Learning Objectives:

The student should be able to:
1. Write all the mole ratios for a balanced equation.

2. Find the number of moles of one substance in an equation, given a number of moles of another substance (mole-mole type).

3. Find the number of grams of one substance in an equation, given a number of grams of another substance (gram-gram type).

4. Find the number of moles of one substance, given the grams of another substance; or find the grams, given the moles.

5. The types of problems which will be studied, require that the equation always be balanced. If necessary go back and practice balancing equations before going any further.

6. The principle that the coefficients of a balanced equation can be used to stand for moles is a very important part of the mole-ratio method of calculation.

7. The coefficient in the balanced equation tell us the relative number of moles of each substance; that is, there is a fixed relationship between the number of moles of all the substances in a balanced equation.
8. Thus for the balanced equation:
   \[ 2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO} \]

   the coefficients stand for:
   \[ 2 \text{ moles Mg} + 1 \text{ mole O}_2 \rightarrow 2 \text{ moles MgO} \]

9. The mole-ratio is a fraction that we can write based on the number of moles of any 2 compounds in an equation.

   The mole-ratio fraction is derived from the coefficients and formulas of the 2 compounds.

10. For example, we can write the following two mole-ratios given the equation:
    \[ 2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO} \]

    \[ \frac{2 \text{ moles Mg}}{1 \text{ mole O}_2} \quad \text{and} \quad \frac{1 \text{ mole O}_2}{2 \text{ moles Mg}} \]

11. All the possible mole-ratios that can be written for a particular equation are obtained by dividing each term in an equation one at a time by every other term.

12. Question

    Knowing the two mole-ratios already presented above, work out the 4 other mole-ratios for the equation: \( 2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO} \)

    Answer
    \[ \frac{2 \text{ mole Mg}}{2 \text{ mole MgO}} \quad \frac{2 \text{ mole MgO}}{1 \text{ mole O}_2} \]
    \[ 2 \text{ mole Mg} \quad 2 \text{ mole MgO} \quad 1 \text{ mole O}_2 \quad 2 \text{ mole MgO} \]

13. Question

    For the balanced equation: \( 2 \text{P} + 3 \text{I}_2 \rightarrow 2 \text{PI}_3 \) work out four mole-ratios which contain the product substance, \( \text{PI}_3 \).

    Answer
    \[ \frac{2 \text{ moles PI}_3}{2 \text{ moles P}} \quad \frac{2 \text{ moles PI}_3}{3 \text{ moles I}_2} \]
    \[ 2 \text{ moles P} \quad 2 \text{ moles PI}_3 \quad 3 \text{ moles I}_2 \quad 2 \text{ moles PI}_3 \]

14. A mole-ratio can be used as the fraction needed to make a conversion calculation from a given quantity of one substance in a balanced equation, to an unknown quantity of any other substance (in the equation).
15. In the mole-ratio, the number of moles of the same substance as in the given quantity is in the denominator- the number of moles of the substance which is the same as that of the unknown quantity is in the numerator.

1) Mole ratio = \( \frac{\text{no. moles unkn. subst. in eqn.}}{\text{no. moles givn. subst. in eqn.}} \)

2) Calculation of unknown quantity:
\[
\text{moles of unkn.} = \text{moles of givn.} \times \frac{\text{no. moles unkn. subst.}}{\text{no. moles givn. subst.}}
\]

16. Illustrative Problem
Use the mole-ratio method to find the number of moles of Cl\(_2\) which react with 0.2 mole Na according to the reaction:
\[
2 \text{ Na} + \text{ Cl}_2 \rightarrow 2 \text{ NaCl}
\]

Answer
First we derive the correct mole-ratio by reading the problem statement to determine the numerator (moles unkn. subst) and the denominator (moles givn. subst). The unknown substance is moles of Cl\(_2\) and the givn. substance is: moles Na

\[
\frac{\text{no. moles unkn.}}{\text{no. moles givn.}} = \frac{1 \text{ mole Cl}_2}{2 \text{ mole Na}}
\]

17. The conversion calculation is made by multiplying the given moles in the problem by the mole ratio:
\[
= 0.2 \text{ mole Na} \times \frac{1 \text{ mole Cl}_2}{2 \text{ mole Na}} = 0.1 \text{ mole Cl}_2
\]

18. The problem illustrated above is a type called mole-mole problem. In this type, both the given quantity and the unknown quantity have moles as units. All types of calculations based on balanced equations include the use of the mole-ratio.
19. **Problem**
Calculate the number of moles of oxygen which react with 0.30 mole of magnesium in the reaction: \(2 \text{ Mg} + \text{O}_2 \rightarrow 2 \text{ MgO}\)

**Answer**
The moles unknown is moles \(\text{O}_2\) and the moles of the given is moles \(\text{Mg}\).

The mole ratio = \(\frac{\text{no. moles unkn.}}{\text{no. moles givn.}} = \frac{1 \text{ mole } \text{O}_2}{2 \text{ mole } \text{Mg}}\)

the answer: \(= 0.30 \text{ mole } \text{Mg} \times \frac{1 \text{ mole } \text{O}_2}{2 \text{ mole } \text{Mg}} = 0.15 \text{ mole } \text{O}_2\)

20. **Review Questions**
1. What meaning can be given to the coefficients in a balanced equation?
2. What is the meaning of the term “mole-ratio”?
3. What is the meaning of the term “mole-mole problem”?

21. **Part II**
Another type problem (objective 3) involves taking a given number of grams of one substance in a balanced equation and converting this into a number of grams of a second substance. This is called a gram-gram type.

22. The gram-gram problem is solved by making 3 conversions – by use of 3 fractions.
The 3 changes are made in the order:

\[
\text{Grams} \rightarrow \text{Moles} \rightarrow \text{Moles} \rightarrow \text{Grams}
\]

\[
\text{givn. (1)} \rightarrow \text{givn. (2)} \rightarrow \text{unkn. (3)} \rightarrow \text{unkn.}
\]

23. The three fractions indicated by numbers under the arrows are:

\[
\begin{align*}
(1) & \quad \frac{1 \text{ mole}}{\text{g.f.w.givn.}} \\
(2) & \quad \text{Mole-Ratio based on eqn.} \\
(3) & \quad \frac{\text{g.f.w.unkn}}{1 \text{ mole}}
\end{align*}
\]

Fractions (1) and (3) are based on the relationship:

\(1 \text{ mole} = \text{gram-formula wt. (g.f.w)}\)
24. **Illustrative Problem**  
Calculate the number of grams of O₂ which react with 12.2 g Mg.

\[ 2 \text{ Mg} + \text{O}_2 \rightarrow 2 \text{ MgO} \]

**Answer**  
This is a gram-gram problem and requires 3 conversions (or steps)

**Step 1.** change 12.2 g Mg into moles Mg:

\[
\frac{12.2 \text{ g Mg}}{24.3 \text{ g Mg}} \times 1 \text{ mole Mg} = 0.50 \text{ mole Mg}
\]

**Step 2** use mole ratio – change given moles Mg into unknown mole O₂

\[
\frac{0.50 \text{ mole Mg}}{2 \text{ mole Mg}} \times \frac{1 \text{ mole O}_2}{1 \text{ mole Mg}} = 0.25 \text{ mole O}_2
\]

**Step 3.** change moles O₂ into grams O₂:

\[
\frac{0.25 \text{ mole O}_2}{1 \text{ mole O}_2} \times \frac{32.0 \text{ g O}_2}{1 \text{ mole O}_2} = 8.0 \text{ g O}_2
\]

or 3 steps combined:

\[
\frac{12.2 \text{ g Mg}}{24.3 \text{ g Mg}} \times \frac{1 \text{ mole Mg}}{2 \text{ mole Mg}} \times \frac{1 \text{ mole O}_2}{1 \text{ mole Mg}} \times \frac{32.0 \text{ g O}_2}{1 \text{ mole O}_2} = 8.0 \text{ g O}_2
\]

25. **Problem**  
Find the number of grams of O₂ produced from 4.5 g H₂O.

\[ 2 \text{ H}_2\text{O} \rightarrow 2 \text{ H}_2 + \text{O}_2 \]

**Hint:** write as a guide the sequence of changes and the fractions that are necessary:

Grams H₂O → Moles H₂O → Moles O₂ → Grams O₂  
(1) (2) (3)
Answer
The fractions to be used are:

1. \( \frac{1 \text{ mole } \text{H}_2\text{O}}{18.0 \text{ g } \text{H}_2\text{O}} \) (1) mole → g
2. \( \frac{1 \text{ mole } \text{O}_2}{2 \text{ moles } \text{H}_2\text{O}} \) mole-ratio → mole
3. \( \frac{32.0 \text{ g } \text{O}_2}{1 \text{ mole } \text{O}_2} \) mole → g

The given quantity 4.5 g \( \text{H}_2\text{O} \) is multiplied by the 3 fractions as 3 separate steps or in combined form:

\[
= 4.5 \text{ g } \text{H}_2\text{O} \times \frac{1 \text{ mole } \text{H}_2\text{O}}{18.0 \text{ g } \text{H}_2\text{O}} \times \frac{1 \text{ mole } \text{O}_2}{2 \text{ mole } \text{H}_2\text{O}} \times \frac{32.0 \text{ g } \text{O}_2}{1 \text{ mole } \text{O}_2} = 4.0 \text{ g } \text{O}_2
\]

26. The gram-mole type or mole-gram type problems (objective 4) require the use of only 2 of the fractions; either 1 and 2 (gram-mole) or 2 and 3 (mole-gram). Note that the mole-ratio is always used.

27. Review Question
1. What is the meaning of the term “gram-gram problem”?
2. Write the equation which shows the sequence of changes used to make a gram-gram calculation.
3. What is the meaning of the term “mole-gram problem?”

28. Test your understanding of the principles presented and also your ability to do the 3 types of problems by working out the Practice Exercises available at the end of the Study Guide.