SUMMER WORK
AP Chemistry

Summer 2014

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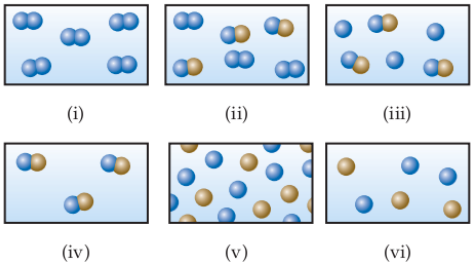
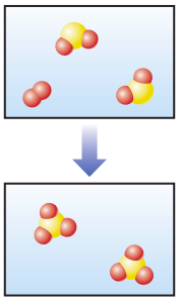
1.1 Which of the following figures represents (a) a pure element, (b) a mixture of two elements, (c) a pure compound, (d) a mixture of an element and a compound? (More than one picture might fit each description.) [Section 1.2]

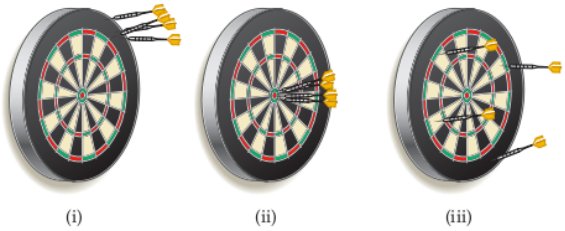


1.2 Does the following diagram represent a chemical or physical change? How do you know? [Section 1.3]



1.5 (a) Three spheres of equal size are composed of aluminum, silver, and nickel . List the spheres from lightest to heaviest. (b) Three cubes of equal mass are composed of gold, platinum, and lead. List the cubes from smallest to largest. [Section 1.4]

1.6 The following dartboards illustrate the types of errors often seen when one measurement is repeated several times. The bull's-eye represents the "true value," and the darts represent the experimental measurements. Which board best represents each of the following scenarios: (a) measurements both accurate and precise, (b) measurements precise but inaccurate, (c) measurements imprecise but yielding an accurate average? [Section 1.5]



1.14 Give the chemical symbol or name for each of the following elements, as appropriate: (a) carbon, (b) nitrogen, (c) titanium, (d) zinc, (e) iron, (f) P, (g) Ca, (h) He, (i) Pb, (j) Ag.

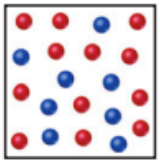
1.24 Use appropriate metric prefixes to write the following measurements without use of exponents: (a) 2.3×10^{-10} L, (b) 4.7×10^{-6} g, (c) 1.85×10^{-12} m, (d) 16.7×10^{6} s, (e) 15.7×10^{3} g, (f) 1.34×10^{-3} m, (g) 1.84×10^{2} cm.

1.30 (a) After the label fell off a bottle containing a clear liquid believed to be benzene, a chemist measured the density of the liquid to verify its identity. A 25.0-mL portion of the liquid had a mass of 21.95 g. A chemistry handbook lists the density of benzene at 15 °C as 0.8787 g/mL. Is the calculated density in agreement with the tabulated value? (b) An experiment requires 15.0 g of cyclohexane, whose density at 25 °C is 0.7781 g/mL. What volume of cyclohexane should be used? (c) A spherical ball of lead has a diameter of 5.0 cm. What is the mass of the sphere if lead has a density of 11.34 $g.cm^3$? (The volume of a sphere is $(4/3)\pi r^3$ where r is the radius.)

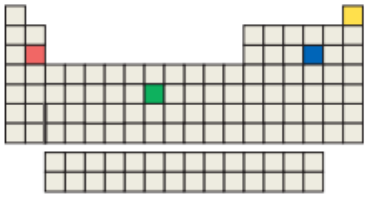
1.49 (a) How many liters of wine can be held in a wine barrel whose capacity is 31 gal? (b) The recommended adult dose of Elixophyllin®, a drug used to treat asthma, is 6 mg/kg of body mass. Calculate the dose in milligrams for a 185-lb person. (c) If an automobile is able to travel 400 km on 47.3 L of gasoline, what is the gas mileage in miles per gallon? (d) A pound of coffee beans yields 50 cups of coffee (4 cups = 1 qt). How many milliliters of coffee can be obtained from 1 g of coffee beans?

1.78 Gold is alloyed (mixed) with other metals to increase its hardness in making jewelry. (a) Consider a piece of gold jewelry that weighs 9.85 g and has a volume of 0.675 cm^3. The jewelry contains only gold and silver, which have densities of 19.3 g/cm^3 and 10.5 g/cm^3, respectively. If the total volume of the jewelry is the sum of the volumes of the gold and silver that it contains, calculate the percentage of gold (by mass) in the jewelry. (b) The relative amount of gold in an alloy is commonly expressed in units of carats. Pure gold is 24 carat, and the percentage of gold in an alloy is given as a percentage of this value. For example, an alloy that is 50% gold is 12 carat. State the purity of the gold jewelry in carats.

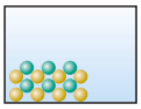
2.2 The following diagram is a representation of 20 atoms of a fictitious element, which we will call nevadium (Nv). The red spheres are ^{293}Nv, and the blue spheres are ^{295}Nv. (a) Assuming that this sample is a statistically representative sample of the element, calculate the percent abundance of each element. (b) If the mass of ^{293}Nv is 293.15 amu and that of ^{295}Nv is 295.15 amu, what is the atomic weight of Nv? [Section 2.4]



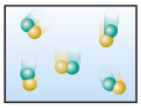
2.3 Four of the boxes in the following periodic table are colored. Which of these are metals and which are nonmetals? Which one is an alkaline earth metal? Which one is a noble gas? [Section 2.5]



2.5 Which of the following diagrams most likely represents an ionic compound, and which represents a molecular one? Explain your choice. [Sections 2.6 and 2.7]

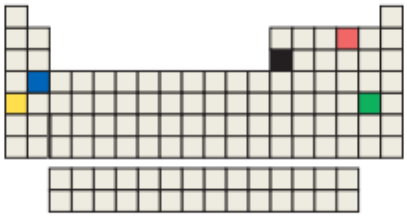


(i)



(ii)

2.7 Five of the boxes in the following periodic table are colored. Predict the charge on the ion associated with each of these elements. [Section 2.7]



2.15 How did Rutherford interpret the following observations made during his α-particle scattering experiments? (a) Most α particles were not appreciably deflected as they passed through the gold foil. (b) A few particles were deflected at very large angles. (c) What differences would you expect if beryllium foil were used instead of gold foil in the α-particle scattering experiment?

2.18 An atom of rhodium (Rh) has a diameter of about 2.7×10^{-8} cm. (a) What is the radius of a rhodium atom in angstroms (Å) and in meters (m)? (b) How many Rh atoms would have to be placed side by side to span a distance of 6.0 μm? (c) If you assume that the Rh atom is a sphere, what is the volume in m^3 of a single atom?

2.26 Fill in the gaps in the following table, assuming each column represents a neutral atom.

Symbol	^{65}Zn				
Protons		38			92
Neutrons		58	49		
Electrons			38	36	
Mass no.				81	235

2.29 (a) What isotope is used as the standard in establishing the atomic mass scale? (b) The atomic weight of boron is reported as 10.81, yet no atom of boron has the mass of 10.81 amu. Explain.

2.50 Fill in the gaps in the following table:

Symbol	$^{31}P^{3-}$			
Protons		34	50	
Neutrons		45	69	118
Electrons			46	76
Net Charge		2-		3+

2.58 Complete the table by filling in the formula for the ionic compound formed by each pair of cations and anions, as shown for the first pair.

Ion	Na^+	Ca^{2+}	Fe^{2+}	Al^{3+}
O^{2-}	Na_2O			
NO_3^-				
SO_4^{2-}				
AsO_4^{3-}				

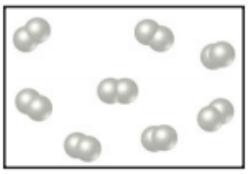
2.65 Name the following ionic compounds: (a) Li_2O, (b) $FeCl_3$, (c) NaClO, (d) $CaSO_3$, (e) $Cu(OH)_2$, (f) $Fe(NO_3)_2$ (g) $Ca(CH_3COO)_2$, (h) $Cr_2(CO_3)_3$, (i) K_2CrO_4 , (j) $(NH_4)_2SO_4$.

2.70 Provide the name or chemical formula, as appropriate, for each of the following acids: (a) hydroiodic acid, (b) chloric acid, (c) nitrous acid, (d) H2CO3 , (e) HClO4 , (f) CH3 COOH

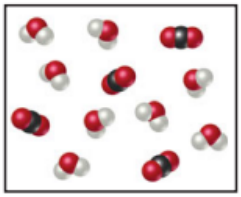
2.99 Fill in the blanks in the following table:

Cation	Anion	Formula	Name
			Lithium oxide
Fe^{2+}	PO_4^{3-}		
		$Al_2(SO_4)_3$	
			Copper(II) nitrate
Cr^{3+}	I^-		
		$MnClO_2$	
			Ammonium carbonate
			Zinc perchlorate

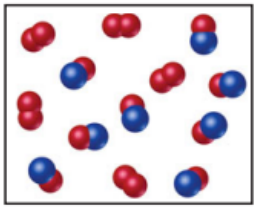
3.2 Under appropriate experimental conditions, H_2 and CO undergo a combination reaction to form CH_3OH. The following drawing represents a sample of H_2. Make a corresponding drawing of the CO needed to react completely with the H_2. How did you arrive at the number of CO molecules in your drawing? [Section 3.2]



3.4 The following diagram represents the collection of CO_2 and H_2O molecules formed by complete combustion of a hydrocarbon. What is the empirical formula of the hydrocarbon? [Section 3.2].



3.8 Nitrogen monoxide and oxygen react to form nitrogen dioxide. Consider the mixture of NO and O_2 shown in the accompanying diagram. The blue spheres represent N, and the red ones represent O. (a) Draw a representation of the product mixture, assuming that the reaction goes to completion. What is the limiting reactant in this case? (b) How many NO_2 molecules would you draw as products if the reaction had a percent yield of 75%? [Section 3.7]



3.12 Balance the following equations:

(a) $Li\ (s) + N_2\ (g) \rightarrow Li_3N\ (s)$
(b) $TiCl_4\ (l) + H_2O\ (l) \rightarrow TiO_2\ (s) + HCl\ (aq)$
(c) $NH_4NO_3\ (s) \rightarrow N_2\ (g) + O_2\ (g) + H_2O\ (g)$
(d) $Ca_3P_2\ (s) + H_2O\ (l) \rightarrow Ca(OH)_2\ (aq) + PH_3\ (g)$
(e) $Al(OH)_3\ (s) + H_2SO_4\ (aq) \rightarrow Al_2(SO_4)_3\ (aq) + H_2O\ (l)$
(f) $AgNO_3\ (aq) + Na_2CO_3\ (aq) \rightarrow Ag_2NO_3\ (s) + Na_2CO_3\ (aq)$
(g) $C_2H_5NH_2\ (g) + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (g) + N_2\ (g)$

3.20 Balance the following equations and indicate whether they are combination, decomposition, or combustion reactions:

(a) $PbCO_3\ (s) \rightarrow PbO\ (s) + CO_2\ (g)$
(b) $C_2H_4\ (s) + O_2 \rightarrow CO_2\ (g) + H_2O\ (g)$
(c) $Mg\ (s) + N_2\ (g) \rightarrow Mg_3N_2\ (s)$
(d) $C_7H_8O_2\ (l) + O_2 \rightarrow CO_2\ (g) + H_2O\ (g)$
(e) $Al(s) + Cl_2\ (g) \rightarrow AlCl_3\ (s)$

3.21 Determine the formula weights of each of the following compounds: (a) nitric acid, HN_3 ; (b) $KMnO_4$; (c) $Ca_3(PO_4)_2$; (d) quartz, SiO_2; (e) gallium sulfide, (f) chromium(III) sulfate, (g) phosphorus trichloride.

3.24 Calculate the percentage by mass of the indicated element in the following compounds: (a) carbon in acetylene, C_2H_2, a gas used in welding; (b) hydrogen in ascorbic acid, $HC_6H_7O_6$, also known as vitamin C; (c) hydrogen in ammonium sulfate, $(NH_4)_2SO_4$, a substance used as a nitrogen fertilizer; (d) platinum in $PtCl_2(NH_3)_2$, a chemotherapy agent called cisplatin; (e) oxygen in the female sex hormone estradiol, $C_{18}H_{24}O_2$; (f) carbon in capsaicin, $C_{18}H_{27}NO_3$, the compound that gives the hot taste to chili peppers.

3.27 (a) What is Avogadro's number, and how is it related to the mole? (b) What is the relationship between the formula weight of a substance and its molar mass?

3.34 Calculate the following quantities:
(a) mass, in grams, of 1.50×10^{-2} mol of CdS
(b) number of moles of NH_4Cl in 86.6 g of this substance
(c) number of molecules in 8.447×10^{-2} mol C_6H_6
(d) number of O atoms in 6.25×10^{-3} mol $Al(NO_3)_3$

3.53 (a) Combustion analysis of toluene, a common organic solvent, gives 5.86 mg of CO_2 and 1.37 mg of H_2O. If the compound contains only carbon and hydrogen, what is its empirical formula? (b) Menthol, the substance we can smell in mentholated cough drops, is composed of C, H, and O. A 0.1005-g sample of menthol is combusted, producing 0.2829 g of CO_2 and 0.1159 g of H_2O. What is the empirical formula for menthol? If menthol has a molar mass of 156 g/mol, what is its molecular formula?

3.68 The complete combustion of octane, C_8H_{18}, the main component of gasoline, proceeds as follows:

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

(a) How many moles of O_2 are needed to burn 1.50 mol of C_8H_{18}?
(b) How many grams of O_2 are needed to burn 10.0 g of C_8H_{18}?
(c) Octane has a density of 0.692 g/mL at 20 °C. How many grams of O2 are required to burn 15.0 gal of C_8H_{18} (the capacity of an average fuel tank)?
(d) How many grams of CO_2 are produced when 15.0 gal of C_8H_{18} are combusted?

3.78 One of the steps in the commercial process for converting ammonia to nitric acid is the conversion of NH_3 to NO: $4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g)$ _ $6\ H_2O\ (g)$ In a certain experiment, 2.00 g of NH_3 reacts with 2.50 g of O_2 (a) Which is the limiting reactant? (b) How many grams of NO and of H_2O form? (c) How many grams of the excess reactant remain after the limiting reactant is completely consumed? (d) Show that your calculations in parts (b) and (c) are consistent with the law of conservation of mass.

3.86 If 1.5 mol of C_2H_5OH, and 1.5 mol C_3H_8, and 1.5 mol of $CH_3CH_2COCH_3$ are completely combusted in oxygen, which produces the largest number of moles of H_2O? Which produces the least? Explain.

[3.94] An organic compound was found to contain only C, H, and Cl. When a 1.50-g sample of the compound was completely combusted in air, 3.52 g of CO_2 was formed. In a separate experiment the chlorine in a 1.00-g sample of the compound was converted to 1.27 g of AgCl. Determine the empirical formula of the compound.

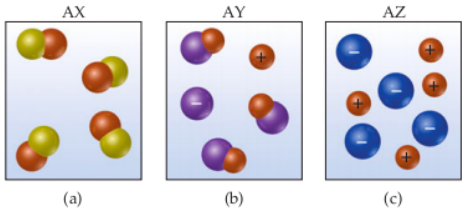
3.111 Hydrogen cyanide, HCN, is a poisonous gas. The lethal dose is approximately 300 mg HCN per kilogram of air when inhaled. (a) Calculate the amount of HCN that gives the lethal dose in a small laboratory room measuring 12 x 15 x 8.0 ft. The density of air at 26 °C is 0.00118 g/cm^3. (b) If the HCN is formed by reaction of NaCN with an acid such as H_2SO_4, what mass of NaCN gives the lethal dose in the room?

$$2\ NaCN\ (s) + H_2SO_4\ (aq) \rightarrow Na_2SO_4\ (aq) + 2\ HCN\ (g)$$

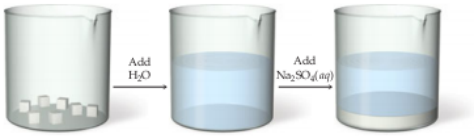
(c) HCN forms when synthetic fibers containing Orlon® or Acrilan® burn. Acrilan® has an empirical formula of CH_2CHCN, so HCN is 50.9% of the formula by mass. A rug measures 12 x 15 ft and contains 30 oz of Acrilan® fibers per square yard of carpet. If the rug burns, will a lethal dose of HCN be generated in the room? Assume that the yield of HCN from the fibers is 20% and that the carpet is 50% consumed.

3.112 The source of oxygen that drives the internal combustion engine in an automobile is air. Air is a mixture of gases, principally N_2 (~79%) and O_2 (~20%). In the cylinder of an automobile engine, nitrogen can react with oxygen to produce nitric oxide gas, NO. As NO is emitted from the tailpipe of the car, it can react with more oxygen to produce nitrogen dioxide gas. (a) Write balanced chemical equations for both reactions. (b) Both nitric oxide and nitrogen dioxide are pollutants that can lead to acid rain and global warming; collectively, they are called "NOx" gases. In 2007, the United States emitted an estimated 22 million tons of nitrogen dioxide into the atmosphere. How many grams of nitrogen dioxide is this? (c) The production of NOx gases is an unwanted side reaction of the main engine combustion process that turns octane, C_8H_{18}, into CO_2 and water. If 85% of the oxygen in an engine is used to combust octane and the remainder used to produce nitrogen dioxide, calculate how many grams of nitrogen dioxide would be produced during the combustion of 500 grams of octane.

4.2 Aqueous solutions of three different substances, AX, AY, and AZ, are represented by the three accompanying diagrams. Identify each substance as a strong electrolyte, weak electrolyte, or nonelectrolyte. [Section 4.1]



4.5 You are presented with a white solid and told that due to careless labeling it is not clear if the substance is barium chloride, lead chloride, or zinc chloride. When you transfer the solid to a beaker and add water, the solid dissolves to give a clear solution. Next, a Na_2SO_4 (aq) solution is added and a white precipitate forms. What is the identity of the unknown white solid? [Section 4.2]



4.15 Specify what ions are present in solution upon dissolving each of the following substances in water: (a) $ZnCl_2$, (b) HNO_3, (c) $(NH_4)_2SO_4$, (d) $Ca(OH)_2$.

4.23 Name the spectator ions in any reactions that may be involved when each of the following pairs of solutions are mixed. (a) Na_2CO_3 (aq) and $MgSO_4$ (aq) (b) $Pb(NO_3)_2$ (aq) and Na_2S (aq) (c) $(NH_4)_3PO_4$ (aq) and $CaCl_2$ (aq).

4.24 Write balanced net ionic equations for the reactions that occur in each of the following cases. Identify the spectator ion or ions in each reaction.
(a) $Cr_2(SO_4)_3$ (aq) + $(NH_4)_2CO_3$ (aq) →
(b) $Ba(NO_3)_2$ (aq) + K_2SO_4 (aq) →
(c) $Fe(NO_3)_2$ (aq) + KOH (aq) →

4.36 An aqueous solution of an unknown solute is tested with litmus paper and found to be acidic. The solution is weakly conducting compared with a solution of NaCl of the same concentration. Which of the following substances could the unknown be: KOH, NH_3, HNO_3, $KClO_2$, H_3PO_3, CH_3COCH_3 (acetone)?

4.37 Classify each of the following substances as a nonelectrolyte, weak electrolyte, or strong electrolyte in water: (a) H_2SO_3, (b) C_2H_5OH (ethanol), (c) NH_3, (d) $KClO_3$, (e) $Cu(NO_3)_2$.

4.48 Determine the oxidation number of sulfur in each of the following substances: (a) barium sulfate, $BaSO_4$, (b) sulfurous acid, H_2SO_3, (c) strontium sulfide, SrS, (d) hydrogen sulfide, H_2S. (e) Based on these compounds what is the range of oxidation numbers seen for sulfur? Is there any relationship between the range of accessible oxidation states and sulfur's position on the periodic table?

4.58 (a) Use the following reactions to prepare an activity series for the halogens:
Br_2 (aq) + 2 NaI (aq) → 2 NaBr (aq) + I_2 (aq)
Cl_2 (aq) + NaBr (aq) → 2 NaCl (aq) + Br_2 (aq)
(b) Relate the positions of the halogens in the periodic table with their locations in this activity series. (c) Predict whether a reaction occurs when the following reagents are mixed: Cl_2 (aq) and KI(aq); Br_2 (aq) and LiCl (aq).

4.69 (a) Which will have the highest concentration of potassium ion: 0.20 M KCl, 0.15 M K_2CrO_4, or 0.080 M K_3PO_4? (b) Which will contain the greater number of moles of potassium ion: 30.0 mL of 0.15 M K_2CrO_4 or 25.0 mL of 0.080 M K_3PO_4?

4.75 (a) Starting with solid sucrose, $C_{12}H_{22}O_{11}$, describe how you would prepare 250 mL of a 0.250 M sucrose solution. (b) Describe how you would prepare 350.0 mL of 0.100 M $C_{12}H_{22}O_{11}$ starting with 3.00 L of 1.50 M $C_{12}H_{22}O_{11}$.

4.86 An 8.65-g sample of an unknown group 2A metal hydroxide is dissolved in 85.0 mL of water. An acid–base indicator is added and the resulting solution is titrated with 2.50 M HCl (aq) solution. The indicator changes color signaling that the equivalence point has been reached after 56.9 mL of the hydrochloric acid solution has been added. (a) What is the molar mass of the metal hydroxide? (b) What is the identity of the metal cation: Ca^{2+}, Sr^{2+}, Ba^{2+}?

4.94 You choose to investigate some of the solubility guidelines for two ions not listed in Table 4.1, the chromate ion (CrO_4^{2-}) and the oxalate ion ($C_2O_4^{2-}$). You are given 0.01 M solutions (A, B, C, D) of four water-soluble salts:

Solution	Solute	Color of Solution
A	Na_2CrO_4	Yellow
B	$(NH_4)_2C_2O_4$	Colorless
C	$AgNO_3$	Colorless
D	$CaCl_2$	Colorless

When these solutions are mixed, the following observations are made:

Expt Number	Solutions Mixed	Result
1	A + B	No precipitate, yellow solution
2	A + C	Red precipitate forms
3	A + D	Yellow precipitate forms
4	B + C	White precipitate forms
5	B + D	White precipitate forms
6	C + D	White precipitate forms

(a) Write a net ionic equation for the reaction that occurs in each of the experiments. (b) Identify the precipitate formed, if any, in each of the experiments.

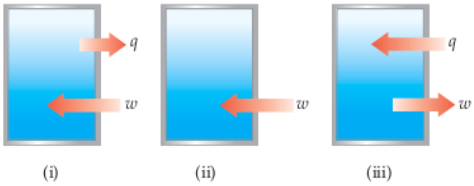
[4.111] The average concentration of bromide ion in seawater is 65 mg of bromide ion per kg of seawater. What is the molarity of the bromide ion if the density of the seawater is 1.025 g/mL?

[4.115] Federal regulations set an upper limit of 50 parts per million (ppm) of NH_3 in the air in a work environment [that is, 50 molecules of NH_3 (g) for every million molecules in the air]. Air from a manufacturing operation was drawn through a solution containing 1.00 x 102 mL of 0.0105 M HCl. The NH_3 reacts with HCl as follows:

$$NH_3\ (aq) + HCl\ (aq) \rightarrow NH_4Cl\ (aq)$$

After drawing air through the acid solution for 10.0 min at a rate of 10.0 L/min , the acid was titrated. The remaining acid needed 13.1 mL of 0.0588 M NaOH to reach the equivalence point. (a) How many grams of NH_3 were drawn into the acid solution? (b) How many ppm of NH_3 were in the air? (Air has a density of 1.20 g/L and an average molar mass of 29.0 g/mol under the conditions of the experiment.) (c) Is this manufacturer in compliance with regulations?

5.4 The contents of the closed box in each of the following illustrations represent a system, and the arrows show the changes to the system during some process. The lengths of the arrows represent the relative magnitudes of q and w. (a) Which of these processes is endothermic? (b) For which of these processes, if any, is $\Delta E < 0$? (c) For which process, if any, does the system experience a net gain in internal energy? [Section 5.2]



5.10 The gas-phase reaction shown, between N_2 and O_2, was run in an apparatus designed to maintain a constant pressure. (a) Write a balanced chemical equation for the reaction depicted, and predict whether w is positive, negative, or zero. (b) Using data from Appendix C, determine ΔH for the formation of one mole of the product. Why is this enthalpy change called the enthalpy of formation of the involved product? [Sections 5.3 and 5.7]

5.27 Calculate ΔE and determine whether the process is endothermic or exothermic for the following cases: (a) q = 0.763 kJ and w = –840 J; (b) a system releases 66.1 kJ of heat to its surroundings while the surroundings do 44.0 kJ of work on the system; (c) the system absorbs 7.25 kJ of heat from the surroundings while its volume remains constant (assume that only P-V work can be done).

5.39 The complete combustion of ethanol, C_2H_5OH (l), to form H_2O (g) and CO_2 (g) at constant pressure releases 1235 kJ of heat per mole of C_2H_5OH. (a) Write a balanced thermochemical equation for this reaction. (b) Draw an enthalpy diagram for the reaction.

5.46 At one time, a common means of forming small quantities of oxygen gas in the laboratory was to heat $KClO_3$:

$$2\ KClO_3\ (s) \rightarrow 2\ KCl\ (s) + 3\ O_2\ (g) \qquad \Delta H = -89.4\ kJ$$

For this reaction, calculate ΔH for the formation of (a) 1.36 mol of O_2 and (b) 10.4 g of KCl. (c) The decomposition of $KClO_3$ proceeds spontaneously when it is heated. Do you think that the reverse reaction, the formation of $KClO_3$ from KCl and O_2, is likely to be feasible under ordinary conditions? Explain your answer.

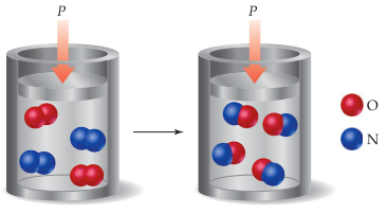
5.52 (a) Which substance in Table 5.2 requires the smallest amount of energy to increase the temperature of 50.0 g of that substance by 10 K? (b) Calculate the energy needed for this temperature change.

5.55 When a 6.50-g sample of solid sodium hydroxide dissolves in 100.0 g of water in a coffee-cup calorimeter (Figure 5.18), the temperature rises from 21.6 °C to 37.8 °C. Calculate ΔH (in kJ/mol NaOH) for the solution process

$$NaOH\ (s) \rightarrow Na^+\ (aq) + OH\ (aq)$$

Assume that the specific heat of the solution is the same as that of pure water.

5.60 Under constant-volume conditions, the heat of combustion of benzoic acid (C_6H_5COOH) is 26.38 kJ/g. A 2.760-g sample of benzoic acid is burned in a bomb calorimeter. The temperature of the calorimeter increases from 21.60 °C to 29.93 °C. (a) What is the total heat capacity of the calorimeter? (b) A 1.440-g sample of a new organic substance is combusted in the same calorimeter. The temperature of the calorimeter increases from 22.14 °C to 27.09 °C. What is the heat of combustion per gram of the new substance? (c) Suppose that in changing samples, a portion of the water in the calorimeter were lost. In what way, if any, would this change the heat capacity of the calorimeter?



5.65 From the enthalpies of reaction

H_2 (g) + F_2 (g) → 2 HF(g) ΔH = -537 kJ

C(s) + 2 F_2 (g) → CF_4 (g) ΔH = -680 kJ

2 C(s) + 2 H_2 (g) → C_2H_4 (g) ΔH = +52.3 kJ

calculate for the reaction of ethylene with F_2:

C_2H_4 (g) + 6 F_2 (g) → 2 CF_4 (g) + 4 HF (g)

5.74 Using values from Appendix C, calculate the value of ΔH° for each of the following reactions:

(a) CaO (s) 2 HCl (g) → $CaCl_2$ (s) + H_2O (g)

(b) 4 FeO (s) + O2 (g) → 2 Fe_2O_3 (s)

(c) 2 CuO (s) + NO (g) → Cu_2O (s) + NO_2 (g)

(d) 4 NH_3 (g) + O_2 (g) → 2 N_2H_4 (g) + 2 H_2O (l)

5.86 The heat of combustion of ethanol, C_2H_5OH (l), is -1367 kJ/mol. A batch of Sauvignon Blanc wine contains 10.6% ethanol by mass. Assuming the density of the wine to be 1.0 g/mL, what is the caloric content due to the alcohol (ethanol) in a 6-oz glass of wine (177 mL)?

5.104 (a) Calculate the standard enthalpy of formation of gaseous diborane (B_2H_6) using the following thermochemical information:

4 B (s) + 3 O_2 (g) → 2 B_2O_3 (s) ΔH° = -2509.1 kJ

2 H_2 (g) + O_2 (g) → 2 H_2O (l) ΔH° = -571.7 kJ

B_2H_6 (g) + 3 O_2 (g) → B_2O_3 (s) + 3 H_2O (l) ΔH° = -2147.5 kJ

(b) Pentaborane (B_5H_9) is another boron hydride. What experiment or experiments would you need to perform to yield the data necessary to calculate the heat of formation of B_5H_9 (l)? Explain by writing out and summing any applicable chemical reactions.

5.110 The Sun supplies about 1.0 kilowatt of energy for each square meter of surface area (1.0 kW/m^2, where a watt = 1 J/s). Plants produce the equivalent of about 0.20 g of sucrose ($C_{12}H_{22}O_{11}$) per hour per square meter. Assuming that the sucrose is produced as follows, calculate the percentage of sunlight used to produce sucrose.

12 CO_2 (g) + 11 H_2O (l) → $C_{12}H_{22}O_{11}$ + 12 O_2 (g) ΔH° = 5645 kJ

[5.111] It is estimated that the net amount of carbon dioxide fixed by photosynthesis on the landmass of Earth is 5.5 x 10^{16} g/yr of CO_2. Assume that all this carbon is converted into glucose. (a) Calculate the energy stored by photosynthesis on land per year in kJ. (b) Calculate the average rate of conversion of solar energy into plant energy in MW (1 W = 1 J/s). A large nuclear power plant produces about 10^3 MW. The energy of how many such nuclear power plants is equivalent to the solar energy conversion?

[5.114] Consider the following acid-neutralization reactions involving the strong base NaOH aq):

HNO_3 (aq) + NaOH (aq) → $NaNO_3$ (aq) + H_2O (l)

HCl (aq) + NaOH (aq) → NaCl (aq) + H_2O (l)

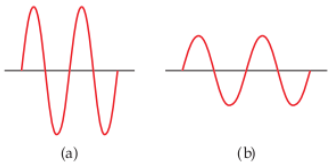
NH_4^+ (aq) + NaOH (aq) → NH_3 (aq) + Na^+ (aq) + H_2O (l)

(a) By using data in Appendix C, calculate ΔH° for each of the reactions. (b) As we saw in Section 4.3, nitric acid and hydrochloric acid are strong acids. Write net ionic equations for the neutralization of these acids. (c) Compare the values of ΔH° for the first two reactions. What can you conclude? (d) In the third equation is acting as an acid. Based on the value of ΔH° for this reaction, do you think it is a strong or a weak acid? Explain.

[5.117] A sample of a hydrocarbon is combusted completely in O_2 (g) to produce 21.83 g CO_2 (g), 4.47 g H_2O (g), and 311 kJ of heat. (a) What is the mass of the hydrocarbon sample that was combusted? (b) What is the empirical formula of the hydrocarbon? (c) Calculate the value of $\Delta H_f°$ per empirical-formula unit of the hydrocarbon. (d) Do you think that the hydrocarbon is one of those listed in Appendix C? Explain your answer.

5.119 World energy supplies are often measured in the unit of quadrillion British thermal units (10^{12} Btu), generally called a "quad." In 2015, world energy consumption is projected to be 5.81×10^{17} kJ. (a) With reference to Exercise 5.17, how many quads of energy does this quantity represent? (b) Current annual energy consumption in the United States is 99.5 quads. Assume that all this energy is to be generated by burning CH_4 (g) in the form of natural gas. If the combustion of the CH_4 (g) were complete and 100% efficient, how many moles of CH_4 (g) would need to be combusted in order to provide the U.S. energy demand? (c) How many kilograms of CO_2 (g) would be generated in the combustion in part (b)? (d) Compare your answer to part (c) with information given in Exercise 5.111. Do you think that photosynthesis is an adequate means to maintain a stable level of CO_2 atmosphere?

6.3 The following diagrams represent two electromagnetic waves. Which wave corresponds to the higher-energy radiation?



6.9 The drawing below shows part of the orbital diagram for an element. (a) As drawn, the drawing is *incorrect*. Why? (b) How would you correct the drawing without changing the number of electrons? (c) To which group in the periodic table does the element belong? [Section 6.8]

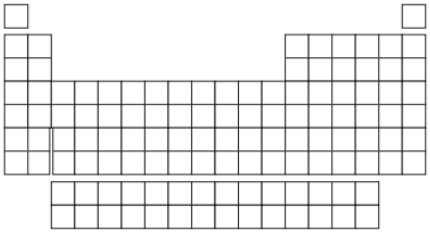
6.10 State where in the periodic table these elements appear:

(a) elements with the valence-shell electron configuration ns2np5

(b) elements that have three unpaired p electrons

(c) an element whose valence electrons are 4s24p1

(d) the d-block elements



6.23 (a) Calculate the energy of a photon of electromagnetic radiation whose frequency is 6.74 x 10^{12} s^{-1}. (b) Calculate the energy of a photon of radiation whose wavelength is 322 nm. (c) What wavelength of radiation has photons of energy 2.87 x 10^{-18} J.

6.38 (a) Calculate the energies of an electron in the hydrogen atom for n = 1 and for n = ∞. How much energy does it require to move the electron out of the atom completely (from n = 1 to n = ∞), according to Bohr? Put your answer in kJ/mol. (b) The energy for the process H + enery → H^+ + e^- is called the ionization energy of hydrogen. The experimentally determined value for the ionization energy of hydrogen is 1210 kJ/mol. How does this compare to your calculation?

6.56 For the table that follows, write which orbital goes with the quantum numbers. Don't worry about x, y, z subscripts. If the quantum numbers are not allowed, write "not allowed."

n	*l*	m_l	Orbital
2	1	-1	2p (example)
1	0	0	
3	-3	2	
3	2	-2	
2	0	-1	
0	0	0	
4	2	1	
5	3	0	

6.66 What is the maximum number of electrons in an atom that can have the following quantum numbers: (a) n = 2, m_l = -½, (b) n = 5, = 3, (c) 2s, (d) 4f?

6.69 Write the condensed electron configurations for the following atoms, using the appropriate noble-gas core abbreviations: (a) Cs, (b) Ni, (c) Se, (d) Cd, (e) U, (f) Pb.

[6.87] Bohr's model can be used for hydrogen-like ions—ions that have only one electron, such as He^+ and Li^{2+}. (a) Why is the Bohr model applicable to He^+ ions but not to neutral He atoms? (b) The ground-state energies of H, He^+, and Li^{2+} are tabulated as follows:

Atom or ion	H	He^+	Li^{2+}
Ground-state energy	-2.18 x 10^{-18} J	-8.72 x 10^{-18} J	-1.96 x 10^{-17} J

By examining these numbers, propose a relationship between the ground-state energy of hydrogen-like systems and the nuclear charge, Z. (c) Use the relationship you derive in part (b) to predict the ground-state energy of the C^{5+} ion.

6.97 Microwave ovens use microwave radiation to heat food. The energy of the microwaves is absorbed by water molecules in food and then transferred to other components of the food. (a) Suppose that the microwave radiation has a wavelength of 11.2 cm. How many photons are required to heat 200 mL of coffee from 23 °C to °60 C? (b) Suppose the microwave's power is 900 W . How long would you have to heat the coffee in part (a)?

6.100 (a) Account for formation of the following series of oxides in terms of the electron configurations of the elements and the discussion of ionic compounds in Section 2.7: K_2O, CaO, Sc_2O, TiO_2, V_2O_5, CeO_3. (b) Name these oxides. (c) Consider the metal oxides whose enthalpies of formation (in kJ mol-1) are listed here.

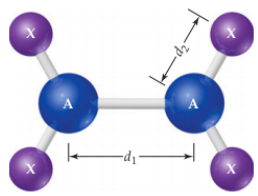
Oxide	K_2O (s)	CaO (s)	TiO_2 (s)	V_2O_5 (s)
$\Delta H_f°$	-363.2	-635.1	-938.7	-1550.6

Calculate the enthalpy changes in the following general reaction for each case:

$$M_nO_m\ (s) + H_2\ (g) \rightarrow n\ M\ (s) + m\ H_2O\ (g)$$

(You will need to write the balanced equation for each case and then compute ΔH°) (d) Based on the data given, estimate a value of $\Delta H_f°$ for Sc_2O_3.

7.3 Consider the A_2X_4 molecule depicted here, where A and X are elements. The bond length in this molecule is d_1, and the four bond lengths are each d_2. (a) In terms of d_1 and d_2, how could you define the bonding atomic radii of atoms A and X? (b) In terms of d_1 and d_2, what would you predict for the bond length of an X_2 molecule? [Section 7.3]



7.11 (a) What is meant by the term *effective nuclear charge*? (b) How does the effective nuclear charge experienced by the valence electrons of an atom vary going from left to right across a period of the periodic table?

7.21 Estimate the bond length from the data in Figure 7.6, and compare your value to the experimental bond length in arsenic triiodide, AsI_3, 2.55 Å.

7.28 Explain the following variations in atomic or ionic radii:
(a) $I^- > I > I^+$, (b) $Ca^{2+} > Mg^{2+} > Be^{2+}$, (c) $Fe > Fe^{2+} > Fe^{3+}$.

7.37 For each of the following sets of atoms and ions, arrange the members in order of increasing size: (a) Se^{2-}, Te^{2-}, Se; (b) Co^{3+}, Fe^{2+}, Fe^{3+}; (c) Ca, Ti^{4+}, Sc^{3+}; (d) Be^{2+}, Na^+, Ne.

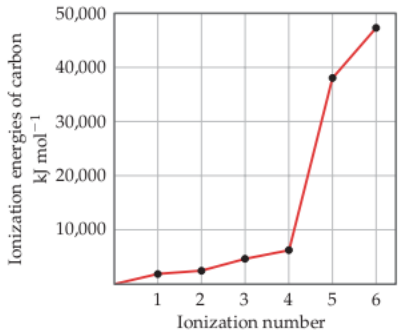
7.46 For each of the following pairs, indicate which element has the smaller first ionization energy: (a) Ti, Ba; (b) Ag, Cu; (c) Ge, Cl; (d) Pb, Sb. (In each case use electron configuration and effective nuclear charge to explain your answer.)

7.49 Find three examples of ions in the periodic table that have an electron configuration of nd^8 (n = 3, 4, 5...).

7.54 What is the relationship between the ionization energy of an anion with a 1- charge such as F^- and the electron affinity of the neutral atom, F?

7.63 (a) What is meant by the terms acidic oxide and basic oxide? (b) How can we predict whether an oxide will be acidic or basic based on its composition?

7.93 Explain the variation in ionization energies of carbon, as displayed in this graph:

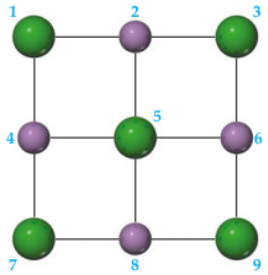


[7.107] One way to measure ionization energies is ultraviolet photoelectron spectroscopy (UPS, or just PES), a technique based on the photoelectric effect. (Section 6.2) In PES, monochromatic light is directed onto a sample, causing electrons to be emitted. The kinetic energy of the emitted electrons is measured. The difference between the energy of the photons and the kinetic energy of the electrons corresponds to the energy needed to remove the electrons (that is, the ionization energy). Suppose that a PES experiment is performed in which mercury vapor is irradiated with ultraviolet light of wavelength 58.4 nm. (a) What is the energy of a photon of this light in eV? (b) Write an equation that shows the process corresponding to the first ionization energy of Hg.(c) The kinetic energy of the emitted electrons is measured to be 10.75 eV. What is the first ionization energy of Hg in ? (d) Using Figure 7.9, determine which of the halogen elements has a first ionization energy closest to that of mercury.

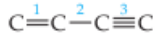
8.1 For each of these Lewis symbols, indicate the group in the periodic table in which the element X belongs: [Section 8.1]

(a) $\cdot\dot{\underset{\cdot}{X}}\cdot$ (b) $\cdot X\cdot$ (c) $:\dot{\underset{\cdot}{X}}\cdot$

8.3 A portion of a two-dimensional "slab" of NaCl(s) is shown here (see Figure 8.3) in which the ions are numbered. (a) Of the following types of interactions (identified by color), which are attractive and which are repulsive: "purple-purple," "purple-green," "green-green"? Explain. (b) Consider the "green-green" interactions between ions 1 and 3, ions 1 and 5, and ions 3 and 5. Which one or more of these three will result in the interaction of largest magnitude? Which one or more will result in the interaction of the smallest magnitude? (c) Consider the "green-green" interactions between ions 1 and 5 and the "green-purple" interactions between ions 1 and 2. Which of these will have the greater magnitude? (d) Does your answer to part (c) help explain why NaCl is a stable ionic solid? [Section 8.2]



8.7 The partial Lewis structure that follows is for a hydrocarbon molecule. In the full Lewis structure, each carbon atom satisfies the octet rule, and there are no unshared electron pairs in the molecule. The carbon–carbon bonds are labeled 1, 2, and 3. (a) Determine where the hydrogen atoms are in the molecule.(b) Rank the carbon–carbon bonds in order of increasing bond length. (c) Rank the carbon–carbon bonds in order of increasing bond enthalpy. [Sections 8.3 and 8.8]



8.13 Write the Lewis symbol for atoms of each of the following elements: (a) Al, (b) Br, (c) Ar, (d) Sr.

8.26 Explain the following trends in lattice energy: (a) NaCl > RbBr > CsBr; (b) BaO > KF; (c) SrO > $SrCl_2$.

8.41 Which of the following bonds are polar: (a) B – F, (b) Cl – Cl, (c) Se – O, (d) H – I? Which is the more electronegative atom in each polar bond?

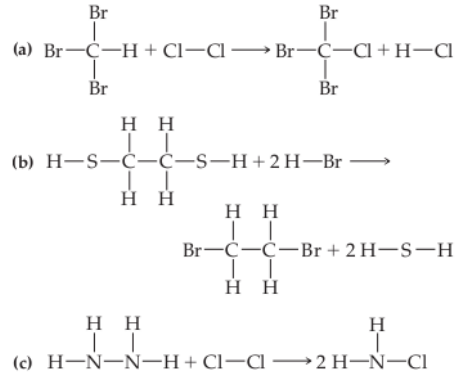
8.43 (a) From the data in Table 8.3, calculate the effective charges on the H and Br atoms of the HBr molecule in units of the electronic charge, *e*. (b) Compare your answers to part (a) with those in Sample Exercise 8.5 for the HCl molecule. Can you explain why the values are different?

8.51 Write Lewis structures that obey the octet rule for each of the following, and assign oxidation numbers and formal charges to each atom: (a) OCS, (b) $SOCl_2$ (S is bonded to the two Cl atoms and to the O), (c) BrO_3^- (d) $HClO_2$ (H is bonded to O).

8.56 Based on Lewis structures, predict the ordering of N – O bond lengths in NO^+, NO_2^-, NO_3^-.

8.63 Draw the Lewis structures for each of the following ions or molecules. Identify those that do not obey the octet rule, and explain why they do not: (a) SO_3^{2-}, (b) AlH_3, (c) N^{3-}, (d) CH_2Cl_2, (e) SbF_5.

8.70 Using Table 8.4, estimate for the following gas-phase reactions:



8.85 For the following collection of nonmetallic elements, O, P, Te, I, B, (a) which two would form the most polar single bond? (b) Which two would form the longest single bond? (c) Which two would be likely to form a compound of formula XY_2? (d) Which combinations of elements would likely yield a compound of empirical formula X_2Y_3? In each case explain your answer.

[8.103] The electron affinity of oxygen is -141 kJ/mol, corresponding to the reaction

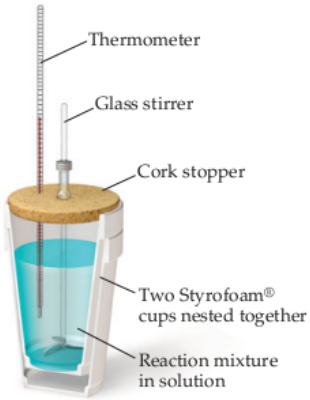
$$O\ (g) + e^- \rightarrow O^-\ (g)$$

The lattice energy of K_2O 2238 kJ/mol(s). Use these data along with data in Appendix C and Figure 7.9 to calculate the "second electron affinity" of oxygen, corresponding to the reaction

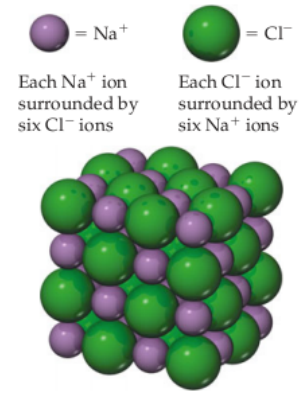
$$O^-\ (g) + e^- \rightarrow O^{2-}\ (g)$$

8.112 Average bond enthalpies are generally defined for gas-phase molecules. Many substances are liquids in their standard state. (Section 5.7) By using appropriate thermochemical data from Appendix C, calculate average bond enthalpies in the liquid state for the following bonds, and compare these values to the gas-phase values given in Table 8.4: (a) Br – Br, from Br_2 (l); (b) C – Cl from CCl_4 (l); (c) O – O, from H_2O_2 (l) (assume that the bond enthalpy is the same as in the gas phase). (d) What can you conclude about the process of breaking bonds in the liquid as compared to the gas phase? Explain the difference in the values between the two phases.

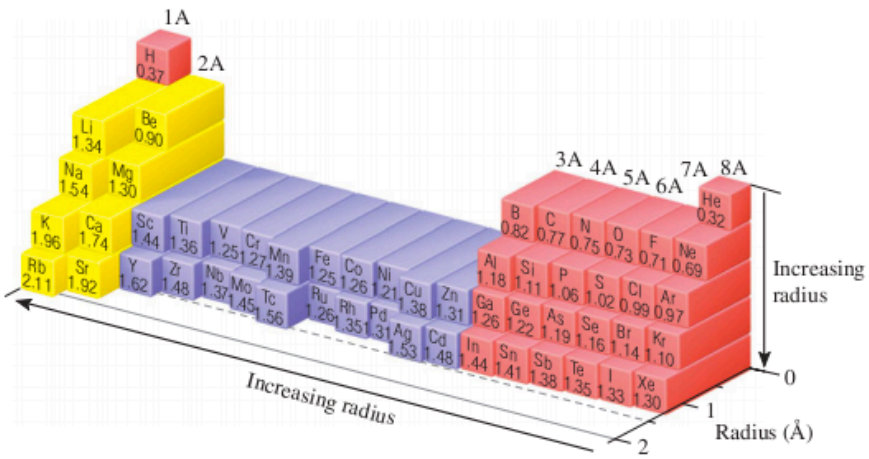
Figures, Tables, et al. referred to in the problem set.



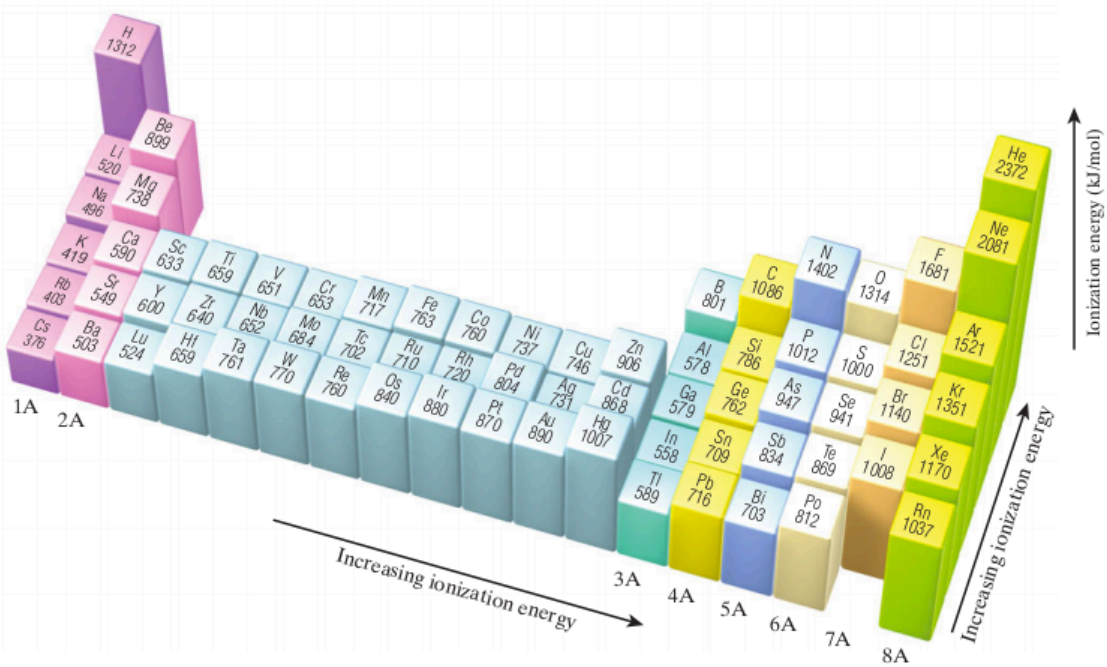
▲ **FIGURE 5.18 Coffee-cup calorimeter.** This simple apparatus is used to measure temperature changes of reactions at constant pressure.



▲ **FIGURE 8.3 The crystal structure of sodium chloride.**



◀ **FIGURE 7.6 Trends in bonding atomic radii for periods 1 through 5.**



▲ **FIGURE 7.9 Trends in first ionization energies of the elements.**

TABLE 4.1 • Solubility Guidelines for Common Ionic Compounds in Water

Soluble Ionic Compounds		Important Exceptions
Compounds containing	NO_3^-	None
	CH_3COO^-	None
	Cl^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	Br^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	I^-	Compounds of Ag^+, Hg_2^{2+}, and Pb^{2+}
	SO_4^{2-}	Compounds of Sr^{2+}, Ba^{2+}, Hg_2^{2+}, and Pb^{2+}
Insoluble Ionic Compounds		**Important Exceptions**
Compounds containing	S^{2-}	Compounds of NH_4^+, the alkali metal cations, Ca^{2+}, Sr^{2+}, and Ba^{2+}
	CO_3^{2-}	Compounds of NH_4^+ and the alkali metal cations
	PO_4^{3-}	Compounds of NH_4^+ and the alkali metal cations
	OH^-	Compounds of NH_4^+, the alkali metal cations, Ca^{2+}, Sr^{2+}, and Ba^{2+}

TABLE 5.2 • Specific Heats of Some Substances at 298 K

Elements		Compounds	
Substance	**Specific Heat (J/g-K)**	**Substance**	**Specific Heat (J/g-K)**
$N_2(g)$	1.04	$H_2O(l)$	4.18
$Al(s)$	0.90	$CH_4(g)$	2.20
$Fe(s)$	0.45	$CO_2(g)$	0.84
$Hg(l)$	0.14	$CaCO_3(s)$	0.82

TABLE 8.3 • Bond Lengths, Electronegativity Differences, and Dipole Moments of the Hydrogen Halides

Compound	Bond Length (Å)	Electronegativity Difference	Dipole Moment (D)
HF	0.92	1.9	1.82
HCl	1.27	0.9	1.08
HBr	1.41	0.7	0.82
HI	1.61	0.4	0.44

TABLE 8.4 • Average Bond Enthalpies (kJ/mol)

Single Bonds

C—H	413	N—H	391	O—H	463	F—F	155
C—C	348	N—N	163	O—O	146		
C—N	293	N—O	201	O—F	190	Cl—F	253
C—O	358	N—F	272	O—Cl	203	Cl—Cl	242
C—F	485	N—Cl	200	O—I	234		
C—Cl	328	N—Br	243			Br—F	237
C—Br	276			S—H	339	Br—Cl	218
C—I	240	H—H	436	S—F	327	Br—Br	193
C—S	259	H—F	567	S—Cl	253		
		H—Cl	431	S—Br	218	I—Cl	208
Si—H	323	H—Br	366	S—S	266	I—Br	175
Si—Si	226	H—I	299			I—I	151
Si—C	301						
Si—O	368						
Si—Cl	464						

Multiple Bonds

C=C	614	N=N	418	O_2	495
C≡C	839	N≡N	941		
C=N	615	N=O	607	S=O	523
C≡N	891			S=S	418
C=O	799				
C≡O	1072				

SAMPLE EXERCISE 8.5 Dipole Moments of Diatomic Molecules

The bond length in the HCl molecule is 1.27 Å. **(a)** Calculate the dipole moment, in debyes, that results if the charges on the H and Cl atoms were 1+ and 1−, respectively. **(b)** The experimentally measured dipole moment of HCl(*g*) is 1.08 D. What magnitude of charge, in units of *e*, on the H and Cl atoms leads to this dipole moment?

SOLUTION

Analyze and Plan We are asked in (a) to calculate the dipole moment of HCl that would result if there were a full charge transferred from H to Cl. We can use Equation 8.11 to obtain this result. In (b), we are given the actual dipole moment for the molecule and will use that value to calculate the actual partial charges on the H and Cl atoms.

Solve:

(a) The charge on each atom is the electronic charge, $e = 1.60 \times 10^{-19}$ C. The separation is 1.27 Å. The dipole moment is therefore

$$\mu = Qr = (1.60 \times 10^{-19}\text{C})(1.27\ \text{Å})\left(\frac{10^{-10}\ \text{m}}{1\ \text{Å}}\right)\left(\frac{1\ \text{D}}{3.34 \times 10^{-30}\text{C-m}}\right) = 6.08\ \text{D}$$

(b) We know the value of μ, 1.08 D, and the value of r, 1.27 Å. We want to calculate the value of Q:

$$Q = \frac{\mu}{r} = \frac{(1.08\ \text{D})\left(\frac{3.34 \times 10^{-30}\text{C-m}}{1\ \text{D}}\right)}{(1.27\ \text{Å})\left(\frac{10^{-10}\ \text{m}}{1\ \text{Å}}\right)} = 2.84 \times 10^{-20}\text{C}$$

We can readily convert this charge to units of e:

$$\text{Charge in } e = (2.84 \times 10^{-20}\ \text{C})\left(\frac{1\ e}{1.60 \times 10^{-19}\text{C}}\right) = 0.178e$$

Thus, the experimental dipole moment indicates that the charge separation in the HCl molecule is

$$\overset{0.178+}{\text{H}} — \overset{0.178-}{\text{Cl}}$$

Because the experimental dipole moment is less than that calculated in part (a), the charges on the atoms are much less than a full electronic charge. We could have anticipated this because the H—Cl bond is polar covalent rather than ionic.

PRACTICE EXERCISE

The dipole moment of chlorine monofluoride, ClF(*g*), is 0.88 D. The bond length of the molecule is 1.63 Å. **(a)** Which atom is expected to have the partial negative charge? **(b)** What is the charge on that atom in units of *e*?

Answers: **(a)** F, **(b)** 0.11−

THERMODYNAMIC QUANTITIES FOR SELECTED SUBSTANCES AT 298.15 K (25 °C)

Substance	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)
Aluminum			
$Al(s)$	0	0	28.32
$AlCl_3(s)$	−705.6	−630.0	109.3
$Al_2O_3(s)$	−1669.8	−1576.5	51.00
Barium			
$Ba(s)$	0	0	63.2
$BaCO_3(s)$	−1216.3	−1137.6	112.1
$BaO(s)$	−553.5	−525.1	70.42
Beryllium			
$Be(s)$	0	0	9.44
$BeO(s)$	−608.4	−579.1	13.77
$Be(OH)_2(s)$	−905.8	−817.9	50.21
Bromine			
$Br(g)$	111.8	82.38	174.9
$Br^-(aq)$	−120.9	−102.8	80.71
$Br_2(g)$	30.71	3.14	245.3
$Br_2(l)$	0	0	152.3
$HBr(g)$	−36.23	−53.22	198.49
Calcium			
$Ca(g)$	179.3	145.5	154.8
$Ca(s)$	0	0	41.4
$CaCO_3(s$, calcite)	−1207.1	−1128.76	92.88
$CaCl_2(s)$	−795.8	−748.1	104.6
$CaF_2(s)$	−1219.6	−1167.3	68.87
$CaO(s)$	−635.5	−604.17	39.75
$Ca(OH)_2(s)$	−986.2	−898.5	83.4
$CaSO_4(s)$	−1434.0	−1321.8	106.7
Carbon			
$C(g)$	718.4	672.9	158.0
$C(s$, diamond)	1.88	2.84	2.43
$C(s$, graphite)	0	0	5.69
$CCl_4(g)$	−106.7	−64.0	309.4
$CCl_4(l)$	−139.3	−68.6	214.4
$CF_4(g)$	−679.9	−635.1	262.3
$CH_4(g)$	−74.8	−50.8	186.3
$C_2H_2(g)$	226.77	209.2	200.8
$C_2H_4(g)$	52.30	68.11	219.4
$C_2H_6(g)$	−84.68	−32.89	229.5
$C_3H_8(g)$	−103.85	−23.47	269.9
$C_4H_{10}(g)$	−124.73	−15.71	310.0
$C_4H_{10}(l)$	−147.6	−15.0	231.0
$C_6H_6(g)$	82.9	129.7	269.2
$C_6H_6(l)$	49.0	124.5	172.8
$CH_3OH(g)$	−201.2	−161.9	237.6
$CH_3OH(l)$	−238.6	−166.23	126.8
$C_2H_5OH(g)$	−235.1	−168.5	282.7
$C_2H_5OH(l)$	−277.7	−174.76	160.7
$C_6H_{12}O_6(s)$	−1273.02	−910.4	212.1
$CO(g)$	−110.5	−137.2	197.9
$CO_2(g)$	−393.5	−394.4	213.6
$CH_3COOH(l)$	−487.0	−392.4	159.8
Cesium			
$Cs(g)$	76.50	49.53	175.6
$Cs(l)$	2.09	0.03	92.07
$Cs(s)$	0	0	85.15
$CsCl(s)$	−442.8	−414.4	101.2
Chlorine			
$Cl(g)$	121.7	105.7	165.2
$Cl(aq)$	−167.2	−131.2	56.5
$Cl_2(g)$	0	0	222.96
$HCl(aq)$	−167.2	−131.2	56.5
$HCl(g)$	−92.30	−95.27	186.69
Chromium			
$Cr(g)$	397.5	352.6	174.2
$Cr(s)$	0	0	23.6
$Cr_2O_3(s)$	−1139.7	−1058.1	81.2
Cobalt			
$Co(g)$	439	393	179
$Co(s)$	0	0	28.4
Copper			
$Cu(g)$	338.4	298.6	166.3
$Cu(s)$	0	0	33.30

Substance	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)
$CuCl_2(s)$	−205.9	−161.7	108.1
$CuO(s)$	−156.1	−128.3	42.59
$Cu_2O(s)$	−170.7	−147.9	92.36
Fluorine			
$F(g)$	80.0	61.9	158.7
$F(aq)$	−332.6	−278.8	−13.8
$F_2(g)$	0	0	202.7
$HF(g)$	−268.61	−270.70	173.51
Hydrogen			
$H(g)$	217.94	203.26	114.60
$H^+(aq)$	0	0	0
$H^+(g)$	1536.2	1517.0	108.9
$H_2(g)$	0	0	130.58
Iodine			
$I(g)$	106.60	70.16	180.66
$I^-(aq)$	−55.19	−51.57	111.3
$I_2(g)$	62.25	19.37	260.57
$I_2(s)$	0	0	116.73
$HI(g)$	25.94	1.30	206.3
Iron			
$Fe(g)$	415.5	369.8	180.5
$Fe(s)$	0	0	27.15
$Fe^{2+}(aq)$	−87.86	−84.93	113.4
$Fe^{3+}(aq)$	−47.69	−10.54	293.3
$FeCl_2(s)$	−341.8	−302.3	117.9
$FeCl_3(s)$	−400	−334	142.3
$FeO(s)$	−271.9	−255.2	60.75
$Fe_2O_3(s)$	−822.16	−740.98	89.96
$Fe_3O_4(s)$	−1117.1	−1014.2	146.4
$FeS_2(s)$	−171.5	−160.1	52.92
Lead			
$Pb(s)$	0	0	68.85
$PbBr_2(s)$	−277.4	−260.7	161
$PbCO_3(s)$	−699.1	−625.5	131.0
$Pb(NO_3)_2(aq)$	−421.3	−246.9	303.3
$Pb(NO_3)_2(s)$	−451.9	—	—
$PbO(s)$	−217.3	−187.9	68.70
Lithium			
$Li(g)$	159.3	126.6	138.8
$Li(s)$	0	0	29.09
$Li^+(aq)$	−278.5	−273.4	12.2
$Li^+(g)$	685.7	648.5	133.0
$LiCl(s)$	−408.3	−384.0	59.30
Magnesium			
$Mg(g)$	147.1	112.5	148.6
$Mg(s)$	0	0	32.51
$MgCl_2(s)$	−641.6	−592.1	89.6
$MgO(s)$	−601.8	−569.6	26.8
$Mg(OH)_2(s)$	−924.7	−833.7	63.24
Manganese			
$Mn(g)$	280.7	238.5	173.6
$Mn(s)$	0	0	32.0
$MnO(s)$	−385.2	−362.9	59.7
$MnO_2(s)$	−519.6	−464.8	53.14
$MnO_4^-(aq)$	−541.4	−447.2	191.2
Mercury			
$Hg(g)$	60.83	31.76	174.89
$Hg(l)$	0	0	77.40
$HgCl_2(s)$	−230.1	−184.0	144.5
$Hg_2Cl_2(s)$	−264.9	−210.5	192.5
Nickel			
$Ni(g)$	429.7	384.5	182.1
$Ni(s)$	0	0	29.9
$NiCl_2(s)$	−305.3	−259.0	97.65
$NiO(s)$	−239.7	−211.7	37.99
Nitrogen			
$N(g)$	472.7	455.5	153.3
$N_2(g)$	0	0	191.50
$NH_3(aq)$	−80.29	−26.50	111.3
$NH_3(g)$	−46.19	−16.66	192.5
$NH_4^+(aq)$	−132.5	−79.31	113.4
$N_2H_4(g)$	95.40	159.4	238.5
$NH_4CN(s)$	0.0	—	—
$NH_4Cl(s)$	−314.4	−203.0	94.6
$NH_4NO_3(s)$	−365.6	−184.0	151
$NO(g)$	90.37	86.71	210.62
$NO_2(g)$	33.84	51.84	240.45
$N_2O(g)$	81.6	103.59	220.0
$N_2O_4(g)$	9.66	98.28	304.3
$NOCl(g)$	52.6	66.3	264
$HNO_3(aq)$	−206.6	−110.5	146
$HNO_3(g)$	−134.3	−73.94	266.4
Oxygen			
$O(g)$	247.5	230.1	161.0
$O_2(g)$	0	0	205.0
$O_3(g)$	142.3	163.4	237.6
$OH^-(aq)$	−230.0	−157.3	−10.7
$H_2O(g)$	−241.82	−228.57	188.83
$H_2O(l)$	−285.83	−237.13	69.91
$H_2O_2(g)$	−136.10	−105.48	232.9
$H_2O_2(l)$	−187.8	−120.4	109.6
Phosphorus			
$P(g)$	316.4	280.0	163.2
$P_2(g)$	144.3	103.7	218.1

Substance	ΔH_f° (kJ/mol)	ΔG_f° (kJ/mol)	S° (J/mol·K)
$P_4(g)$	58.9	24.4	280
$P_4(s, \text{red})$	−17.46	−12.03	22.85
$P_4(s, \text{white})$	0	0	41.08
$PCl_3(g)$	−288.07	−269.6	311.7
$PCl_3(l)$	−319.6	−272.4	217
$PF_5(g)$	−1594.4	−1520.7	300.8
$PH_3(g)$	5.4	13.4	210.2
$P_4O_6(s)$	−1640.1	—	—
$P_4O_{10}(s)$	−2940.1	−2675.2	228.9
$POCl_3(g)$	−542.2	−502.5	325
$POCl_3(l)$	−597.0	−520.9	222
$H_3PO_4(aq)$	−1288.3	−1142.6	158.2
Potassium			
$K(g)$	89.99	61.17	160.2
$K(s)$	0	0	64.67
$KCl(s)$	−435.9	−408.3	82.7
$KClO_3(s)$	−391.2	−289.9	143.0
$KClO_3(aq)$	−349.5	−284.9	265.7
$K_2CO_3(s)$	−1150.18	−1064.58	155.44
$KNO_3(s)$	−492.70	−393.13	132.9
$K_2O(s)$	−363.2	−322.1	94.14
$KO_2(s)$	−284.5	−240.6	122.5
$K_2O_2(s)$	−495.8	−429.8	113.0
$KOH(s)$	−424.7	−378.9	78.91
$KOH(aq)$	−482.4	−440.5	91.6
Rubidium			
$Rb(g)$	85.8	55.8	170.0
$Rb(s)$	0	0	76.78
$RbCl(s)$	−430.5	−412.0	92
$RbClO_3(s)$	−392.4	−292.0	152
Scandium			
$Sc(g)$	377.8	336.1	174.7
$Sc(s)$	0	0	34.6
Selenium			
$H_2Se(g)$	29.7	15.9	219.0
Silicon			
$Si(g)$	368.2	323.9	167.8
$Si(s)$	0	0	18.7
$SiC(s)$	−73.22	−70.85	16.61
$SiCl_4(l)$	−640.1	−572.8	239.3
$SiO_2(s, \text{quartz})$	−910.9	−856.5	41.84
Silver			
$Ag(s)$	0	0	42.55
$Ag^+(aq)$	105.90	77.11	73.93
$AgCl(s)$	−127.0	−109.70	96.11
$Ag_2O(s)$	−31.05	−11.20	121.3
$AgNO_3(s)$	−124.4	−33.41	140.9
Sodium			
$Na(g)$	107.7	77.3	153.7
$Na(s)$	0	0	51.45
$Na^+(aq)$	−240.1	−261.9	59.0
$Na^+(g)$	609.3	574.3	148.0
$NaBr(aq)$	−360.6	−364.7	141.00
$NaBr(s)$	−361.4	−349.3	86.82
$Na_2CO_3(s)$	−1130.9	−1047.7	136.0
$NaCl(aq)$	−407.1	−393.0	115.5
$NaCl(g)$	−181.4	−201.3	229.8
$NaCl(s)$	−410.9	−384.0	72.33
$NaHCO_3(s)$	−947.7	−851.8	102.1
$NaNO_3(aq)$	−446.2	−372.4	207
$NaNO_3(s)$	−467.9	−367.0	116.5
$NaOH(aq)$	−469.6	−419.2	49.8
$NaOH(s)$	−425.6	−379.5	64.46
$Na_2SO_4(s)$	−1387.1	−1270.2	149.6
Strontium			
$SrO(s)$	−592.0	−561.9	54.9
$Sr(g)$	164.4	110.0	164.6
Sulfur			
$S(s, \text{rhombic})$	0	0	31.88
$S_8(g)$	102.3	49.7	430.9
$SO_2(g)$	−296.9	−300.4	248.5
$SO_3(g)$	−395.2	−370.4	256.2
$SO_4^{2-}(aq)$	−909.3	−744.5	20.1
$SOCl_2(l)$	−245.6	—	—
$H_2S(g)$	−20.17	−33.01	205.6
$H_2SO_4(aq)$	−909.3	−744.5	20.1
$H_2SO_4(l)$	−814.0	−689.9	156.1
Titanium			
$Ti(g)$	468	422	180.3
$Ti(s)$	0	0	30.76
$TiCl_4(g)$	−763.2	−726.8	354.9
$TiCl_4(l)$	−804.2	−728.1	221.9
$TiO_2(s)$	−944.7	−889.4	50.29
Vanadium			
$V(g)$	514.2	453.1	182.2
$V(s)$	0	0	28.9
Zinc			
$Zn(g)$	130.7	95.2	160.9
$Zn(s)$	0	0	41.63
$ZnCl_2(s)$	−415.1	−369.4	111.5
$ZnO(s)$	−348.0	−318.2	43.9