate (K₂Cr₂O₇), 2.335 g, is dissolved in enough water to make exactly 500. mL of solution. What is the molarity of the potassium dichromate? What are the molar concentrations of the K⁺ and Cr₂O₇²⁻ ions?

What is the mass, in grams, of solute in 250. mL of a 0.0125 M solution of KMnO₄?

What is the mass, in grams, of solute in 125 mL of a 1.023 x 10⁻³ M solution of Na₃PO₄? What are the molar concentrations of the Na⁺ and PO₄³⁻ ions?

What volume of 0.123 M NaOH, in milliliters, contains 25.0 g of NaOH?

What volume of 2.06 M KMnO₄, in Liters, contains 322 g of solute?

If 4.00 mL of 0.0250 M CuSO₄ is diluted to 10.0 mL with pure water, what is the molarity of copper(II) sulfate in the diluted solution?

If you dilute 25.0 mL of 1.50 M hydrochloric acid to 500. mL, what is the molar concentration of the dilute acid?

If you need 1.00 L of 0.125 M H₂SO₄, which of the following methods would you use to prepare this solution?

a) Dilute 20.8 mL of 6.00 M H₂SO₄ to a volume of 1.00 L.
b) Add 950. mL of water to 50.0 mL of 3.00 M H₂SO₄.

If you need 300. mL of 0.500 M K₂Cr₂O₇, which of the following methods would you use to prepare this solution?

a) Add 30.0 mL of 1.50 M K₂Cr₂O₇ to 270. mL of water.
b) Dilute 250. mL of 0.600 M K₂Cr₂O₇ to a volume of 300. mL.

For each solution, identify the ions that exist in aqueous solution & specify the concentration of each.

a) 0.25 M (NH₄)₂SO₄
b) 0.056 M HNO₃
c) 0.123 M Na₂CO₃
d) 0.00124 M KClO₄

For each solution, identify the ions that exist in aqueous solution & specify the concentration of each.
a) 0.12 M BaCl\(_2\)
b) 0.0125 M CuSO\(_4\)
c) 0.146 M AlCl\(_3\)
d) 0.500 M K\(_2\)Cr\(_2\)O\(_7\)
Stoichiometry of Reactions in Solution

What volume of 0.125 M HNO$_3$, in milliliters, is required to react completely with 1.30 g of Ba(OH)$_2$?  

\[ 2 \text{HNO}_3(\text{aq}) + \text{Ba(OH)}_2(\text{s}) \rightarrow \text{Ba(NO}_3)_2(\text{aq}) + 2 \text{H}_2\text{O(l)} \]

One of the most important industrial processes in our economy is the electrolysis of brine solutions (aqueous solutions of NaCl). When an electric current is passed through an aqueous solution of salt, the NaCl and water produce H$_2$(g), Cl$_2$(g), and NaOH—all valuable industrial chemicals.  

\[ 2 \text{NaCl(}\text{aq}) + 2 \text{H}_2\text{O(l)} \rightarrow \text{H}_2(\text{g}) + \text{Cl}_2(\text{g}) + 2 \text{NaOH(}\text{aq}) \]

What mass of NaOH can be formed from 10.0 L of 0.15 M NaCl? What mass of chlorine can be obtained?

In the photographic developing process, silver bromide is dissolved by adding sodium thiosulfate:  

\[ \text{AgBr(s)} + 2 \text{Na}_2\text{S}_2\text{O}_3(\text{aq}) \rightarrow \text{Na}_3\text{Ag(S}_2\text{O}_3)_2(\text{aq}) + \text{NaBr(}\text{aq}) \]

If you want to dissolve 0.250 g of AgBr, what volume of 0.0138 M Na$_2$S$_2$O$_3$, in milliliters, should be used?

What volume of 0.750 M Pb(NO$_3$)$_2$, in milliliters, is required to react completely with 1.00 L of 2.25 M NaCl solution? the balanced equation is  

\[ \text{Pb(NO}_3)_2(\text{aq}) + 2 \text{NaCl(}\text{aq}) \rightarrow \text{PbCl}_2(\text{s}) + 2 \text{NaNO}_3(\text{aq}) \]

You place 2.56 g of CaCO$_3$ in a beaker containing 250. mL of 0.125 M HCl (Figure 5.13). When the reaction has ceased,  

\[ \text{CaCO}_3(\text{s}) + 2 \text{HCl(}\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O(l)} \]

does any calcium carbonate remain? Explain your reasoning. What mass of CaCl$_2$ can be produced?

Titration

What volume of 0.812 M HCl, in milliliters, is required to titrate 1.33 g of NaOH to the equivalence point?  

\[ \text{NaOH(}\text{aq}) + \text{HCl(}\text{aq}) \rightarrow \text{NaCl(}\text{aq}) + \text{H}_2\text{O(l)} \]

What volume of 0.955 M HCl, in milliliters, is needed to titrate 2.152 g of Na$_2$CO$_3$ to the equivalence point?  

\[ \text{Na}_2\text{CO}_3(\text{aq}) + 2 \text{HCl(}\text{aq}) \rightarrow 2 \text{NaCl(}\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O(l)} \]
AP Question

1981 B
A 1.2516 gram sample of a mixture of CaCO$_3$ and Na$_2$SO$_4$ was analyzed by dissolving the sample and completely precipitating the Ca$^{2+}$ as CaC$_2$O$_4$. The CaC$_2$O$_4$ was dissolved in sulfuric acid and the resulting H$_2$C$_2$O$_4$ was titrated with a standard KMnO$_4$ solution.

(a) Write the balanced equation for the titration reaction, shown unbalanced below.

\[
\text{MnO}_4^- + \text{H}_2\text{C}_2\text{O}_4 + \text{H}^+ \rightarrow \text{Mn}^{2+} + \text{CO}_2 + \text{H}_2\text{O}
\]

Indicate which substance is the oxidizing agent and which substance is the reducing agent.

(b) The titration of the H$_2$C$_2$O$_4$ obtained required 35.62 milliliters of 0.1092 molar MnO$_4^-$ solution. Calculate the number of moles of H$_2$C$_2$O$_4$ that reacted with the MnO$_4^-$

(c) Calculate the number of moles of CaCO$_3$ in the original sample.

(d) Calculate the percentage by weight of CaCO$_3$ in the original sample.
The Gas Laws

The Ideal Gas Law

\[ PV = nRT \]
where
- \( P \) = pressure in atmosphere
- \( V \) = volume in liters
- \( n \) = number of moles of gas
- \( R \) = Universal Gas Constant = 0.0821 L·atm/mol·K
- \( T \) = Kelvin temperature

1. How many moles of oxygen will occupy a volume of 2.50 liters at 1.20 atm and 25 °C?

2. What volume will 2.00 moles of nitrogen occupy at 720. torr and 20.°C?

3. What pressure will be exerted by 25.0 g of CO\(_2\) at temperature of 25 °C and a volume of 500. mL?

4. At what temperature will 5.00 g of Cl\(_2\) exert a pressure of 900. torr at a volume of 750. mL?

5. What is the density of NH\(_3\) at 800. torr and 25 °C?

6. If the density of a gas is 1.2 g/L at 745 torr and 20.°C, what is its molar mass?

7. How many moles of nitrogen gas will occupy a volume of 347 mL at 6680 torr and 27 °C?

8. What volume will 454 grams (1 lb) of hydrogen occupy at 1.05 atm and 25 °C?
9. Find the number of grams of CO\textsubscript{2} that exert a pressure of 785 torr at a volume of 32.5 L and a temperature of 32 \degree C. ___________________

10. An elemental gas has a mass of 10.3 g. If the volume is 58.4 L and the pressure is 758 torr at a temperature of 2.5 \degree C, what is the gas? ___________________

---

**Gases and Their Properties**

Represented above are five identical balloons, each filled to the same volume at 25\degree C and 1.0 atmosphere pressure with the pure gases indicated.

(a) Which balloon contains the greatest mass of gas? Explain.

(b) Compare the average kinetic energies of the gas molecules in the balloons. Explain.

(c) Which balloon contains the gas that would be expected to deviate most from the behavior of an ideal gas? Explain.

(d) Twelve hours after being filled, all the balloons have decreased in size. Predict which balloon will be the smallest. Explain your reasoning.
Energy and Chemical Reactions

UNITS AND CALORIMETRY

1. A 35.0-mL sample of water at 95.0°C and mixed with 150. mL of water at 15.0°C in an insulated cup and the temperature is recorded after 30 seconds and every 30 seconds as shown. Plot the data and determine the theoretical temperature of liquids when they were mixed. This is your “final temperature” for ΔT.

<table>
<thead>
<tr>
<th>Time (minutes)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>0.50</td>
<td>28.3</td>
</tr>
<tr>
<td>1.0</td>
<td>27.6</td>
</tr>
<tr>
<td>1.5</td>
<td>26.8</td>
</tr>
<tr>
<td>2.0</td>
<td>26.0</td>
</tr>
</tbody>
</table>

2. a. Calculate the energy gained (Δq) by the cold water (Δq_{cold} = m_{cold}CΔT_{cold})

Recall that C = 4.184 J/g.°C

b. Calculate the energy lost (Δq) by the hot water (Δq_{hot} = m_{hot}CΔT_{hot})
3. Calculate the absolute difference between the energy lost by the hot water (\(\Delta q_{\text{hot}}\)) and the energy gained by the cold water (\(\Delta q_{\text{cold}}\)).

\[
\Delta q_{\text{hot}} - \Delta q_{\text{cold}}
\]

4. Where did this energy go?

5. Calculate the calorimeter constant in \(J/\circ C\) by dividing the absolute difference in energy by the temperature change of the hot water.

\[
\text{calorimeter constant} = \frac{|\Delta q_{\text{hot}} - \Delta q_{\text{cold}}|}{\Delta T_{\text{hot}}}
\]
6. A pot of water (2.5 Liters of water) initially at 25.0°C is heated to boiling. How much energy is needed to heat the water?

7. 74.8 J of heat is required to raise the temperature of 18.69 g of silver from 10.0°C to 27.0°C.
   a. What is the heat capacity of the silver sample? (J/°C)
   b. What is the specific heat of silver? (J/g.°C)
   c. What is the molar heat capacity of silver? (J/mol.°C)
Energy and Chemical Reactions

**HESS’S LAW CALCULATIONS**

The enthalpy of the reactants, $H_{\text{reactants}}$ and the enthalpy of the products, $H_{\text{products}}$ depend on the bonding of the reactants and products... nothing else. So, the $\Delta H_{\text{reaction}}$ only depends on the initial and final state of the reaction, not how you got from one state to another state. It is called a “state function”.

Practically speaking, if we can find several equations that “add up” to the equation we want, the $\Delta H_{\text{reactions}}$ will add up to the overall $\Delta H$. This is called Hess’s Law.

Heats of Formation: Write the formation equations for the following. [See Table 6.2 on page 270 of text.]

<table>
<thead>
<tr>
<th>Compound</th>
<th>Formation Equation</th>
<th>$\Delta H_f$ (kJ·mol$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_4$(g)</td>
<td>C(s) + 2H$_2$(g) → CH$_4$(g)</td>
<td>-74.8</td>
</tr>
<tr>
<td>H$_2$O(l)</td>
<td></td>
<td>-285.8</td>
</tr>
<tr>
<td>H$_2$O(g)</td>
<td></td>
<td>-241.8</td>
</tr>
<tr>
<td>CO$_2$(g)</td>
<td></td>
<td>-393.5</td>
</tr>
<tr>
<td>C$_2$H$_6$(g)</td>
<td></td>
<td>-84.7</td>
</tr>
<tr>
<td>C$_3$H$_8$(g)</td>
<td></td>
<td>-103.8</td>
</tr>
<tr>
<td>C$<em>4$H$</em>{10}$(g)</td>
<td></td>
<td>-125.6</td>
</tr>
</tbody>
</table>

a) Calculate the heat of combustion, $\Delta H_{\text{combustion}}$, for each of the fuels in the chart.
b) Use the heat of combustion of C$_3$H$_8$, 2220kJ/mol, to calculate the $\Delta H_f$ of C$_3$H$_8$.  

26
1. Consider the following hypothetical reactions:

\[
\begin{align*}
A & \rightarrow B \quad \Delta H = +30 \text{ kJ} \\
B & \rightarrow C \quad \Delta H = +60 \text{ kJ}
\end{align*}
\]

a. Use Hess’s law to calculate the enthalpy change for reaction \( A \rightarrow C \).

2. Suppose you are given the following hypothetical reactions:

\[
\begin{align*}
X & \rightarrow Y \quad \Delta H = -40 \text{ kJ} \\
X & \rightarrow Z \quad \Delta H = -95 \text{ kJ}
\end{align*}
\]

a. Use Hess’s law to calculate the enthalpy change for the reaction \( Y \rightarrow Z \).

3. From the following heats of reaction:

\[
\begin{align*}
2 \, \text{H}_2 (g) + \text{O}_2 (g) & \rightarrow 2 \, \text{H}_2\text{O} (g) \quad \Delta H = -483.6 \text{ kJ} \\
3 \, \text{O}_2 (g) & \rightarrow 2 \, \text{O}_3 (g) \quad \Delta H = +284.6 \text{ kJ}
\end{align*}
\]

calculate the heat of the reaction

\[
3 \, \text{H}_2 (g) + \text{O}_3 (g) \rightarrow 3 \, \text{H}_2\text{O} (g)
\]

4. From the following enthalpies of reaction:

\[
\begin{align*}
\text{H}_2 (g) + \text{F}_2 (g) & \rightarrow 2 \, \text{HF} (g) \quad \Delta H = -537 \text{ kJ} \\
\text{C} (s) + 2 \, \text{F}_2 (g) & \rightarrow \text{CF}_4 (g) \quad \Delta H = -680 \text{ kJ} \\
2 \, \text{C} (s) + 2 \, \text{H}_2 (g) & \rightarrow \text{C}_2\text{H}_4 (g) \quad \Delta H = +52.3 \text{ kJ}
\end{align*}
\]

Calculate the \( \Delta H \) for the reaction of ethylene with \( \text{F}_2 \).

\[
\text{C}_2\text{H}_4 (g) + 6 \, \text{F}_2 (g) \rightarrow 2 \, \text{CF}_4 (g) + 4 \, \text{HF}(g)
\]

\( \Delta H = \) 

5. Given the following data:

\[
\begin{align*}
\text{N}_2 (g) + \text{O}_2 (g) & \rightarrow 2 \, \text{NO} (g) \quad \Delta H = +180.7 \text{ kJ} \\
2 \, \text{NO} (g) + \text{O}_2 (g) & \rightarrow 2 \, \text{NO}_2 (g) \quad \Delta H = -113.1 \text{ kJ} \\
2 \, \text{N}_2\text{O} (g) & \rightarrow 2 \, \text{N}_2 (g) + \text{O}_2 (g) \quad \Delta H = -162.3 \text{ kJ}
\end{align*}
\]
Use Hess’s law to calculate $\Delta H$ for the reaction.

\[ \text{N}_2\text{O} (g) + \text{NO}_2 (g) \rightarrow 3 \text{NO} (g) \quad \Delta H = \]

---

**Energy & Chemical Thermodynamics**

**APRIMARY TEST**

\[ \text{C}_2\text{H}_5(g) + 2 \text{H}_2(g) \rightarrow \text{C}_2\text{H}_6(g) \]

Information about the substances involved in the reaction represented above is summarized in the following tables.

<table>
<thead>
<tr>
<th>Substance</th>
<th>$\Delta H^\circ_f$ (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{C}_2\text{H}_5(g)$</td>
<td>226.7</td>
</tr>
<tr>
<td>$\text{C}_2\text{H}_6(g)$</td>
<td>-84.7</td>
</tr>
</tbody>
</table>

(a) Write the equation for the heat of formation of $\text{C}_2\text{H}_6(g)$

(b) Use the above information to determine the enthalpy of reaction for the equation given.

\[ \text{C}_6\text{H}_5\text{OH}(s) + 7 \text{O}_2(g) \rightarrow 6 \text{CO}_2(g) + 3 \text{H}_2\text{O}(l) \]

When a 2.000-gram sample of pure phenol, $\text{C}_6\text{H}_5\text{OH}(s)$, is completely burned according to the equation above, 64.98 kilojoules of heat is released. Use the information in the table below to answer the questions that follow.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Standard Heat of Formation, $\Delta H^\circ_f$ at 25°C (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CO}_2(g)$</td>
<td>-393.5</td>
</tr>
<tr>
<td>$\text{H}_2\text{O}(l)$</td>
<td>-285.85</td>
</tr>
<tr>
<td>$\text{C}_6\text{H}_5\text{OH}(s)$</td>
<td>?</td>
</tr>
</tbody>
</table>

(a) Calculate the molar heat of combustion of phenol in kilojoules per mole at 25°C.
(b) Calculate the standard heat of formation, $\Delta H^\circ_f$, of phenol in kilojoules per mole at 25°C.

---

### Atomic Structure

#### Calculation Practice—1

<table>
<thead>
<tr>
<th>Formulas and Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c = \lambda \nu$</td>
</tr>
<tr>
<td>$\lambda = \frac{c}{\nu}$</td>
</tr>
<tr>
<td>$\nu = \frac{c}{\lambda}$</td>
</tr>
<tr>
<td>$E = h \nu$</td>
</tr>
<tr>
<td>$E = \frac{hc}{\lambda}$</td>
</tr>
</tbody>
</table>

- $c = 2.998 \times 10^8$ m/s
- $h = 6.626 \times 10^{-34}$ J·s

1. List all electromagnetic radiations from low energy to high.

2. An FM radio station has a frequency of 88.9 MHz (1 MHz = $10^6$ Hz, or cycles per second). What is the wavelength of this radiation in meters?

3. The U.S. Navy has a system for communicating with submerged submarines. The system uses radio waves with a frequency of 76 s$^{-1}$. What is the wavelength of this radiation in meters? In miles?

4. Violet light has a wavelength of about 410 nm. What is its frequency? Calculate the energy of one photon of violet light. What is the energy of 1.0 mol of violet photons?

5. The energy of a mole of photons of red light from a laser is 175 kJ/mol. Calculate the energy of one photon of red light. What is the wavelength of red light in meters? In nm? Compare the energy of photons of violet light with those of red light. Which is more energetic and by what factor?
6. The most prominent line in the spectrum of neon is found at 865.438 nm. Other lines are found at 837.761 nm, 878.062 nm, 878.438 nm, and 1885.387 nm.
(a) Which of these lines represents the most energetic light?
(b) What is the frequency of the most prominent line? What is the energy of one photon of this wavelength?

---

**Atomic Structure**

<table>
<thead>
<tr>
<th>Formulas and Constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c = \lambda \nu )</td>
</tr>
</tbody>
</table>

- \( c = 2.998 \times 10^8 \text{ m/s} \)
- \( h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s} \)
- \( Rhc = 2.18 \times 10^{-18} \text{ J} \)
- \( R = 1.0974 \times 10^{7} \text{ m}^{-1} \)

1. Sketch the electron energy levels (n=1 through n=5) for the hydrogen atom.

2. Calculate the energy of an electron in the n=2 energy level of hydrogen. Calculate the energy of an electron in the n=3 energy level. What is the difference in energy of these two levels? If a photon of light had this energy, what would its wavelength be?

3. Use the Rydberg equation above to calculate the wavelength of a photon when n=3. How does this compare with your answer in question 2?

4. An electron moves from the n=5 to the n=1 quantum level and emits a photon with an energy of \( 2.093 \times 10^{-18} \text{ J} \). How much energy must the atom absorb to move an electron from n=1 to n=5? What is the wavelength of this energy?
5. An electron moves with a velocity of $2.5 \times 10^8$ cm/s. What is its wavelength? (The mass of an electron is $9.109 \times 10^{-28}$ g.)

6. Calculate the wavelength (in nanometers) associated with a $1.0 \times 10^{-2}$-g golf ball moving at 30. m/s (about 67 mph). How fast must the ball travel to have a wavelength of $5.6 \times 10^{-3}$ nm?

**Atomic Structure**

**QUANTUM NUMBER PRACTICE**

1. Summarize:
   - The principal quantum number, $n$, can have the values of: ___ ___ ___ ___ ___, etc.
   - The angular momentum quantum number, $l$, can have integer values from ______ to ______.
   - The magnetic quantum number, $m_l$, can have integer values from _____ to _.

2. When $n = 3$, $l$ can have values of ___________________________.
   - For the 3d orbital, $l$ has a value of ___.

   - When $n = 4$, $l$ can have values of ___________________________.
   - For the 4p orbital, $l$ has a value of ___.

   - When $n = 2$, $l$ can have values of ___________________________.
   - For the 2s orbital, $l$ has a value of ___

3. Summarize:

<table>
<thead>
<tr>
<th>orbital</th>
<th>s</th>
<th>p</th>
<th>d</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>value of $l$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. There are five 4d orbitals. List the quantum numbers for each orbital.

<table>
<thead>
<tr>
<th>$n$</th>
<th>$l$</th>
<th>$m_l$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Questions from the textbook (answers in the book)

5. Rank the following orbitals in the H atom in order of increasing energy: 3s, 2s, 2p, 4s, 3p, 1s, and 3d.

6. How many orbitals in an atom can have the following quantum number or designation?
   a) 3p
   b) 4p
   c) 4px
   d) 6d
   e) 5d
   f) 5f
   g) n = 5
   h) 7s

7. Answer the following questions as a summary quiz on the chapter.
   a) The quantum number n describes the _______ of an atomic orbital.
   b) The shape of an atomic orbital is given by the quantum number ____.
   c) A photon of orange light has _____ (less or more) energy than a photon of yellow light.
   d) The maximum number of orbitals that may be associated with the set of quantum numbers n=4 and l =3 is ____.
   e) The maximum number of orbitals that may be associated with the quantum number set n=3, l=2, and ml = -2 is ____.
   f) When n=5, the possible values of l are _______.
   g) The maximum number of orbitals that can be assigned to the n=4 shell is ____.

8. Suppose you live in a different universe where a different set of quantum numbers is required to describe the atoms of that universe. These quantum numbers have the following rules:
   N, principal 1, 2, 3, … ∞
   L, orbital = N
   M, magnetic -1, 0, +1

   How many orbitals are there altogether in the first three electron shells? [Check answer in book #80]
9. Assume an electron is assigned to the 1s orbital in the H atom. Is the electron density zero at a distance of 0.40 nm from the nucleus? ___ (See A Closer Look: Atomic Orbitals)

---

**Electron Configurations & Periodicity**

**WRITING ELECTRON CONFIGURATIONS**

For each given element, fill in the orbital diagram and then write the electron configuration for the element.

<table>
<thead>
<tr>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Orbital Diagram 1" /></td>
<td><img src="image2" alt="Orbital Diagram 2" /></td>
<td><img src="image3" alt="Orbital Diagram 3" /></td>
<td><img src="image4" alt="Orbital Diagram 4" /></td>
<td><img src="image5" alt="Orbital Diagram 5" /></td>
<td><img src="image6" alt="Orbital Diagram 6" /></td>
</tr>
</tbody>
</table>

Element: Ar
# of e⁻'s: ___
# of e⁺'s: ___

Element: Mg
# of e⁻'s: ___
# of e⁺'s: ___

Element: N
# of e⁻'s: ___
# of e⁺'s: ___

Element: Li
# of e⁻'s: ___
# of e⁺'s: ___

Element: P
# of e⁻'s: ___
# of e⁺'s: ___

Element: Cl
# of e⁻'s: ___
# of e⁺'s: ___

Write the electron configurations of each of these in **long form** and **short form**:

1. Ar

2. Mg

3. N
4. Li

5. P

6. Cl

7. Fill in the orbital diagram for the element, Fe, and write the electron configuration of Fe in the long and short form.

Fe

Fe
A few elements do not follow the “rules”. There is some lowering of the energy of the atom by completely filling or half-filling the five d-orbitals.

8. Fill in the orbital diagram for the element, Cu, and write the electron configuration of Cu in the long and short form.

Cu

9. Fill in the orbital diagram for the element, Cr, and write the electron configuration of Cr in the long and short form.

Cr

Shade in the six elements that do not follow the Aufbau Principle:

<table>
<thead>
<tr>
<th></th>
<th>Sc</th>
<th>Ti</th>
<th>V</th>
<th>Cr</th>
<th>Mn</th>
<th>Fe</th>
<th>Co</th>
<th>Ni</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Y</td>
<td>Zr</td>
<td>Nb</td>
<td>Mo</td>
<td>Tc</td>
<td>Ru</td>
<td>Rh</td>
<td>Pd</td>
<td>Ag</td>
<td>Cd</td>
</tr>
<tr>
<td></td>
<td>La</td>
<td>Hf</td>
<td>Ta</td>
<td>W</td>
<td>Re</td>
<td>Os</td>
<td>Ir</td>
<td>Pt</td>
<td>Au</td>
<td>Hg</td>
</tr>
</tbody>
</table>

Fill in the orbitals that are filled by these elements.

|   | 1s | 2s |

10. Write the orbital occupied by the last electron of each of the following elements:

| As | W | Li | U | O | Rn | V |

35
Atomic Structure and Properties

AP Practice Question

2006 D
Suppose that a stable element with atomic number 119, symbol Q, has been discovered.
(a) Write the ground-state electron configuration for Q, showing only the valence-shell electrons.
(b) Would Q be a metal or a nonmetal? Explain in terms of electron configuration.
(c) On the basis of periodic trends, would Q have the largest atomic radius in its group or would it have the smallest? Explain in terms of electronic structure.
(d) What would be the most likely charge of the Q ion in stable ionic compounds?
(e) Write a balanced equation that would represent the reaction of Q with water.
(f) Assume that Q reacts to form a carbonate compound.
   (i) Write the formula for the compound formed between Q and the carbonate ion, CO$_3^{2-}$.
   (ii) Predict whether or not the compound would be soluble in water. Explain your reasoning.
## Bonding & Molecular Structure

*LEWIS STRUCTURES*

Indicate the # of VALENCE electrons for each species. Write the correct Lewis electron-dot structure for each.

<table>
<thead>
<tr>
<th>Species</th>
<th>Valence Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₂H₄</td>
<td></td>
</tr>
<tr>
<td>C₂F₄</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td></td>
</tr>
<tr>
<td>O₂</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
</tr>
<tr>
<td>C₂H₂ (H C C H)</td>
<td></td>
</tr>
<tr>
<td>N₂</td>
<td></td>
</tr>
<tr>
<td>HCN</td>
<td></td>
</tr>
<tr>
<td>CN⁻</td>
<td></td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td></td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td></td>
</tr>
<tr>
<td>ClO₃⁻</td>
<td></td>
</tr>
<tr>
<td>CO₃²⁻</td>
<td></td>
</tr>
<tr>
<td>NO₃⁻</td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td></td>
</tr>
<tr>
<td>O₃ (O O O)</td>
<td></td>
</tr>
</tbody>
</table>
Bonding & Molecular Structure

 Bonds & Molecular Structure

<table>
<thead>
<tr>
<th>SF₆</th>
<th>XeF₄</th>
<th>PCl₅</th>
<th>SeF₄</th>
</tr>
</thead>
<tbody>
<tr>
<td># of valence e⁻’s =</td>
<td># of valence e⁻’s =</td>
<td># of valence e⁻’s =</td>
<td># of valence e⁻’s =</td>
</tr>
</tbody>
</table>

**Bond Energies**

Some Average Single- and Multiple-Bond Energies (kJ/mol)

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>F</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cl</th>
<th>Br</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>436</td>
<td>413</td>
<td>391</td>
<td>463</td>
<td>565</td>
<td>318</td>
<td>322</td>
<td>347</td>
<td>432</td>
<td>366</td>
<td>299</td>
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<tr>
<td>C</td>
<td>346</td>
<td>305</td>
<td>358</td>
<td>485</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>163</td>
<td>201</td>
<td>283</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>192</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>452</td>
<td>335</td>
</tr>
<tr>
<td>Si</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>283</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>192</td>
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<td>Cl</td>
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<tr>
<td>I</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>201</td>
</tr>
</tbody>
</table>

**Multiple Bonds**

<table>
<thead>
<tr>
<th></th>
<th>N=N</th>
<th>C=C</th>
<th>N≡N</th>
<th>C≡C</th>
<th>C=N</th>
<th>C=O</th>
<th>C≡N</th>
<th>C≡O</th>
<th>O=O (in O₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>418</td>
<td>602</td>
<td>945</td>
<td>835</td>
<td>615</td>
<td>732</td>
<td>887</td>
<td>1072</td>
<td>498</td>
</tr>
</tbody>
</table>

**Table 6.2 • Standard Enthalpies of Formation (kJ/mol)**

<table>
<thead>
<tr>
<th></th>
<th>C₂H₆(g)</th>
<th>ethane</th>
<th>-84.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O(g)</td>
<td></td>
<td>water vapor</td>
<td>-241.8</td>
</tr>
<tr>
<td>CO₂(g)</td>
<td></td>
<td>carbon dioxide</td>
<td>-393.5</td>
</tr>
</tbody>
</table>

1. Write the balanced chemical equation for the complete combustion of ethane, C₂H₆(g).

2. Draw structural formulas (shortcut Lewis structures) for each of the species.

3. Calculate the energy needed to break the bonds in the reactants. ________
Calculate the energy released as the bonds in the products are formed. ________

4. What is the $\Delta H_{\text{combustion}}$ based on bond energies? ______________

---

**Bonding & Molecular Structure**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>2.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li</td>
<td>Be</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>Mg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Ca</td>
<td>Sc</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>1.0</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Rb</td>
<td>Sr</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>1.0</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Cs</td>
<td>Ba</td>
<td>La</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>1.0</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>Fr</td>
<td>Ra</td>
<td>Ac</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>1.0</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

**Electronegativity**

<table>
<thead>
<tr>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>C</td>
<td>N</td>
<td>O</td>
<td>F</td>
</tr>
<tr>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Al</td>
<td>Si</td>
<td>P</td>
<td>S</td>
<td>Cl</td>
</tr>
<tr>
<td>1.5</td>
<td>1.8</td>
<td>2.1</td>
<td>2.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

1. In each pair of bonds, put a star (★) next to the more polar bond and use an arrow (+→) to show the direction of polarity in each bond.

   a) C—O and C—N
   b) P—Br and P—Cl
   c) B—O and B—S
   d) B—F and B—I

2. For each of the bonds listed below, indicate (+→) which atom is the more negatively charged.

   a) C—N
   b) C—H
   c) C—Br
   d) S—O

---

It is somewhat artificial to classify bonds based on the differences in the electronegativities ($\Delta \chi$) of the two atoms. However, we will use these ranges to do so:

- **Ionic** $\Delta \chi > 1.7$ (symbolized as $A^+ \text{ and } Z^-$)
- **Polar Covalent** $1.7 \geq \Delta \chi \geq .5$ (symbolized as $A^\delta+ \text{ and } Z^\delta-$)
- **Pure Covalent** $\Delta \chi < .5$ (no charges)
3. For each of the bonds listed below, classify each bond and indicate full or partial charges, if any.

- a) Na—Cl
- b) C—O
- c) Cu—O
- d) C—H
- e) Mg—H
- f) Cs—F
- g) Cl—Cl
- h) Al—Cl

Hybridization & Molecular Orbitals

STUDY QUESTIONS

1. What hybridization is required at the central atom of the following molecules or ions? (These are the same molecules examined in questions 3, 5, 12, and 13 in Chapter 9.) Sketch the Lewis electron-dot diagram; state the Steric Number (SN) and then state the hybridization.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>AlCl₃</td>
<td>f.</td>
<td>BCl₃</td>
</tr>
<tr>
<td>b.</td>
<td>PCl₃</td>
<td>g.</td>
<td>ClO₂⁻</td>
</tr>
<tr>
<td>c.</td>
<td>PCl₅</td>
<td>h.</td>
<td>O₃</td>
</tr>
<tr>
<td>d.</td>
<td>SiCl₄</td>
<td>i.</td>
<td>GaH₃</td>
</tr>
<tr>
<td>e.</td>
<td>NCl₃</td>
<td>j.</td>
<td>SO₂Cl₂</td>
</tr>
<tr>
<td>f.</td>
<td>NO₂</td>
<td>k.</td>
<td>XeO₄</td>
</tr>
<tr>
<td>g.</td>
<td>ClO₂⁻</td>
<td>l.</td>
<td>CCl₄</td>
</tr>
<tr>
<td>h.</td>
<td>O₃</td>
<td>m.</td>
<td>SCl₂</td>
</tr>
<tr>
<td>i.</td>
<td>GaH₃</td>
<td>n.</td>
<td>SF₆</td>
</tr>
<tr>
<td>j.</td>
<td>SO₂Cl₂</td>
<td>o.</td>
<td>BeCl₂</td>
</tr>
<tr>
<td>k.</td>
<td>XeO₄</td>
<td>p.</td>
<td>NO₂</td>
</tr>
<tr>
<td>l.</td>
<td>CCl₄</td>
<td>q.</td>
<td>XeF₄</td>
</tr>
<tr>
<td>m.</td>
<td>SCl₂</td>
<td>r.</td>
<td>SF₄</td>
</tr>
<tr>
<td>n.</td>
<td>SF₆</td>
<td>s.</td>
<td>OCS</td>
</tr>
<tr>
<td>o.</td>
<td>BeCl₂</td>
<td>t.</td>
<td>SO₂</td>
</tr>
<tr>
<td>p.</td>
<td>NO₂</td>
<td>u.</td>
<td>NO₂⁺</td>
</tr>
<tr>
<td>q.</td>
<td>XeF₄</td>
<td>v.</td>
<td>ClO₄⁻</td>
</tr>
<tr>
<td>r.</td>
<td>SF₄</td>
<td>w.</td>
<td>IF₄⁻</td>
</tr>
<tr>
<td>s.</td>
<td>OCS</td>
<td>x.</td>
<td>ClF₂⁺</td>
</tr>
<tr>
<td>t.</td>
<td>SO₂</td>
<td>y.</td>
<td>BF₃</td>
</tr>
</tbody>
</table>
2. In the organic chemistry of carbon, three hybridizations are common. What are they, and why are they limited to three?

AP Questions

1982 D
(a) Draw the Lewis electron-dot structures for CO$_3^2-$, CO$_2$, and CO, including resonance structures where appropriate.
(b) Which of the three species has the shortest C-O bond length? Explain the reason for your answer.
(c) Predict the molecular shapes for the three species. Explain how you arrived at your predictions.

1990 D (Required)
Use simple structure and bonding models to account for each of the following.
(a) The bond length between the two carbon atoms is shorter in C$_2$H$_4$ than in C$_2$H$_6$.
(b) The H-N-H bond angle is 107.5º, in NH$_3$.
(c) The bond lengths in SO$_3$ are all identical and are shorter than a sulfur-oxygen single bond.
(d) The I$_3^-$ ion is linear.
1992 D

\[ \text{NO}_2 \quad \text{NO}_2^- \quad \text{NO}_2^+ \]

Nitrogen is the central atom in each of the species given above.

(a) Draw the Lewis electron-dot structure for each of the three species.
(b) List the species in order of increasing bond angle. Justify your answer.
(c) Select one of the species and give the hybridization of the nitrogen atom in it.
(d) Identify the only one of the species that dimerizes and explain what causes it to do so.

1996 D

Explain each of the following observations in terms of the electronic structure and/or bonding of the compounds involved.

(b) Molecules of AsF$_3$ are polar, whereas molecules of AsF$_5$ are nonpolar.
(c) The N-O bonds in the NO$_2$ ion are equal in length, whereas they are unequal in HNO$_2$.
(d) For sulfur, the fluorides SF$_2$, SF$_4$, and SF$_6$ are known to exist, whereas for oxygen only OF$_2$ is known to exist.

1997 D (Required)

Consider the molecules PF$_3$ and PF$_5$.

(a) Draw the Lewis electron-dot structures for PF$_3$ and PF$_5$ and predict the molecular geometry of each.
(b) Is the PF$_3$ molecule polar, or is it nonpolar? Explain.
(c) On the basis of bonding principles, predict whether each of the following compounds exists. In each case, explain your prediction.
   (i) NF$_5$
   (ii) AsF$_5$
Intermolecular Force Worksheet

1. Identify the strongest intermolecular force present in pure samples of the following substances:

   SO₂  H₂O  CH₂Cl₂

   SCO  PCl₃  SO₃

2. Identify the strongest intermolecular force operating in the condensed phases of the following substances. Fully explain how you determined this.

   a. Cl₂  b. CO
   c. SO₂  d. CH₂Cl₂
3. Based on the intermolecular forces present, predict the relative boiling points of each of the substances below. Arrange each series of substances in order of increasing boiling point. State your reasons for the order you use (identify the forces and explain how they affect the boiling point).

   a. dimethyl ether (CH$_3$OCH$_3$), ethanol (CH$_3$CH$_2$OH), and propane (CH$_3$CH$_2$CH$_3$)
   b. Br$_2$, Cl$_2$, I$_2$

4. For each pair of substance identify the substance that is likely to have the higher vapor pressure. Explain your reasoning.

   a. CO$_2$ or SO$_2$
   b. CH$_3$OH or CH$_3$-O-CH$_3$

**More Intermolecular Force Practice Problems**

1) For each of the following compounds indicate which intermolecular force is most important:

   a) FCN ________________________________
   b) HCN ______________________________
   c) C$_2$H$_6$ ____________________________
   d) CF$_2$H$_2$ ____________________________

2) Explain why ethyl alcohol (C$_2$H$_5$OH) has a higher boiling point (78.4$^0$ C) than methyl alcohol (CH$_3$OH; 64.7$^0$ C).
3) Rank the following by from lowest to highest anticipated boiling point: $\text{C}_2\text{H}_4$, $\text{CH}_4$, Ne, $\text{H}_3\text{COCH}_3$.

4) Motor oil largely consists of molecules that consist of long chains of carbon atoms with hydrogen atoms attached to them. Using your knowledge of intermolecular forces, why wouldn't it be better to use a compound like glycerol. The formula of glycerol is $\text{CHOH(CH}_2\text{OH)}_2$. 
2006 D Required
Answer each of the following in terms of principles of molecular behavior and chemical concepts.
(a) The structures for glucose, C$_6$H$_{12}$O$_6$, and cyclohexane, C$_6$H$_{12}$, are shown below.

Identify the type(s) of intermolecular attractive forces in
(i) pure glucose
(ii) pure cyclohexane
(b) Glucose is soluble in water but cyclohexane is not soluble in water. Explain.
(c) Consider the two processes represented below.
\[
\text{Process 1: } \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(g) \quad \Delta H^\circ = +44.0 \text{ kJ mol}^{-1} \\
\text{Process 2: } \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) \quad \Delta H^\circ = +286 \text{ kJ mol}^{-1}
\]
(i) For each of the two processes, identify the type(s) of intermolecular or intramolecular attractive forces that must be overcome for the process to occur.
(ii) Indicate whether you agree or disagree with the statement in the box below. Support your answer with a short explanation.

When water boils, H$_2$O molecules break apart to form hydrogen molecules and oxygen molecules.
(d) Consider the four reaction-energy profile diagrams shown below.
(i) Identify the two diagrams that could represent a catalyzed and an uncatalyzed reaction pathway for the same reaction. Indicate which of the two diagrams represents the catalyzed reaction pathway for the reaction.

(ii) Indicate whether you agree or disagree with the statement in the box below. Support your answer with a short explanation.

Adding a catalyst to a reaction mixture adds energy that causes the reaction to proceed more quickly.

2006 D

Answer the following questions about the structures of ions that contain only sulfur and fluorine.

(a) The compounds SF₄ and BF₃ react to form an ionic compound according to the following equation.

\[ \text{SF}_4 + \text{BF}_3 \rightarrow \text{SF}_3\text{BF}_4 \]

(i) Draw a complete Lewis structure for the SF₃⁺ cation in SF₃BF₄.
(ii) Identify the type of hybridization exhibited by sulfur in the SF₃⁺ cation.
(iii) Identify the geometry of the SF₃⁺ cation that is consistent with the Lewis structure drawn in part (a)(i).
(iv) Predict whether the F—S—F bond angle in the SF₃⁺ cation is larger than, equal to, or smaller than 109.50°. Justify your answer.

(b) The compounds SF₄ and CsF react to form an ionic compound according to the following equation.

\[ \text{SF}_4 + \text{CsF} \rightarrow \text{CsSF}_5 \]

(i) Draw a complete Lewis structure for the SF₅⁻ anion in CsSF₅.
(ii) Identify the type of hybridization exhibited by sulfur in the SF₅⁻ anion.
(iii) Identify the geometry of the SF₅⁻ anion that is consistent with the Lewis structure drawn in part (b)(i).
(iv) Identify the oxidation number of sulfur in the compound CsSF₅.
Solutions

Write the definition of each concentration in terms of solute, solvent, and/or solution:

<table>
<thead>
<tr>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>molarity (M)</td>
</tr>
<tr>
<td>molality (m)</td>
</tr>
<tr>
<td>mole fraction (X)</td>
</tr>
<tr>
<td>weight percent (%)</td>
</tr>
</tbody>
</table>

Each of these concentrations involves grams or moles of solute, solvent, or solution. Determine those values.

These are problems from your textbook. Check for answers in the back of the book. Do work on another sheet of paper.

Assume you dissolve 2.56 g of malic acid, C₄H₆O₅, in half a liter of water (500.0 g). Calculate the molarity, molality, mole fraction, and weight percentage of acid in the solution.

Fill in the blanks in the table. Aqueous solutions are assumed.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Molality</th>
<th>Weight Percentage</th>
<th>Mole Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaI</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₂H₅OH</td>
<td></td>
<td>5.0</td>
<td></td>
</tr>
</tbody>
</table>
Concentration Review Worksheet

1) If I make a solution by adding 83 grams of sodium hydroxide to 750 mL of water…
   a) What is the molality of sodium hydroxide in this solution?
   b) What is the percent by mass of sodium hydroxide in this solution?
   c) What is the mole fraction of sodium hydroxide in this solution?

2) If I make a solution by adding water to 35 mL of methanol (CH₃OH) until the final volume of the solution is 275 mL…
   a) What is the molarity of methanol in this solution? (The density of methanol is 0.792 g/mL)
b) What is the percent by volume of methanol in this solution?
Molarity, Molality, and % by mass problems

Explain how you would make the following solutions. (You should tell how many grams of the substance you need to make the solution, since balances do not read in moles!).

1) 2 L of 6 M HCl

2) 1.5 L of 2 M NaOH

3) 0.75 L of 0.25 M \( \text{Na}_2\text{SO}_4 \)

4) Calculate the molality when 75.0 grams of MgCl\(_2\) is dissolved in 500.0 g of solvent.

5) 100.0 grams of sucrose (\( \text{C}_{12}\text{H}_{22}\text{O}_{11} \), mol. wt. = 342.3 g/mol) is dissolved in 1.50 L of water. What is the molality?

6) 49.8 grams of KI is dissolved in 1.00 kg of solvent. What is the molality?

7) Determine the molal concentration of a solution in which 320 grams of glucose \( \text{C}_6\text{H}_{12}\text{O}_6 \) are dissolved in 4000 grams of water.

8) How many grams MgCl\(_2\) will be needed to prepare 3000 grams of a 0.8 molal solution?

9) Find the mass percent of sodium acetate in each of the following solutions:
   
a. 5.00g of sodium acetate in 25.0 g of water
b. 10.0g of sodium acetate in 25.0 g of water

10) Calculate the mass, in grams, of NaCl present in each of the following solutions.
   a. 11.5g of 6.25% NaCl solution

   b. 6.25 g of 11.5% NaCl solution

   c. 54.3 g of 0.91% NaCl solution

11) For a 15.0% (by mass) NaCl solution, calculate:
   a. the mass of NaCl in 150g of the solution

   b. the amount of solution needed to obtain 35.0g NaCl

   c. the mass of NaCl needed to make 1000. g of the solution
Solution

AP Practice Question

1993 A
Elemental analysis of an unknown pure substance indicated that the percent composition by mass is as follows.

<table>
<thead>
<tr>
<th>Element</th>
<th>Percent by Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>49.02%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>2.743%</td>
</tr>
<tr>
<td>Chlorine</td>
<td>48.23%</td>
</tr>
</tbody>
</table>

A solution that is prepared by dissolving 3.150 grams of the substance in 25.00 grams of benzene, C₆H₆, has a freezing point of 1.12°C. (The normal freezing point of benzene is 5.50°C and the molal freezing-point depression constant, K_ƒ, for benzene is 5.12°C/molal.)

(a)  Determine the empirical formula of the unknown substance.
(b)  Using the data gathered from the freezing-point depression method, calculate the molar mass of the unknown substance.
(c)  Calculate the mole fraction of benzene in the solution described above.
(d)  The vapor pressure of pure benzene at 35°C is 150. millimeters of Hg. Calculate the vapor pressure of benzene over the solution described above at 35°C.

2001 D Required

Solution 1  Solution 2  Solution 3  Solution 4  Solution 5

Answer the questions below that relate to the five aqueous solutions at 25°C shown above.
(a)  Which solution has the highest boiling point? Explain.
(b)  Which solution has the highest pH? Explain.
(c)  Identify a pair of the solutions that would produce a precipitate when mixed together. Write the formula of the precipitate.
(d)  Which solution could be used to oxidize the Cl^−(aq) ion? Identify the product of the oxidation.
(e)  Which solution would be the least effective conductor of electricity? Explain.
Chemical Kinetics

1. Consider the reaction: \(2 \text{NO}(g) + \text{O}_2(g) \rightarrow 2 \text{NO}_2(g)\)

The following data were obtained from three experiments using the method of initial rates:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [NO] mol L(^{-1})</th>
<th>Initial [O(_2)] mol L(^{-1})</th>
<th>Initial rate NO mol L(^{-1})s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td>0.010</td>
<td>0.010</td>
<td>2.5 \times 10^{-5}</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>0.020</td>
<td>0.010</td>
<td>1.0 \times 10^{-4}</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>0.010</td>
<td>0.020</td>
<td>5.0 \times 10^{-5}</td>
</tr>
</tbody>
</table>

a. Determine the order of the reaction for each reactant.
b. Write the rate equation for the reaction.
c. Calculate the rate constant.
d. Calculate the rate (in mol L\(^{-1}\)s\(^{-1}\)) at the instant when [NO] = 0.015 mol L\(^{-1}\) and [O\(_2\)] = 0.0050 mol L\(^{-1}\).
e. At the instant when NO is reacting at the rate 1.0 \times 10^{-4} mol L\(^{-1}\)s\(^{-1}\), what is the rate at which O\(_2\) is reactant and NO\(_2\) is forming?

2. The reaction \(2 \text{NO}(g) + 2 \text{H}_2(g) \rightarrow \text{N}_2(g) + 2 \text{H}_2\text{O}(g)\) was studied at 904 °C, and the data in the table were collected.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [NO] mol L(^{-1})</th>
<th>Initial [H(_2)] mol L(^{-1})</th>
<th>Initial rate N(_2) mol L(^{-1})s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td>0.420</td>
<td>0.122</td>
<td>0.136</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>0.210</td>
<td>0.122</td>
<td>0.0339</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>0.210</td>
<td>0.244</td>
<td>0.0678</td>
</tr>
<tr>
<td>Experiment 4</td>
<td>0.105</td>
<td>0.488</td>
<td>0.0339</td>
</tr>
</tbody>
</table>

a. Determine the order of the reaction for each reactant.
b. Write the rate equation for the reaction.
c. Calculate the rate constant at 904 °C.
d. Find the rate of appearance of N\(_2\) at the instant when [NO] = 0.350 M and [H\(_2\)] = 0.205 M.

3. The reaction of \(\text{t}\)-butyl-bromide (\(\text{CH}_3\)_3\text{CBr}\) with water is represented by the equation:

\[(\text{CH}_3)_3\text{CBr} + \text{H}_2\text{O} \rightarrow (\text{CH}_3)_3\text{COH} + \text{HBr}\]

The following data were obtained from three experiments using the method of initial rates:

<table>
<thead>
<tr>
<th>Initial [((\text{CH}_3)_3\text{CBr}]</th>
<th>Initial [H(_2)O]</th>
<th>Initial rate</th>
</tr>
</thead>
</table>

54
### Experiment 1

<table>
<thead>
<tr>
<th>Experiment</th>
<th>mol L$^{-1}$</th>
<th>mol L$^{-1}$</th>
<th>mol L$^{-1}$min$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td>$5.0 \times 10^{-2}$</td>
<td>$2.0 \times 10^{-2}$</td>
<td>$2.0 \times 10^{-6}$</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>$5.0 \times 10^{-2}$</td>
<td>$4.0 \times 10^{-2}$</td>
<td>$2.0 \times 10^{-6}$</td>
</tr>
<tr>
<td>Experiment 3</td>
<td>$1.0 \times 10^{-1}$</td>
<td>$4.0 \times 10^{-2}$</td>
<td>$4.0 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

a. What is the order with respect to (CH$_3$)$_3$CBr?
b. What is the order with respect to H$_2$O?
c. What is the overall order of the reaction?
d. Write the rate equation.
e. Calculate the rate constant, k, for the reaction.

### Rate Law Worksheet

1. The rate of a reaction is given by $k[A][B]$. The reactants are gases. If the volume occupied by the reacting gases is suddenly reduced to one-fourth the original volume, the rate of reaction (relative to the original rate) will be:
   a. 8/1
   b. 16/1
c. 1/8
d. 1/16
e. 4/1

2. The following data are for Questions 2 through 8 and refer to the reaction: 
   $2B + 3C \rightarrow 2Y + Z$. All data were taken at 50.0°C.

<table>
<thead>
<tr>
<th>trial</th>
<th>initial [B]</th>
<th>initial [C]</th>
<th>rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0.02</td>
<td>0.04</td>
<td>10 M/hr</td>
</tr>
<tr>
<td>#2</td>
<td>0.03</td>
<td>0.04</td>
<td>15 M/hr</td>
</tr>
<tr>
<td>#3</td>
<td>0.02</td>
<td>0.08</td>
<td>80 M/hr</td>
</tr>
<tr>
<td>#4</td>
<td>0.02</td>
<td>0.16</td>
<td>160 M/hr</td>
</tr>
<tr>
<td>#5</td>
<td>0.01</td>
<td>0.08</td>
<td>?</td>
</tr>
</tbody>
</table>

3. Doubling [B] would change the rate of formation Y by a factor of:
   a. $\frac{1}{2}$
b. 3
c. $\frac{3}{2}$
d. 2
e. 1 (no change)

4. The rate of formation of Z in trial 3 was (in M/hr):
   a. 160
   b. 80
c. 60
d. 40
e. 20

5. The rate of disappearance of C in trial 2 was (in M/hr):
   a. 45
   b. 10
c. 30

d. 7.5

e. 22.5

6. The rate law derived for the reaction from the above data is:
   a. \( k[B]^2[C] \)
   b. \( k[C]^2 \)
   c. \( k[B]^2 \)
   d. \( k[B][C] \)
   e. \( k[B][C]^2 \)

7. The missing rate (trial 5) in units of M/hr should be:
   a. 2.5
   b. 5.0
   c. 10
   d. 7.5
   e. none of these

8. The value of the specific rate constant is:
   a. \( 1.25 \times 10^{-6} \text{ M}^3\text{hr}^{-1} \)
   b. \( 1.25 \times 10^4 \text{ M}^3\text{hr}^{-1} \)
   c. \( 1.25 \times 10^{-4} \text{ M}^3\text{hr}^{-1} \)
   d. \( 1.25 \times 10^6 \text{ M}^3\text{hr}^{-1} \)
   e. none of these

9. After a long time (assuming the reverse reaction can be neglected), the concentration of Z in trial 3 would be:
   a. 0.20 M
   b. 0.02 M
   c. 0.01M
   d. 0.04 M
   e. 0.005 M

10. The times listed in the following table are those required for the concentration of \( S_2O_8^{2-} \) to decrease by 0.00050 M as measured in an “iodine clock” reaction at 23°C. What is the rate law? The net reaction is: 
    \( S_2O_8^{2-} + 2 \, \text{I}^- \rightarrow \text{I}_2 + 2 \, \text{SO}_4^{2-} \)

<table>
<thead>
<tr>
<th>trial</th>
<th>initial ([S_2O_8^{2-}])</th>
<th>initial [I]</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0.0400</td>
<td>0.0800</td>
<td>39</td>
</tr>
<tr>
<td>#2</td>
<td>0.0400</td>
<td>0.0400</td>
<td>78</td>
</tr>
<tr>
<td>#3</td>
<td>0.0100</td>
<td>0.0800</td>
<td>156</td>
</tr>
<tr>
<td>#4</td>
<td>0.0200</td>
<td>0.0200</td>
<td>?</td>
</tr>
</tbody>
</table>

11. Calculate the expected time in seconds for trial 4.
   a. 78
   b. 156
   c. 634
   d. 312
   e. 234

12. Determine the rate law and calculate the rate constant for the following data.

<table>
<thead>
<tr>
<th>trial</th>
<th>initial [A]</th>
<th>initial [B]</th>
<th>rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.00 \times 10^3</td>
<td>0.25 \times 10^3</td>
<td>0.26 \times 10^{-9}</td>
</tr>
</tbody>
</table>
13. Determine the rate law and calculate the rate constant for the following data.

<table>
<thead>
<tr>
<th>trial</th>
<th>initial [X]</th>
<th>initial [Y]</th>
<th>rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.00 x 10^2</td>
<td>4.00 x 10^4</td>
<td>2.50 x 10^-4</td>
</tr>
<tr>
<td>#2</td>
<td>2.00 x 10^2</td>
<td>4.00 x 10^4</td>
<td>5.00 x 10^-4</td>
</tr>
<tr>
<td>#3</td>
<td>4.00 x 10^2</td>
<td>4.00 x 10^4</td>
<td>3.75 x 10^-4</td>
</tr>
<tr>
<td>#4</td>
<td>1.00 x 10^2</td>
<td>8.00 x 10^4</td>
<td>3.00 x 10^-3</td>
</tr>
</tbody>
</table>

Chemical Kinetics

AP Practice Question

2003 B

5 Br^− (aq) + BrO_3^- (aq) + 6 H^+ (aq) → 3 Br_2 (l) + 3 H_2O (l)

In a study of the kinetics of the reaction represented above, the following data were obtained at 298 K.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [Br^−] (mol L^-1)</th>
<th>Initial [BrO_3^-] (mol L^-1)</th>
<th>Initial [H^+] (mol L^-1)</th>
<th>Rate of Disappearance of BrO_3^- (mol L^-1 s^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00100</td>
<td>0.00500</td>
<td>0.100</td>
<td>2.50 x 10^-4</td>
</tr>
<tr>
<td>2</td>
<td>0.00200</td>
<td>0.00500</td>
<td>0.100</td>
<td>5.00 x 10^-4</td>
</tr>
<tr>
<td>3</td>
<td>0.00100</td>
<td>0.00750</td>
<td>0.100</td>
<td>3.75 x 10^-4</td>
</tr>
<tr>
<td>4</td>
<td>0.00100</td>
<td>0.01500</td>
<td>0.200</td>
<td>3.00 x 10^-3</td>
</tr>
</tbody>
</table>

(a) From the data given above, determine the order of the reaction for each reactant listed below. Show your reasoning.
   (i) Br^−
   (ii) BrO_3^−
   (iii) H^+

(b) Write the rate law for the overall reaction.

(c) Determine the value of the specific rate constant for the reaction at 298 K. Include the correct units.

(d) Calculate the value of the standard cell potential, E°, for the reaction using the information in the table below.
2004 B
The first-order decomposition of a colored chemical species, $X$, into colorless products is monitored with a spectrophotometer by measuring changes in absorbance over time. Species $X$ has a molar absorptivity constant of $5.00 \times 10^3 \text{ cm}^{-1}\text{M}^{-1}$ and the pathlength of the cuvette containing the reaction mixture is 1.00 cm. The data from the experiment are given in the table below.

<table>
<thead>
<tr>
<th>[X] ($M$)</th>
<th>Absorbance</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>0.600</td>
<td>0.0</td>
</tr>
<tr>
<td>$4.00 \times 10^{-5}$</td>
<td>0.200</td>
<td>35.0</td>
</tr>
<tr>
<td>$3.00 \times 10^{-5}$</td>
<td>0.150</td>
<td>44.2</td>
</tr>
<tr>
<td>$1.50 \times 10^{-5}$</td>
<td>0.075</td>
<td>?</td>
</tr>
</tbody>
</table>

(a) Calculate the initial concentration of the unknown species.
(b) Calculate the rate constant for the first order reaction using the values given for concentration and time. Include units with your answers.
(c) Calculate the minutes it takes for the absorbance to drop from 0.600 to 0.075.
(d) Calculate the half-life of the reaction. Include units with your answer.

**Chemical Equilibria**

**Problem Set #1**

For the following three reactions,

a) write the $K_{eq}$ expression in terms of concentration, $K_c$.

b) given the equilibrium concentrations, state whether each equilibrium is product-favored, reactant-favored, or fairly even ([products] $\approx$ [reactants]).

c) calculate the value of $K_c$.

1. $N_2(g) + 3 H_2(g) \rightleftharpoons 2 NH_3(g)$
   
   At equilibrium:
   
   $\begin{align*}
   [N_2] &= 1.50 \text{ M} \\
   [H_2] &= 2.00 \text{ M} \\
   [NH_3] &= 0.01 \text{ M}
   \end{align*}$

2. $HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$
   
   At equilibrium:
   
   $\begin{align*}
   [HF] &= 0.55 \text{ M} \\
   [H^+] &= 0.001 \text{ M} \\
   [F^-] &= 0.001 \text{ M}
   \end{align*}$
3. \( \text{Fe}^{3+}(aq) + \text{SCN}^- (aq) \rightleftharpoons \text{FeSCN}^{2+}(aq) \)

At equilibrium:

\[ [\text{Fe}^{3+}] = 0.55 \text{ M} \]
\[ [\text{SCN}^-] = 0.001 \text{ M} \]
\[ [\text{FeSCN}^{2+}] = 0.001 \text{ M} \]

Summarize:
Fill in the blanks with product-favored, reactant-favored, and approximately equal

<table>
<thead>
<tr>
<th>( K_c )</th>
<th>state of equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_c \gg 1 )</td>
<td></td>
</tr>
<tr>
<td>( K_c &lt;&lt; 1 )</td>
<td></td>
</tr>
<tr>
<td>( K_c \approx 1 )</td>
<td></td>
</tr>
</tbody>
</table>

4. Knowing that pure water has a density of 1g/1mL calculate the mass of 1.00 Liter of water.

Calculate the number of moles in 1.00 L of \( \text{H}_2\text{O} \).

What is the concentration (M) of water in water?
Important Note:
Since the concentrations of solids and liquids are constant, they are incorporated into the equilibrium constant, K_{eq}. That means, just leave them out of the K_c or K_p expression. Only include (g) and (aq)!

5. Write equilibrium expressions for each of the following reactions:
   a) CaCO_3(s) ⇌ CaO(s) + CO_2(g)
   
b) Ni(s) + 4CO(g) ⇌ Ni(CO)_4(g)
   
c) 5CO(g) + I_2O_5(s) ⇌ I_2(g) + 5CO_2(g)
   
d) Ca(HCO_3)_2(aq) ⇌ CaCO_3(s) + H_2O(l) + CO_2(g)
   
e) AgCl(s) ⇌ Ag^+(aq) + Cl^−(aq)

6. Write the equilibrium expression in terms of partial pressures (K_p) for each of the following reactions. Rate the reactions in order of their increasing tendency to proceed toward completion:
   ____  ____  ____  ____
   
   (a) 4NH_3(g) + 3O_2(g) ⇌ 2N_2(g) + 6H_2O(g)  \quad K_p = 1 \times 10^{228} \text{ atm}
   
   (b) N_2(g) + O_2(g) ⇌ 2NO(g)  \quad K_p = 5 \times 10^{-31}
   
   (c) 2HF(g) ⇌ H_2(g) + F_2(g)  \quad K_p = 1 \times 10^{13}
   
   (d) 2NOCl(g) ⇌ 2NO(g) + Cl_2(g)  \quad K_p = 4.7 \times 10^{-4} \text{ atm}
   
   (b) If we **reverse** the equation, it is:
   
   2 SO_3(g) ⇌ 2 SO_2(g) + O_2(g)
   
   Write the K_c expression for this equation and calculate the new value of K_c:
How does the expression and the value of $K_c$ in 7(b) compare with those in 7(a)?
1. Consider the equilibrium: \(2 \text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{SO}_3(g)\) \(K_c = 4.36 \text{M}^{-1}\)
Calculate the value of “Q” for a situation in which the concentrations are \([\text{SO}_2] = 2.00 \text{ M}, [\text{O}_2] = 1.50 \text{ M},\) and \([\text{SO}_3] = 1.25 \text{ M}\).

Does this mixture shift toward the reactants or products to reach equilibrium? ____________________

2. Study the discussion in your textbook about converting \(K_c\) and \(K_p\). Write the \(K_p\) expression for the reaction in question 1 and calculate its value at 0°C. Remember, \(R = 0.0821 \text{ L·atm/mol·K}\).

3. Consider the equilibrium \(\text{PCl}_3(g) + \text{Cl}_2(g) \rightleftharpoons \text{PCl}_5(g)\).
How would the following changes affect the partial pressures of each gas at equilibrium?
\(\text{PCl}_3(g) + \text{Cl}_2(g) \rightleftharpoons \text{PCl}_5(g)\)

a) addition of \(\text{PCl}_3\) ______ ______ ______

b) removal of \(\text{Cl}_2\) ______ ______ ______

c) removal of \(\text{PCl}_5\) ______ ______ ______

d) decrease in the volume of the container ______ ______ ______

e) addition of He without change in volume ______ ______ ______

4. How will each of the changes in question 3 affect the \(K_{eq}\)? (\(\uparrow\)=increase; \(\downarrow\)=decrease; \(\rightleftharpoons\)=unchanged)

a ___ b ___ c ___ d ___ e ___

5. Indicate how each of the following changes affects the amount of each gas in the system below, for which \(\Delta H_{reaction} = +9.9 \text{ kcal}\).

\(\text{H}_2(g) + \text{CO}_2(g) \rightleftharpoons \text{H}_2\text{O}(g) + \text{CO}(g)\)

a) addition of \(\text{CO}_2\) ______ ______ ______ ______

b) addition of \(\text{H}_2\text{O}\) ______ ______ ______ ______

c) addition of a catalyst ______ ______ ______ ______

d) increase in temperature ______ ______ ______ ______

e) decrease in the volume of the container ______ ______ ______ ______

6. How will each of the changes in question 5 affect the equilibrium constant?
a ___ b ___ c ___ d ___ e ___
7. Consider the equilibrium: \(2\text{N}_2\text{O}(g) + \text{O}_2(g) \rightleftharpoons 4\text{NO}(g)\)
How will the amount of chemicals at equilibrium be affected by
\[2\text{N}_2\text{O}(g) + \text{O}_2(g) \rightleftharpoons 4\text{NO}(g)\]

a) adding \(\text{N}_2\text{O}\)  

b) removing \(\text{O}_2\)  

c) increasing the volume of the container  

d) adding a catalyst  

8. For the reaction, \(4\text{NH}_3(g) + 3\text{O}_2(g) \rightleftharpoons 2\text{N}_2(g) + 6\text{H}_2\text{O}(l)\)
How will the concentration of each chemical be affected by
\[4\text{NH}_3(g) + 3\text{O}_2(g) \rightleftharpoons 2\text{N}_2(g) + 6\text{H}_2\text{O}(l)\]
a) adding \(\text{O}_2\) to the system  

b) adding \(\text{N}_2\) to the system  

c) removing \(\text{H}_2\text{O}\) from the system  

d) decreasing the volume of the container  

9. Consider the equilibrium: \(2\text{N}_2\text{O}(g) + \text{O}_2(g) \rightleftharpoons 4\text{NO}(g)\)
3.00 moles of \(\text{NO}(g)\) are introduced into a 1.00-Liter evacuated flask. When the system comes to equilibrium, 1.00 mole of \(\text{N}_2\text{O}(g)\) has formed. Determine the equilibrium concentrations of each substance. Calculate the \(K_c\) for the reaction based on these data.

<table>
<thead>
<tr>
<th></th>
<th>2 (\text{N}_2\text{O})</th>
<th>(\text{O}_2)</th>
<th>4 (\text{NO})</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>equilibrium</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remember: The “ice” box may be used with moles, molarity, or Liters (for gaseous equilibria)… never grams.
Chemical Equilibrium

\[ H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g) \]

When \( H_2(g) \) is mixed with \( CO_2(g) \) at 2,000 K, equilibrium is achieved according to the equation above. In one experiment, the following equilibrium concentrations were measured:

- \([H_2] = 0.20 \text{ mol/L}\)
- \([CO_2] = 0.30 \text{ mol/L}\)
- \([H_2O] = [CO] = 0.55 \text{ mol/L}\)

(a) What is the mole fraction of CO(g) in the equilibrium mixture?

(b) Using the equilibrium concentrations given above, calculate the value of \( K_c \), the equilibrium constant for the reaction.

(c) Determine \( K_p \), in terms of \( K_c \) for this system.

(d) When the system is cooled from 2,000 K to a lower temperature, 30.0 percent of the CO(g) is converted back to \( CO_2(g) \). Calculate the value of \( K_c \) at this lower temperature.

(e) In a different experiment, 0.50 mole of \( H_2(g) \) is mixed with 0.50 mole of \( CO_2(g) \) in a 3.0-liter reaction vessel at 2,000 K. Calculate the equilibrium concentration, in moles per liter, of CO(g) at this temperature.
1. Write the pH of each solution above the [H⁺]'s. pH = -log[H⁺]

2. Label the “Z” diagram as “Acidic”, “Basic” and “Neutral.”

3. Knowing that the [H⁺] x [OH⁻] always equals 1 x 10⁻¹⁴, fill in the [OH⁻] for each of the five solutions in the “Z” Diagram. (1 x 10⁻¹⁴ is called the Dissociation Constant for water, Kₘₚ) (1 x 10⁻¹⁴ = 10 x 10⁻¹⁵)

4. Write the “pOH” of each solution below the [OH⁻]'s.

5. pH + pOH always equals ________.

6. A solution of acid has [H⁺] = 3.0 x 10⁻³ M
   a. Calculate the [OH⁻] ________
   b. Calculate the pH ________ the pOH ________

7. A solution of base has an [OH⁻] = 4.25 x 10⁻⁵ M
   a. Calculate the [H⁺] ________
   b. Calculate the pH ________ the pOH ________

8. Calculate the pH’s of the following solutions:
   2.53 x 10⁻² M HCl  pH =
   2.53 x 10⁻⁴ M HCl  pH =
   2.53 x 10⁻⁵ M HCl  pH =

   A pH with 3 significant figures is written with ____ numbers after the decimal place.
The Chemistry of Acids and Bases

pH Calculation Situations

Ch 17

1. **strong acid solution** – determine [H+], calculate pH
   Calculate the pH of 0.00125M HNO₃

2. **strong base solution** – determine [OH-], calculate pOH, calculate pH
   Calculate the pH of 0.00125M KOH

3. **weak acid solution** – determine [H+] using ICE box, calculate pH
   Calculate the pH of 0.00125M HOCl \( K_a = 3.5 \times 10^{-8} \)

4. **weak base solution** – determine [OH-] using ICE box, calculate pOH, calculate pH
   Calculate the pH of 0.00125M NH₃ \( K_b = 1.8 \times 10^{-5} \)

5. **salt of a weak acid** – write hydrolysis, calc \( K_b \), determine [OH-] using ICE box, calc pOH, calc pH
   Calculate the pH of 0.00125M NaOCl

6. **salt of a weak base** – write hydrolysis, calc \( K_a \), determine [H+] using ICE box, calc pH
   Calculate the pH of 0.00125M NH₄Cl

7. **diprotic acid solution** – assume all [H+] from first ionization, determine [H+] using ICE box, calculate pH
   Calculate the pH of 0.00125M H₂CO₃ \( K_{a1} = 4.2 \times 10^{-7} \) \( K_{a2} = 4.8 \times 10^{-11} \)

8. **mixture of acid and base** – calculate moles of H+ and OH-, determine moles of excess H+ or OH-, determine total volume, calculate [H+] or [OH-], calculate pH
   Calculate the pH of 20.0 mL of 0.00125M HNO₃ + 30.0 mL of 0.00125M KOH
Acid-Base Equilibrium

A P   P R   O   B L E M   P R   A C T I C E

The overall dissociation of oxalic acid, H₂C₂O₄, is represented below. The overall dissociation constant is also indicated.

\[ \text{H}_2\text{C}_2\text{O}_4 \rightleftharpoons 2 \text{H}^+ + \text{H}_2\text{C}_2\text{O}_4^{2-} \quad K = 3.78 \times 10^{-6} \]

(a) What volume of 0.400-molar NaOH is required to neutralize completely a 5.00 \times 10^{-3} mole sample of pure oxalic acid?

(b) Give the equations representing the first and second dissociations of oxalic acid.

Calculate the value of the first dissociation constant, \( K_1 \), for oxalic acid if the value of the second dissociation constant, \( K_2 \), is 6.40 \times 10^{-5}.

(c) To a 0.015-molar solution of oxalic acid, a strong acid is added until the pH is 0.5. Calculate the \([\text{C}_2\text{O}_4^{2-}]\) in the resulting solution. (Assume the change in volume is negligible.)

(d) Calculate the value of the equilibrium constant, \( K_b \), for the reaction that occurs when solid Na₂C₂O₄ is dissolved in water
Acid-Base Reactions

Titration Curve

Consider a 10. mL sample of 0.10 M HCl.

_____ a) What is the pH of the solution?

_____ b) How many mL of 0.10 M NaOH would be required to neutralize it?

_____ c) What is the pH of the neutralized solution?

_____ d) What would the pH of the solution be if you added 20. mL of NaOH?

<table>
<thead>
<tr>
<th>volume of 0.10 M HCl</th>
<th>volume of 0.10 M NaOH</th>
<th>moles of H+</th>
<th>moles of OH-</th>
<th>moles of XS H+ or OH-</th>
<th>total volume</th>
<th>[H+] or [OH-]</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
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</table>

Let’s do this more carefully:

<table>
<thead>
<tr>
<th>volume of 0.10 M HCl</th>
<th>volume of 0.10 M NaOH</th>
<th>moles of H+</th>
<th>moles of OH-</th>
<th>moles of XS H+ or OH-</th>
<th>total volume</th>
<th>[H+] or [OH-]</th>
<th>pH</th>
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</tbody>
</table>

Graph this data: \( x = \text{Volume of NaOH added} \) and \( y = \text{pH} \). This is called a “titration curve.”

Questions:
1. At what point on this curve is the acid neutralized?
2. What would a graph of the slope of this curve vs. Volume of NaOH added look like?
   Sketch it over your titration curve.
3. Identify the “equivalence point” on your titration curve and on the sketch of the slope vs. NaOH.
4. Phenolphthalein is an acid-base indicator that changes color at pH of 9. It is commonly used for this titration. Indicate on your graph when the phenolphthalein will change color.
The Half-Reaction Method:
1. Write the equation as two half-reactions. Include the particles (atoms, ions, molecules) that are involved in change of oxidation state.
2. Balance each half-reaction with respect to atoms and charges; first atoms other than H and O, then O with H₂O and H with H⁺, and ionic charges with electrons (e⁻).
3. Equalize the number of electrons lost in the oxidation half-reaction with the number of electrons gained in the reduction half-reaction.
4. Add the two half-reactions to form a balanced net ionic equation.
5. (Basic solution) Add OH⁻ ions to each side of the equation to neutralize H⁺ ions. Cancel H₂O molecules.

Example 1: \[ \text{HCl} + \text{K}_2\text{Cr}_2\text{O}_7 \rightarrow \text{KCl} + \text{CrCl}_3 + \text{H}_2\text{O} + \text{Cl}_2 \]

Example 2: \[ \text{FeCl}_2 + \text{KMnO}_4 + \text{HCl} \rightarrow \text{FeCl}_3 + \text{KCl} + \text{MnCl}_2 + \text{H}_2\text{O} \]

Example 3: \[ \text{S}^{2⁻} + \text{MnO}_4⁻ \rightarrow \text{S} + \text{MnO}_2 \] (basic solution)

Example 4: \[ \text{CuS} + \text{NO}_3⁻ \rightarrow \text{Cu}^{2⁺} + \text{S} + \text{NO} \] (acidic)
PROBLEMS: Balance these equations:

1. \( \text{HNO}_3 + \text{S} \rightarrow \text{NO}_2 + \text{H}_2\text{SO}_4 + \text{H}_2\text{O} \)

2. \( \text{KMnO}_4 + \text{HCl} + \text{H}_2\text{S} \rightarrow \text{KCl} + \text{MnCl}_2 + \text{S} + \text{H}_2\text{O} \)

3. \( \text{FeCl}_3 + \text{H}_2\text{S} \rightarrow \text{FeCl}_2 + \text{HCl} + \text{S} \)

4. \( \text{Cu} + \text{HNO}_3 \rightarrow \text{Cu(NO}_3)_2 + \text{NO}_2 + \text{H}_2\text{O} \)

5. \( \text{NaCl} + \text{H}_2\text{SO}_4 + \text{MnO}_2 \rightarrow \text{Na}_2\text{SO}_4 + \text{MnSO}_4 + \text{H}_2\text{O} + \text{Cl}_2 \)

6. \( \text{HMnO}_4 + \text{HCl} \rightarrow \text{MnCl}_2 + \text{H}_2\text{O} + \text{Cl}_2 \)

7. \( \text{MnO}_4^{-} + \text{SO}_3^{2-} \rightarrow \text{Mn}^{2+} + \text{SO}_4^{2-} \) (acidic)

8. \( \text{H}_2\text{O}_2 + \Gamma \rightarrow \text{H}_2\text{O} + \text{I}_2 \) (acidic)

9. \( \text{AsO}_3^{3-} + \text{I}_2 \rightarrow \text{AsO}_4^{3-} + \Gamma \) (basic)

10. \( \text{Cr} + \text{ClO}_4^{-} \rightarrow \text{CrO}_2^{-} + \text{ClO}_3^{-} \) (basic)
Electrochemistry

<table>
<thead>
<tr>
<th>Standard Reduction Potential</th>
<th>E° (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl₂(g) + 2e⁻ → 2Cl⁻(aq)</td>
<td>+1.36</td>
</tr>
<tr>
<td>O₂(g) + 4H⁺(aq) + 4e⁻ → 2H₂O(l)</td>
<td>+1.23</td>
</tr>
<tr>
<td>Ag⁺(aq) + e⁻ → Ag(s)</td>
<td>+0.80</td>
</tr>
<tr>
<td>I₂(s) + 2e⁻ → 2I⁻(aq)</td>
<td>+0.535</td>
</tr>
<tr>
<td>Cu²⁺(aq) + 2e⁻ → Cu(s)</td>
<td>+0.337</td>
</tr>
<tr>
<td>SO₄²⁻(aq) + 4 H⁺(aq) + 2e⁻ → SO₂(g) + 2 H₂O</td>
<td>+0.20</td>
</tr>
<tr>
<td>2 H⁺(aq) + 2 e⁻ → H₂(g) (reference electrode)</td>
<td>0.00</td>
</tr>
<tr>
<td>2H₂O(l) + 2 e⁻ → H₂(g) + 2OH⁻(aq)</td>
<td>-0.828</td>
</tr>
<tr>
<td>Na⁺(aq) + e⁻ → Na(s)</td>
<td>-2.714</td>
</tr>
<tr>
<td>K⁺(aq) + e⁻ → K(s)</td>
<td>-2.93</td>
</tr>
</tbody>
</table>

1. All of the equations in the chart above are written as _______________ (oxidations/reductions).

2. The chemicals at the upper left (Cl₂ and O₂) are the most likely to be _______________ (oxidized/reduced) and therefore the best _______________ (oxidizing agents/reducing agents).

3. The chemicals at the lower right (Na and K) are the most likely to be _______________ (oxidized/reduced) and therefore the best _______________ (oxidizing agents/reducing agents).

4. In an electrolytic cell, the (−) electrode is negative because it has _______________ (too many/too few) electrons. Chemicals that come into contact with the (−) electrode will ________ (gain/lose) electrons and be _______________ (oxidized/reduced). The (−) electrode in electrolysis is called the _____________ (cathode/anode).

5. Write the change that water goes through at the (−) electrode. ____________________________________

6. In an electrochemical cell, the (+) electrode is positive because it has _______________ (too many/too few) electrons. Chemicals that come into contact with the (+) electrode will ________ (gain/lose) electrons and be _______________ (oxidized/reduced). The (+) electrode in electrolysis is called the _____________ (cathode/anode).

7. Write the change that water goes through at the (+) electrode. ____________________________________

8. Add these two reactions together (make certain the electrons cancel) and write the overall reaction for the electrolysis of water. ____________________________________

9. We will perform this electrolysis using an aqueous solution of sodium sulfate. Both the Na⁺ and H₂O will be near the (−) electrode. Which chemical is more likely to be reduced? ____

10. Both the SO₄²⁻ and H₂O will be near the (+) electrode. Which chemical will be oxidized? ____
11. In the electrolysis of KI(aq)
Both the K\(^+\) and H\(_2\)O will be near the (−) electrode. Which chemical is more likely to be reduced? ____
Both the I\(^−\) and H\(_2\)O will be near the (+) electrode. Which chemical is more likely to be oxidized? ____
Write the reactions at each electrode and the overall reaction:

Cathode:

Anode:

Overall:

12. In the electrolysis of CuSO\(_4\)(aq)
Both the Cu\(^{2+}\) and H\(_2\)O will be near the (−) electrode. Which chemical will be reduced? ____
Both the SO\(_4^{2−}\) and H\(_2\)O will be near the (+) electrode. Which chemical will be oxidized? ____
Write the reactions at each electrode and the overall reaction:

Cathode:

Anode:

Overall:

13. Silver plating occurs when electrolysis of a Ag\(_2\)SO\(_4\) solution is used because silver metal is formed at the ______________(cathode/anode).
This is the (__) ( + / − ) electrode. The reaction at this electrode is: _____________________.

Recall that 1 amp·sec = 1 Coulomb and 96,500 Coulombs = 1 mole e\(^−\)s (Faraday’s constant).
If a cell is run for 200. seconds with a current of 0.250 amps, how many grams of Ag\(^{\circ}\) will be deposited?

14. A current of 10.0 amperes flows for 2.00 hours through an electrolytic cell containing a molten salt of metal X. This results in the decomposition of 0.250 mole of metal X at the cathode. The oxidation state of X in the molten salt is ____ (X\(^+\), X\(^{2+}\), X\(^{3+}\), X\(^{4+}\))

15. Solutions of Ag\(^+\), Cu\(^{2+}\), Fe\(^{3+}\) and Ti\(^{4+}\) are electrolyzed with a constant current until 0.10 mol of metal is deposited. Which will require the greatest length of time? ____
Consider the reduction potential chart. Find and copy the reduction equations for Ag⁺ → Ag⁰ and Pb²⁺ → Pb⁰. Be sure to include their reduction potentials (in volts).

1. Which metal ion has the greater reduction potential? ____
2. If these two metals (and their solutions) were used to create a galvanic cell, which metal would be the anode? ____
3. Write the reaction at the anode: __________________________
4. Write the reaction at the cathode: __________________________
5. What is the overall reaction? __________________________
6. What would be the voltage of the standard electrochemical cell? ______
7. Sketch the cell:

8. Write the cell notation for the cell: ______|________||________|_____
9. How many moles of electrons are involved in this reaction?  n =_____

10. Find and copy down the Nernst Equation: _________________________________
11. If a new cell is set up with the [Ag⁺] = 0.50 M and the [Pb²⁺] = 2.0 M, the cell voltage will be _____________ (greater / less).
12. Use the Nernst equation to calculate the cell voltage with these new concentrations.
## Naming Alkanes, Alkenes and Alkynes (Hydrocarbons)

(Note: remember, each carbon must make 4 bonds)

<table>
<thead>
<tr>
<th># of C atoms in the chain</th>
<th>Type of bond</th>
<th>Structural formula</th>
<th>Name</th>
<th>Molar mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 C</td>
<td>Single bonds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 C</td>
<td>One double bond</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 C</td>
<td>Single bonds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 C</td>
<td>Double bonds</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5 C</td>
<td>One triple bond</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 C</td>
<td>One double bond</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 C</td>
<td>Single bonds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 C</td>
<td>Triple bond</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of C atoms in the longest chain</td>
<td>Functional group attached to C</td>
<td>Lewis structure</td>
<td>Name</td>
<td>Molar mass</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------------------------------</td>
<td>-----------------</td>
<td>------</td>
<td>------------</td>
</tr>
<tr>
<td>4 C</td>
<td>Methyl on 2\textsuperscript{nd} carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 C</td>
<td>Methyl on 3\textsuperscript{rd} carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 C</td>
<td>Ethyl on 2\textsuperscript{nd} carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 C</td>
<td>-OH on 7\textsuperscript{th} carbon</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>6 C</td>
<td>In a ring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 C</td>
<td>Methyl on 2\textsuperscript{nd}, 3\textsuperscript{rd} and 5\textsuperscript{th} carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 C</td>
<td>Ethyl on 3\textsuperscript{rd} carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 C</td>
<td>Methyl on 2\textsuperscript{nd} and 3\textsuperscript{rd} carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 C</td>
<td>-OH on 3\textsuperscript{rd} carbon</td>
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</table>
Naming Organic Compounds

a. What are the suffixes used for naming carbon compound with a) carbon-carbon single bonds b) one
carbon- carbon double bond c) one carbon-carbon triple bond

2. Write the structural formula for the following:
   a) 5-ethyl-2,8-dimethyldecane  b) 2,2,4,4,-tetramethylpentane
   c) 2,2,6-trimethyloctane  d) 3-ethyl-3,5-dimethylheptane
   e) 3- methyl pentane  e) 2,2-dimethyl propane

3. Draw the line formula for each of the following cycloalkanes:
   a) ethylcyclobutane  b) 1,1-dimethylcyclopentane  c) 1,3,5-trimethylcyclohexane

4. Write the line formula for each of the following haloalkanes:
   a) 1,1-dichloro-2,2-difluoroethane  b) 2,4-dichloro-2,4-difluorohexane
   c) 1,1,3,5-tetrachlorocyclohexane  d) 2-fluorooctane