The Mathematics of Formulas and Equations

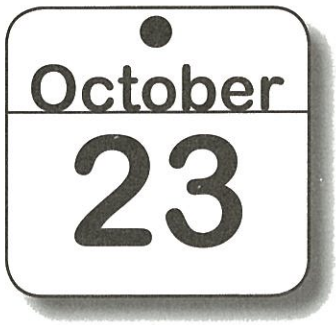
TOPIC 3

How Scientists Use Math to Solve Problems

Why do you think chemists celebrate Mole Day on October 23?

Every October 23, chemists celebrate Mole Day! Avogadro's Number or 6.02×10^{23}, is the number of particles in a mole. Look at the "molely" math problem below.

$$\begin{array}{r} 72 \text{ g carbon} \\ 12 \text{ g hydrogen} \\ + \ 96 \text{ g oxygen} \\ \hline 6.02 \times 10^{23} \text{ molecules of glucose} \end{array}$$



How many molecules of glucose is this?

If each molecule were one kilogram, they would equal over 20 times the mass of Earth! Calculate how many years it would take to count 1 mole of glucose atoms at the rate of 1 molecule per second. Hint: there are about 31.5 million seconds (3.15×10^7) in a year.

TOPIC 3

The Mathematics of Formulas and Equations

Vocabulary

formula mass	mole
gram formula mass	percentage composition

Topic Overview

Math is the language of chemistry. It enables us to easily determine the amount of a chemical needed for a reaction or the amount that will be produced. In this topic you will learn how to apply simple math relations to the solving of chemical problems.

SAMPLE PROBLEM

What is the formula mass of K_2CO_3?

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
formula = K_2CO_3	formula mass = ? amu
atomic masses from the periodic table	

1. Determine the number of atoms of each element from the formula.

Element:	Number of atoms:
K	2
C	1
O	3

2. Consult the table of the elements for the atomic mass of each element, and multiply it by the number of atoms to determine the total mass for each element.

For K: 2 atoms × 39.1 amu/atom = 78.2 amu
For C: 1 atom × 12.0 amu/atom = 12.0 amu
For O: 3 atoms × 16.0 amu/atom = 48.0 amu

3. Add the total mass for each element to determine the formula mass.

	78.2 amu
	12.0 amu
	+ 48.0 amu
Formula mass	138.2 amu

The Mathematics of Formulas

Recall that the mass of an atom is a relative value based on the mass of a carbon-12 atom. All atoms are compared to this standard. Thus, a magnesium atom with an atomic mass of 24 amu is twice as massive as the standard carbon atom with an atomic mass of 12. This relationship will remain the same in any system of weights or masses. As long as there is a mass ratio of 12 parts of carbon to 24 parts of magnesium, equal numbers of carbon and magnesium atoms are present. Twelve grams of carbon contain the same number of atoms as 24 grams of magnesium. These mass relationships of atoms are the basis for mass relationships in compounds.

Formula Mass

Remember that compounds are represented by formulas that show the type and number of atoms present in the compound. Because compounds are represented by formulas, the mass of the smallest unit of the compound is the **formula mass,** which is the sum of the atomic masses of all the atoms present. While the term *molecular mass* is often used to represent the mass of a unit of a compound, *formula mass* is preferred because ionic and network solids do not form discrete molecules. For example, sodium bromide (NaBr) is an ionic compound. No molecules of NaBr exist, so *molecular mass* does not apply to NaBr. However, formula mass can be calculated for a formula unit

of the compound. The formula mass of NaBr is the mass of one atom of Na plus the mass of one atom of Br in amu.

Gram Formula Mass The **gram formula mass** of a substance is simply the formula mass expressed in grams instead of atomic mass units. Thus, the gram formula mass of K_2CO_3 is 138.2 g. Some substances, such as sucrose (table sugar), form molecules. It is common to express the gram formula masses of molecular substances as gram molecular masses.

Review Questions — Set 3.1

1. What is the gram formula mass of $Ca(OH)_2$?
(1) 29 g (3) 56 g
(2) 34 g (4) 74 g

2. Which substance has the greatest molecular mass?
(1) H_2O_2 (3) CF_4
(2) NO (4) I_2

3. What is the gram formula mass of $C_3H_5(OH)_3$?
(1) 48 g (3) 74 g
(2) 58 g (4) 92 g

4. What is the gram formula mass of Na_2CO_3?
(1) 51 g (3) 106 g
(2) 74 g (4) 138 g

5. What is the gram formula mass of $(NH_4)_3PO_4$?
(1) 113 g (3) 149 g
(2) 121 g (4) 404 g

6. What is the gram formula mass of calcium nitrate $Ca(NO_3)_2$?
(1) 70.0 g (3) 150 g
(2) 102 g (4) 164 g

7. What is the gram formula mass of Li_2SO_4?
(1) 54 g (3) 110 g
(2) 55 g (4) 206 g

8. What is the gram formula mass of $Mg(ClO_3)_2$?
(1) 107 g (3) 174 g
(2) 142 g (4) 191 g

9. What is the gram molecular mass of the compound with the formula CH_3COOH?
(1) 22.4 g (2) 44.0 g (3) 48.0 g (4) 60.0 g

10. Determine the formula mass and the gram formula mass of each of the following compounds.
(a) $NaHCO_3$ (f) $Mg(NO_3)_2$
(b) $MgCl_2$ (g) $Al_2(SO_4)_3$
(c) NH_4Cl (h) $(NH_4)_2SO_4$
(d) $FeCl_3$ (i) $C_5H_{10}(OH)_2$
(e) Al_2O_3 (j) $C_{12}H_{22}O_{11}$

For each of the following, compute the answer, showing your work.

11. What is the formula mass of $Al(OH)_3$?

12. What is the formula mass of $C_6H_{12}O_6$?

13. What is the formula mass of $MgBr_2 \cdot 6H_2O$?

Percentage Composition

Formulas represent the composition of a substance. Using the subscripts and atomic masses of the elements, the percent by mass of a substance can be calculated. The **percentage composition** of a substance represents the composition as a percentage of each element compared with the total mass of the compound.

Hydrates Ionic substances often include definite amounts of water as part of the crystal structure. The water molecules are shown as part of the formula, such as $CuSO_4 \cdot 5H_2O$. Crystals that contain attached water molecules are called hydrates, while substances without water are termed anhydrous. If it is necessary to calculate the percentage of water in such a crystal, treat the water molecule as a single unit.

SAMPLE PROBLEM

What is the percentage of oxygen in potassium chlorate ($KClO_3$)?

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
formula = $KClO_3$	%O = ? %
atomic masses from the periodic table	

1. Determine the formula mass of potassium chlorate.

For K: 1 atom × 39.1 amu/atom = 39.1 amu
For Cl: 1 atom × 35.5 amu/atom = 35.5 amu
For O: 3 atoms × 16.0 amu/atom = 48.0 amu
Formula mass = 122.6 amu

2. Calculate the percent of oxygen in the compound by dividing the mass of oxygen by the formula mass and multiplying by 100%.

$$\%O = \frac{48.0\ \cancel{amu}}{122.6\ \cancel{amu}} \times 100\%$$

$$\%O = 39.2\%$$

SAMPLE PROBLEM

What is the percentage, by mass, of water in sodium carbonate crystals, $Na_2CO_3 \cdot 10H_2O$?

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
formula = $Na_2CO_3 \cdot 10H_2O$	$\%H_2O$ = ? %
atomic masses from the periodic table	

1. Determine the formula mass of the crystal. (Hint: Treat the water as a unit.)

For Na: 2 atoms × 23.0 amu/atom = 46.0 amu
For C: 1 atom × 12.0 amu/atom = 12.0 amu
For O: 3 atoms × 16.0 amu/atom = 48.0 amu
For H_2O: 10 units × 18.0 amu/unit = 180.0 amu
Formula mass = 286.0 amu

2. Calculate the percent of water in the compound by dividing the mass of water by the formula mass and multiplying by 100%.

$$\%H_2O = \frac{180.0\ \cancel{amu}}{286.6\ \cancel{amu}} \times 100\%$$

$$\%H_2O = 62.9\%$$

Review Questions — Set 3.2

14. The percent by mass of nitrogen in NH_4NO_3 is closest to

(1) 15% (3) 35%
(2) 20% (4) 60%

15. What is the percent by mass of carbon in CO_2?

(1) 12% (3) 44%
(2) 27% (4) 73%

16. What is the percent by mass of water present in $CaSO_4 \cdot 2H_2O$?

(1) 10.% (3) 21%
(2) 12% (4) 79%

17. What is the percent by mass of oxygen in magnesium oxide (MgO)?

(1) 20% (3) 50%
(2) 40% (4) 60%

18. The percent by mass of oxygen in $H_2C_2O_4$ is equal to

(1) $\frac{90 \text{ amu}}{64 \text{ amu}} \times 100\%$ (3) $\frac{8 \text{ amu}}{4 \text{ amu}} \times 100\%$

(2) $\frac{64 \text{ amu}}{90 \text{ amu}} \times 100\%$ (4) $\frac{4 \text{ amu}}{8 \text{ amu}} \times 100\%$

19. What is the percent by mass of oxygen in Fe_2O_3? The formula mass of Fe_2O_3 = 160 amu.

(1) 16% (2) 30.% (3) 56% (4) 70.%

20. What is the percent by mass of sulfur in sulfur dioxide?

(1) 32 % (2) 33% (3) 50.% (4) 67%

21. The percent by mass of Ca in $CaCl_2$ is equal to

(1) $\frac{40 \text{ amu}}{111 \text{ amu}} \times 100\%$ (3) $\frac{3 \text{ amu}}{1 \text{ amu}} \times 100\%$

(2) $\frac{111 \text{ amu}}{40 \text{ amu}} \times 100\%$ (4) $\frac{1 \text{ amu}}{3 \text{ amu}} \times 100\%$

22. Which species contains the greatest percent by mass of hydrogen?

(1) OH^- (2) H_2O (3) H_3O^+ (4) H_2O_2

23. The percent by mass of water in $BaCl_2 \cdot 2H_2O$ (formula mass = 243 amu) is equal to

(1) $\frac{18 \text{ amu}}{243 \text{ amu}} \times 100\%$ (3) $\frac{243 \text{ amu}}{18 \text{ amu}} \times 100\%$

(2) $\frac{36 \text{ amu}}{243 \text{ amu}} \times 100\%$ (4) $\frac{243 \text{ amu}}{36 \text{ amu}} \times 100\%$

Answer each of the following questions in complete sentences.

24. A crystalline material containing 30.0 g of barium chloride crystals was placed into an oven at 400°C and heated for two hours. It was then cooled and weighed. The new mass was less than before it was heated, containing 20.0 g of barium chloride. How is this possible?

25. Copper(II) sulfate is a hydrated crystal with the formula $CuSO_4 \cdot 5H_2O$ and a deep blue color. When it is heated the crystals crumble and turn white.

(a) Propose an explanation for this change of color.

(b) What would you do to restore the blue color?

26. A chemist needs to order $Na_2B_4O_7$. One supplier offers it in an anhydrous (without water) form, while another offers it as a hydrated crystal, $Na_2B_4O_7 \cdot 10H_2O$. If the prices from the two suppliers are the same for a 500.0-g bottle, which one would supply more of the desired $Na_2B_4O_7$? Explain your answer.

The Mole

We are quite familiar with collective nouns in our everyday life. *Dozen* is a convenient word to describe 12 of something. A gross of paper contains 144 sheets, while a ream contains 500. These units enable you to count by collective units of items instead of by individual items.

Chemists use a specific collective noun to define a particularly usable number of particles. A **mole** is defined as the number of atoms of carbon present in 12.000 grams of C-12. The number of particles in a mole of a substance is 6.022×10^{23}, which is called Avogadro's number. While it would be impossible to individually count a mole of particles, the mass of one mole of a substance can be found by determining its gram formula mass. This quantity contains 6.02×10^{23} particles of that substance. Therefore, the gram formula mass of any substance is the mass of one mole of that substance. The accepted abbreviation for mole is mol.

Converting Grams to Moles To convert grams to moles:

$$\text{moles} = \text{number of grams} \times \frac{1 \text{ mol}}{\text{gram formula mass}}$$

Converting Moles to Grams To convert moles to grams:

$$\text{grams} = \text{number of moles} \times \frac{\text{gram formula mass}}{1 \text{ mol}}$$

SAMPLE PROBLEM

How many grams are present in 40.5 mol of sulfuric acid (H_2SO_4)?

SOLUTION: Identify the known and unknown values.

Known
moles H_2SO_4 = 40.5 mol

Unknown
mass H_2SO_4 = ? g

1. Calculate the formula mass of sulfuric acid.

For H: 2 atoms × 1.0 amu/atom = 2.0 amu
For S: 1 atom × 32.1 amu/atom = 32.1 amu
For O: 4 atoms × 16.0 amu/atom = 64.0 amu
Formula mass H_2SO_4 = 98.1 amu

2. Calculate the gram formula mass of sulfuric acid.

gram formula mass = formula mass in grams
gram formula mass of H_2SO_4 = 98.1 g

3. Use the gram formula mass to convert the given number of moles to grams.

$$\text{number of grams} = \text{moles} \times \frac{\text{gram formula mass}}{1 \text{ mol}}$$

$$\text{grams } H_2SO_4 = 40.5 \cancel{\text{mol}} \times \frac{98.1 \text{ g}}{1 \cancel{\text{mol}}}$$

grams H_2SO_4 = 3970 g

SAMPLE PROBLEM

How many moles are equivalent to 4.75 g of sodium hydroxide (NaOH)?

SOLUTION: Identify the known and unknown values.

Known
mass NaOH = 4.75 g

Unknown
moles NaOH = ? mol

1. Calculate the formula mass of sodium hydroxide.

For Na: 1 atom × 23.0 amu/atom = 23.0 amu
For O: 1 atom × 16.0 amu/atom = 16.0 amu
For H: 1 atom × 1.0 amu/atom = 1.0 amu
Formula mass NaOH = 40.0 amu

2. Calculate the gram formula mass of sodium hydroxide.

gram formula mass = formula mass in grams
gram formula mass of NaOH = 40.0 g

3. Use the gram formula mass to convert the given mass to moles.

$$\text{moles} = \text{number of grams} \times \frac{1 \text{ mol}}{\text{gram formula mass}}$$

$$\text{moles NaOH} = 4.74 \cancel{\text{g}} \times \frac{1 \text{ mol}}{40.0 \cancel{\text{g}}}$$

moles NaOH = 0.119 mol

Review Questions

Set 3.3

27. Which quantity is equivalent to 39 g of LiF?
(1) 0.50 mol (3) 1.5 mol
(2) 1.0 mol (4) 2.0 mol

28. What is the total mass of 0.75 mol of SO_2?
(1) 16 g (2) 24 g (3) 32 g (4) 48 g

29. The mass in grams of 2 mol of H_2SO_4 is
(1) $\frac{98 \text{ g}}{2}$ (3) $\frac{196 \text{ g}}{2}$
(2) 2(98 g) (4) 2(196 g)

30. The mass of 1 mol of $NaNO_3$ is
(1) 42 g (2) 53 g (3) 85 g (4) 116 g

31. The mass of a mole of nitrogen gas is
(1) 7 g (2) 14 g (3) 28 g (4) 56 g

32. What is the number of moles of potassium chloride (gram formula mass = 74 g) present in 148 g of KCl?
(1) 2.0 mol (3) 3.0 mol
(2) 2.5 mol (4) 3.5 mol

33. How many moles are in 168 g of KOH? (gram formula mass = 56 g)

(1) 0.3 mol (3) 1.0 mol
(2) 0.5 mol (4) 3.0 mol

34. How many moles of oxygen atoms are in one mole of $Mg_3(PO_4)_2$?

(1) 1 (2) 4 (3) 6 (4) 8

35. What is the mass of 4.5 mol of KOH?

(1) 0.080 g (3) 56 g
(2) 36 g (4) 252 g

36. What is the mass of 0.50 mol of $CuSO_4 \cdot 5H_2O$?

(1) 47.8 g (3) 125 g
(2) 95.6 g (4) 250 g

Finding Molecular Formulas from Empirical Formulas

When the molecular mass of a compound and its empirical formula are known, it is possible to determine the correct molecular formula. For example, the molecular mass of propene is 42 amu. The empirical formula of propene is CH_2, and the molecular mass of CH_2 is 14 amu. Divide the mass of the compound by the mass of the empirical formula. The result will be an integer. In this case it is 3. This tells you that the molecular formula is three times the empirical formula. Simply multiply each subscript by three to find the molecular formula, C_3H_6.

Memory Jogger

Recall the difference between an empirical formula and a molecular formula. The empirical formula shows the simplest integer ratio of elements in a compound. C_3H_6 is the molecular formula of a substance named propene. Its empirical formula is CH_2.

SAMPLE PROBLEM

A compound has a molecular mass of 180 amu and an empirical formula of CH_2O. What is its molecular formula?

SOLUTION: Identify the known and unknown values.

Known	*Unknown*
molecular mass = 180 amu	molecular
empirical formula = CH_2O	formula = ?

1. Determine the molecular mass of CH_2O:

For C: 1 atom × 12.0 amu/atom = 12.0 amu
For H: 2 atoms × 1.0 amu/atom = 2.0 amu
For O: 1 atom × 16.0 amu/atom = 16.0 amu
Molecular mass of CH_2O = 30.0 amu

2. Divide the molecular mass of the compound by the mass of the empirical formula.

$$\frac{180 \text{ amu}}{30 \text{ amu}} = 6$$

3. Multiply the subscripts in the empirical formula by 6.

$$C_{1\times6}H_{2\times6}O_{1\times6} = C_6H_{12}O_6$$

The molecular formula of the compound is $C_6H_{12}O_6$.

Review Questions — Set 3.4

37. The empirical formula of a compound is CH_4. The molecular formula of the compound could be

(1) CH_4 (2) C_2H_6 (3) C_3H_8 (4) C_4H_{10}

38. A compound with an empirical formula of CH_2 has a molecular mass of 70 amu. What is its molecular formula?

(1) CH_2 (2) C_2H_4 (3) C_4H_8 (4) C_5H_{10}

39. A compound has an empirical formula of CH and a molecular mass of 78 amu. What is the molecular formula of the compound?

(1) C_2H_2 (2) C_3H_3 (3) C_4H_4 (4) C_6H_6

40. A compound has an empirical formula of CH_2 and a molecular mass of 28 amu. What is its molecular formula?

41. A compound has an empirical formula of CH_2 and a molecular mass of 56 amu. What is its molecular formula?

42. Vitamin C has an empirical formula of $C_3H_4O_3$ and a molecular mass of 176 amu. What is its molecular formula?

43. A compound has a molecular mass of 30 amu and an empirical formula of CH_3. What is its molecular formula?

44. Why can't a substance have an empirical formula of NO and a gram-formula mass of 45 g?

Mole Relations in Balanced Equations

Chemical equations include both qualitative and quantitative information about the reaction. The formulas of the compounds give qualitative information about the nature of the reactants and products, along with some quantitative information. The coefficients represent quantitative information that relates specifically to that reaction.

Balanced chemical equation:

$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

Moles C_2H_6	Moles O_2	Moles CO_2	Moles H_2O
2	7	4	6
4	14	8	12
1	3.5	2	3

Figure 3-1. Mole ratios from a balanced equation: Regardless of the number of moles of any of the reactants or products, the ratio must remain 2:7:4:6 for this reaction.

In problems involving chemical reactions, the relative amounts of reactants and products are represented by the coefficients. Coefficients represent both the basic unit and mole ratios in balanced equations.

Consider the equation for the combustion of ethane, C_2H_6, as shown in Figure 3-1. The coefficients tell you that 2 mol of ethane combines with 7 mol of oxygen to produce 4 mol of carbon dioxide and 6 mol of water. These ratios will remain constant for any amounts of the substances involved, as shown in the figure.

Volume Relationships of Gases in Balanced Equations

Not only do coefficients represent mole ratios in balance equations, they also represent volume relations of gases. Using the same equation in the previous sample problem, we can solve for unknown quantities of gases.

SAMPLE PROBLEM

How many liters of carbon dioxide gas will be produced from the complete combustion of 30.0 liters of ethane according to the following equation?

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$$

SOLUTION: Identify the known and unknown values.

Known
Volume of $C_2H_6(g)$ = 30.0 L
Ratio of $C_2H_6(g)$: CO_2 = 2:4

Unknown
Vol of $CO_2(g)$ = ? liters

Set up proportion and solve:

$$\frac{30.0\text{ L}}{2} = \frac{x}{4}$$

$$x = 60\text{ liters}$$

SAMPLE PROBLEM

How many moles of water will be produced from the complete combustion of 3.0 mol of ethane according to the following equation?

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(g)$$

SOLUTION: Identify the known and unknown values.

Known
moles C_2H_6 = 3.0 mol balanced equation

Unknown
moles water = ? mol

1. Use the balanced equation to determine the mole ratio between ethane and water.

moles ethane: moles water = 2:6

2. Set up a proportion between the known moles of ethane (3.0 mol) and the coefficient of ethane, and moles of water (x) and the coefficient of water

$$\frac{3.0 \text{ mol } C_2H_6}{2 \text{ mol } C_2H_6} = \frac{x}{6 \text{ mol } H_2O}$$

3. Solve for the number of moles of H_2O (x).

$$x = \frac{(3.0 \text{ mol } \cancel{C_2H_6})(6 \text{ mol } H_2O)}{2 \text{ mol } \cancel{C_2H_6}}$$

$$x = 9.0 \text{ mol } H_2O$$

Review Questions

Set 3.5

45. Given the reaction $4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$, what is the minimum number of moles of oxygen gas required to produce 1.00 mol of aluminum oxide?

(1) 1.0 mol (3) 3.0 mol
(2) 1.5 mol (4) 6.0 mol

46. Given the reaction $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$, what is the maximum number of moles of H_2O that can be produced when 2.0 mol of NH_3 are completely reacted?

(1) 1.0 mol (3) 3.0 mol
(2) 2.0 mol (4) 6.0 mol

47. Given the reaction $2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$, what is the total number of moles of $KClO_3$ needed to produce 6 mol of O_2?

(1) 1 mol (2) 2 mol (3) 3 mol (4) 4 mol

48. Given the reaction $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$, what amount of oxygen is needed to completely react with 1 mol of CH_4?

(1) 2 mol (3) 2 g
(2) 2 atoms (4) 2 molecules

49. Given the reaction $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$, what is the total number of moles of O_2 required to produce 40 mol of NO?

(1) 5 mol (2) 9 mol (3) 32 mol (4) 50 mol

50. Given the reaction $2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g)$, how many moles of $O_2(g)$ are needed to produce exactly 20. mol of $CO_2(g)$?

(1) 10. mol (3) 30. mol
(2) 20. mol (4) 40. mol

51. Given the reaction $4Na + O_2 \rightarrow 2Na_2O$, how many moles of oxygen are completely consumed in the production of 1.00 mol of Na_2O?

(1) 0.50 mol (3) 2 mol
(2) 1 mol (4) 4.0 mol

52. Given the reaction $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$, what is the total number of moles of Ca needed to react completely with 4.0 mol of H_2O?

(1) 0.50 mol (3) 2.0 mol
(2) 1.0 mol (4) 4.0 mol

53. Consider the following equation.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

How many moles of oxygen are needed for the complete combustion of 3.0 mol of $CH_4(g)$?

(1) 2.0 mol
(2) 3.0 mol
(3) 4.0 mol
(4) 6.0 mol

54. According to the reaction $2Al + 3H_2SO_4 \rightarrow 3H_2 + Al_2(SO_4)_3$, the total number of moles of H_2SO_4 needed to react completely with 5.0 mol of Al is

(1) 2.5 mol (3) 7.5 mol
(2) 5.0 mol (4) 9.0 mol

55. Given the equation $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$, what is the total number of moles of NH_3 produced when 10. mol of H_2 reacts completely with N_2?

(1) 2.0 mol (3) 6.7 mol
(2) 3.0 mol (4) 15 mol

56. According to the equation $2K(s) + Cl_2(g) \rightarrow 2KCl(s)$, potassium reacts with chlorine to form potassium chloride. If 100 atoms of potassium react with chlorine gas, how many chlorine molecules will be needed to completely react?

57. What do coefficients represent in a balanced equation?

58. A student is given the equation $N_2 + H_2 \rightarrow NH_3$ to balance. She answers with $N_2 + 2H_2 \rightarrow 2NH_2$. Explain why her answer is not correct. Balance the equation correctly.

59. Consider the equation $H_2 + Cl_2 \rightarrow 2HCl$. A student suggests that according to the ratio shown by the coefficients, 20 g of hydrogen will react with 20 g of chlorine to form 40 g of HCl. Is the student correct? Explain.

60. The process of photosynthesis can be represented by the following equation.
$6CO_2(g) + 6H_2O(\ell) + \text{energy} \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$
If 4 mol of $C_6H_{12}O_6$ is produced by the process, how many moles of $CO_2(g)$ and $H_2O(\ell)$ were used?

61. How many molecules of water are needed to produce 6 molecules of $C_6H_{12}O_6$ according to the equation in the previous question?

62. How many moles of oxygen gas are produced when 6 mol of CO_2 are consumed in the process of photosynthesis? (See problem 59 for the equation.)

63. Hydrogen gas and chlorine gas react to form hydrogen chloride.

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

If 2 mol of hydrogen gas are mixed with 4 mol of chlorine gas, how many moles of hydrogen chloride will be produced?

64. In the previous question, one of the reactants will not be completely used up. Which one will not be completely used, and how many moles will not react?

65. Make a drawing of 6 molecules of hydrogen gas (H_2) in a container. Using a different symbol, add the correct number of nitrogen gas (N_2) molecules to form ammonia according to the following equation.

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3$$

In a second drawing, show the number and composition of ammonia molecules in the container after the reaction has been completed.

66. In the reaction $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g)$ and $6H_2O(g)$, what volume of oxygen is required if 20 liters of NH_3 is consumed?

(1) 5 liters
(2) 25 liters
(3) 47 liters
(4) 125 liters

67. Given the balanced equation:

$C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H_2O(g)$

How many liters of CO_2 are produced when 15 liters of O_2 are consumed?

(1) 10 (2) 15 (3) 30 (4) 45

68. Given the reaction: $H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

What is the total volume of $H_2(g)$ consumed when 22.4 liters of $Cl_2(g)$ completely reacts?

(1) 11.2 L (2) 22.4 L (3) 44.8 L (4) 89.6 L

69. Given the reaction:
$2C_8H_{18}(g) + 25\ O_2(g) \rightarrow 16CO_2(g) + 18\ H_2O(g)$
What is the total number of liters of oxygen required for the complete combustion of 4.00 liters of C_8H_{18}?

(1) 25.0 (2) 50.0 (3) 100. (4) 200.

70. Given the reaction:
$C_3H_8(g) + 5O_2(g) \rightarrow 4H_2O(g) + 3CO_2(g)$
What is the total number of liters of $CO_2(g)$ produced when 150. liters of $O_2(g)$ reacts with C_3H_8?

(1) 90. (2) 150. (3) 3.0 (4) 250.

71. Given the reaction:

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$$

What is the total number of liters of $SO_3(g)$ produced when 32.0 liters of $SO_2(g)$ reacts completely?

(1) 11.2 L
(2) 32.0 L
(3) 40.0 L
(4) 44.8 L

Practice Questions for the New York Regents Exam

TOPIC 3

Directions

Review the Test-Taking Strategies section of this book. Then answer the following questions. Read each question carefully and answer with a correct choice or response.

Part A

1 The term *mole* is a unit used to represent
(1) density of particles (3) numbers of particles
(2) kinds of particles (4) reactivity of particles

2 One mole of carbon and one mole of neon both have the same
(1) mass (3) number of particles
(2) volume (4) number of protons

3 The mass of a mole of a substance is equal to
(1) the atomic number in grams
(2) the mass of the most common isotope in grams
(3) the gram formula mass
(4) the mass of 22.4 L of any substance

4 A hydrated crystal is one in which
(1) water molecules are part of the crystal
(2) water molecules have been removed
(3) hydrogen molecules are part of the crystal
(4) hydrogen molecules have been removed

5 To find the percent of an element in a compound
(1) divide the atomic mass of the element by its atomic number × 100%
(2) divide the total mass of an element by the total mass of the compound × 100%
(3) multiply the atomic mass of the element by the total mass of the compound × 100%
(4) multiply the atomic mass of the elements by their subscripts × 100%

6 In a balanced equation, coefficients always represent
(1) the number of atoms present
(2) the ratio of volumes of substances
(3) the mole ratios of reactants and products
(4) the volume ratios of reactants and products

Part B–1

7 What is the gram atomic mass of zinc?
(1) 1.33 g (2) 30. g (3) 65 g (4) 130. g

8 The mass of a mole of $O_2(g)$ is
(1) 8.0 g (2) 16.0 g (3) 24.0 g (4) 32.0 g

9 If the mass of a mole of H_2X is 34 g, then X must represent
(1) O (2) Cl (3) Kr (4) S

10 The mass of a mole of $Ca(OH)_2$ is
(1) 38 g (2) 57 g (3) 58 g (4) 74 g

11 The mass of 4 moles of CO_2 is
(1) 22 g (2) 44 g (3) 88 g (4) 176 g

12 What is the total number of moles in 80.0 grams of C_2H_5Cl (gram-formula mass = 64.5 grams/mole)?
(1) 0.806 (2) 1.24 (3) 2.48 (4) 5.16

13 Consider the following equation.

$$2C_2H_6 + O_2 \rightarrow 4CO_2 + 6H_2O$$

When 4 mol of C_2H_6 are burned the number of moles of CO_2 produced will be
(1) 2 mol (2) 6 mol (3) 7 mol (4) 8 mol

14 Given the equation $Mg + 2HCl \rightarrow MgCl_2 + H_2$, how many moles of hydrogen chloride are needed to react with 0.50 mol of magnesium?
(1) 0.5 mol (3) 2.0 mol
(2) 1.0 mol (4) 4.0 mol

15 Given the balanced equation representing a reaction:
$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

What is the mole ratio of $CO(g)$ to $CO_2(g)$ in this reaction?
(1) 1:1 (2) 1:2 (3) 2:1 (4) 3:2

Parts B–2 and C

Base your answers to questions 16 and 17 on the following information.

Glycine, NH_2CH_2COOH, is an organic compound found in proteins. Acetamide, CH_3CONH_2, is an organic compound that is an excellent solvent. Both glycine and acetamide consist of the same four elements, but the compounds have a different molecular structure.

16 Calculate the gram-formula mass of glycine. Your response must include *both* a numerical setup and the calculated result.

17 Determine the percent composition by mass of the element carbon in the acetamide compound.

Base your answers to questions 18 through 20 on the following information.

The burning of propane gas can be represented as a balanced chemical reaction as follows:

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

18 Determine the gram-formula mass of the propane gas.

19 State the mole ratio represented in the equation of oxygen to carbon dioxide.

20 Calculate the number of liters of water vapor produced when 25.0 liters of oxygen gas are consumed.

Base your answers on questions 21 through 23 on the following information.

A student places a 2.50 gram sample of magnesium metal in a bottle and adds hydrochloric acid. The acid reacts with The magnesium to produce hydrogen gas and $MgCl_2$.

21 Balance the equation for this reaction of magnesium and hydrochloric acid, using the smallest whole-number coefficients.

$$\_\_\_\_Mg + \_\_\_\_HCl \rightarrow \_\_\_\_MgCl_2 + \_\_\_\_H_2$$

22 How many moles of magnesium were used in this reaction?

23 How many moles of hydrogen gas were produced if all of the magnesium reacted?

Base your answers to questions 24 through 26 on the following information.

Some dry chemicals can be used to put out forest fires. One of these chemicals is $NaHCO_3$. When $NaHCO_3(s)$ is heated, one of the products is $CO_2(g)$, as shown in the following equation:

$$NaHCO_3(s) + \text{heat} \rightarrow Na_2CO_3(s) + H_2O(l) + CO_2(g)$$

24 The equation can be correctly balanced by placing a coefficient of 2 in front of one of the formulas. Give the proper name of the compound that requires the coefficient of 2.

25 Using the properly balanced version of this equation, determine the number of moles of CO_2 produced from the complete reaction of 7.0 moles of the reactant.

26 Determine the mass (in grams) of 7.0 moles of the reactant compound.

Base your answers to questions 27 through 29 on the information below.

Vitamin C, also known as ascorbic acid, is water soluble and cannot be produced by the human body. Each day, a person's diet should include a source of vitamin C, such as orange juice. Ascorbic acid has a molecular formula of $C_6H_8O_6$ and a gram-formula mass of 176 grams per mole.

27 Determine the number of moles of vitamin C in an orange that contains 0.071 grams of vitamin C.

28 Show a proper numerical setup for calculating the percent composition by mass of oxygen in ascorbic acid.

29 Write the empirical formula for ascorbic acid.

Base your answers to questions 30 and 31 on the information below.

One process used to manufacture sulfuric acid is called the contact process. One step in this process, the reaction between sulfur dioxide and oxygen, is represented by the forward reaction in the system at equilibrium shown below.

$$2SO_2(g) + O_2(g) \rightleftarrows 2SO_3(g) + 394\ kJ$$

30 Determine the number of moles of sulfur trioxide produced when 3.5 moles of oxygen gas is consumed in the reaction.

31 If 192 grams of sulfur dioxide are reacted completely, determine both the number of moles of sulfur dioxide reacted (the formula mass for sulfur dioxide is 64 g/mol), and the number of moles of sulfur trioxide produced.