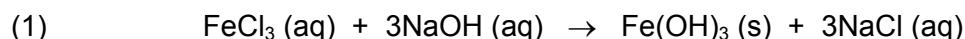


Tutorial 3

THE MOLE AND STOICHIOMETRY

A chemical equation shows the reactants (left side) and products (right side) in a chemical reaction. A balanced equation shows, in terms of moles, how much of each substance is involved in the reaction. Stoichiometry is the study of the relationships of quantities of substances in a chemical reaction.

Consider the reaction:



This balanced equation tells us: one mole of iron(III) chloride reacts with three moles of sodium hydroxide to produce one mole of iron(III) hydroxide and three moles of sodium chloride. Several mole ratio fractions are possible:

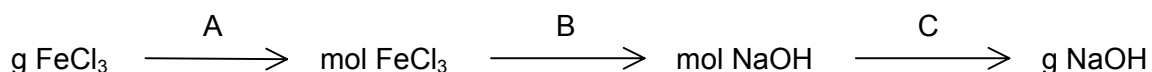
$$\frac{3 \text{ mol NaOH}}{1 \text{ mol FeCl}_3} \quad \text{or} \quad \frac{1 \text{ mol FeCl}_3}{1 \text{ mol Fe}(\text{OH})_3} \quad \text{or} \quad \frac{3 \text{ mol NaCl}}{1 \text{ mol FeCl}_3} \quad \text{and others}$$

You recognize these as conversion factors. The first relates moles of the two reactants; the second and third relate one of the reactants to one of the products.

No matter how much of each reactant there is to start with they will react only in the ratio of 1 mol FeCl_3 / 3 mol NaOH . If exactly one mole of FeCl_3 and three moles of NaOH are brought together, both reactants will be completely consumed. If one mole of FeCl_3 and five moles of NaOH are brought together, only three moles of the NaOH will react; two moles of NaOH will be left unreacted. If three moles of FeCl_3 and three moles of NaOH are brought together, two moles of FeCl_3 will remain unreacted.

EXAMPLE: What mass of sodium hydroxide is needed to react completely with 10.0 g of iron(III) chloride?

The conversion sequence is:



(A) Mass to moles:

$$10.0 \text{ g FeCl}_3 \times \frac{1 \text{ mol FeCl}_3}{162.3 \text{ g FeCl}_3} = 0.0616 \text{ mol FeCl}_3$$

(B) Moles to moles (Using the mole ratio from the balanced chemical equation):

$$0.0616 \text{ mol FeCl}_3 \times \frac{3 \text{ mol NaOH}}{1 \text{ mol FeCl}_3} = 0.185 \text{ mol NaOH}$$

(C) Moles to mass:

$$0.185 \text{ mol NaOH} \times \frac{40.0 \text{ g NaOH}}{1 \text{ mol NaOH}} = 7.40 \text{ g NaOH}$$

Steps (A), (B), and (C) may be combined:

$$10.0 \text{ g FeCl}_3 \times \frac{1 \text{ mol FeCl}_3}{162.3 \text{ g FeCl}_3} \times \frac{3 \text{ mol NaOH}}{1 \text{ mol FeCl}_3} \times \frac{40.0 \text{ g NaOH}}{1 \text{ mol NaOH}} = 7.39 \text{ g NaOH}$$

Can you see why the answer is different when all three steps are combined?

EXAMPLE: What mass of iron(III) hydroxide will be formed from 10.0 g of iron(III) chloride?

The conversion sequence is:



Combining the three steps:

$$10.0 \text{ g FeCl}_3 \times \frac{1 \text{ mol FeCl}_3}{162.3 \text{ g FeCl}_3} \times \frac{3 \text{ mol Fe(OH)}_3}{1 \text{ mol FeCl}_3} \times \frac{106.8 \text{ g Fe(OH)}_3}{1 \text{ mol Fe(OH)}_3} = 6.58 \text{ g Fe(OH)}_3$$

A variation of this kind of problem is one in which you are given amounts of both reactants and asked to find the amount of product formed. Usually the amount of one of the reactants given is in excess and the yield of product is determined by the reactant present in the (stoichiometrically) smaller amount: the limiting reagent. First you decide which is the limiting reagent then calculate the amount of product formed.

EXAMPLE: With reference to equation (1): What mass of iron(III) hydroxide will be formed if a solution containing 10.0 g of iron(III) chloride is mixed with a solution containing 10.0 g of sodium hydroxide?

You recognize this as a limiting reagent problem because masses of both reactants are given. First find moles of each reactant:

$$(D) \quad 10.0 \text{ g FeCl}_3 \times \frac{1 \text{ mol FeCl}_3}{162.3 \text{ g FeCl}_3} = 0.0616 \text{ mol FeCl}_3 \text{ given}$$

$$(E) \quad 10.0 \text{ g NaOH} \times \frac{1 \text{ mol NaOH}}{40.0 \text{ g NaOH}} = 0.250 \text{ mol NaOH given}$$

Take either of these moles of reactants and calculate how much of the other reactant would be needed to react completely with it. Let us take mol FeCl₃:

$$(F) \quad 0.0616 \text{ mol FeCl}_3 \times \frac{3 \text{ mol NaOH}}{1 \text{ mol FeCl}_3} = 0.185 \text{ mol NaOH needed}$$

Compare the moles needed (F) with the available moles from (E), above. We see that more NaOH is available than is needed: 0.250 mole available is more than 0.185 mol needed. Therefore NaOH is in excess over what is needed to react with the given amount of FeCl₃; the FeCl₃ is the limiting reagent.

To arrive at this conclusion we arbitrarily picked FeCl_3 to make the comparison. Suppose, instead, we should choose NaOH for the comparison. Find out how much FeCl_3 would be needed to react completely with the given amount of NaOH :

$$(G) \quad 0.250 \text{ mol NaOH} \times \frac{1 \text{ mol FeCl}_3}{3 \text{ mol NaOH}} = 0.0833 \text{ mol FeCl}_3 \text{ needed}$$

Comparing this amount needed with the amount available from (D), above, we see that less FeCl_3 is available than is needed: 0.0616 mol available is less than 0.0833 mol needed. Thus, there is not enough FeCl_3 to react with all the available NaOH , and the NaOH is in excess; the FeCl_3 is the limiting reagent.

Once we have determined the limiting reagent the amount of product is calculated from moles of limiting reagent:

$$0.0616 \text{ mol FeCl}_3 \times \frac{1 \text{ mol Fe(OH)}_3}{1 \text{ mol FeCl}_3} \times \frac{106.8 \text{ g Fe(OH)}_3}{1 \text{ mol Fe(OH)}_3} = 6.58 \text{ g Fe(OH)}_3$$

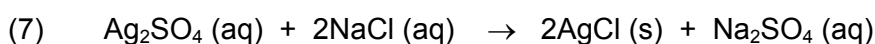
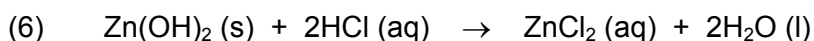
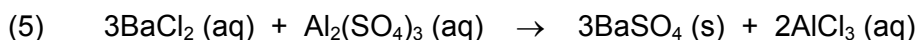
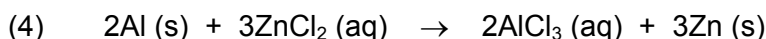
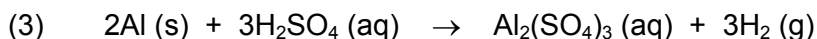
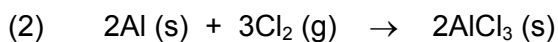
In the foregoing EXAMPLES we have twice calculated that 6.58 g Fe(OH)_3 can be obtained from 10.0 g FeCl_3 by chemical reaction (1). This is the maximum amount that can be obtained from 10.0 g FeCl_3 : this is the theoretical yield of Fe(OH)_3 . (In general, stoichiometry calculations are theoretical yields.) In actual practice this theoretical yield is very seldom realized: there are always some losses in isolation of a reaction product: something less than 6.48 g Fe(OH)_3 would be obtained from 10.0 g FeCl_3 ; this lesser amount will be some percent of the theoretical yield: it will be the percentage yield.

EXAMPLE: A solution containing 10.0 g of iron(III) chloride is mixed with a solution containing an excess of sodium hydroxide. The solid iron(III) hydroxide is collected, dried, and weighed. It weighs 6.27 g. Calculate the percentage yield.

We have already calculated the theoretical yield for this reaction: 6.58 g Fe(OH)_3 . The percentage yield is:

$$\text{Percent yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100 = \frac{6.27 \text{ g}}{6.58 \text{ g}} \times 100 = 95.3\%$$

The following equations are needed for the problems in this Tutorial. You decide which equation is needed for each problem.



- 1) What mass of barium chloride is required to react completely with 10.0 g of aluminum sulfate?
- 2) What mass of chlorine gas is required to react with 10.0 g of aluminum metal?
- 3) What mass of sodium chloride is required to react with 0.0115 mol of silver sulfate?
- 4) What mass of HCl, in tons, is required to react completely with 1.25 tons of zinc hydroxide?
- 5) How many pounds of aluminum will react with 150.0 pounds of zinc chloride?
- 6) What mass of silver chloride could be formed from 1.250 g of silver sulfate? What is the percent yield if 1.092 g AgCl is actually obtained?
- 7) What mass of barium sulfate could be formed from 155 g of aluminum sulfate? What is the percent yield if 300.15 g BaSO₄ is actually obtained?
- 8) What mass of aluminum chloride could be formed from 0.100 mol of aluminum metal? What is the percent yield if 12.5 g AlCl₃ is actually obtained?
- 9) What mass of zinc metal could be formed from 5.55 g of aluminum metal reacting with an excess of zinc chloride solution? What is the percent yield if 18.93 g Zn is actually obtained?
- 10) What mass of aluminum sulfate, in tons, could be formed from the reaction of 1.00 ton of aluminum metal with excess sulfuric acid?
- 11) Reaction of hydrochloric acid with a sample of zinc hydroxide gave 0.555 g of zinc chloride. What was the mass of the zinc hydroxide sample?

- 12) When a barium chloride solution is mixed with a solution containing excess aluminum sulfate, 0.888 g of barium sulfate is obtained. What mass of barium chloride was contained in the solution?
- 13) A 0.187 g sample of impure aluminum metal was treated with excess sulfuric acid. 0.921 g of aluminum sulfate was obtained. Calculate the percent purity of the aluminum sample.
- 14) A solution containing 15.0 g of barium chloride is mixed with a solution containing 15.0 g of aluminum sulfate. What mass of barium sulfate will form?
- 15) A solution containing 0.0252 mol of silver sulfate is mixed with a solution containing 2.52 g of sodium chloride. What mass of metallic zinc will form?
- 16) 1.00 g of aluminum metal is treated with a solution containing 7.00 g of zinc chloride. What mass of metallic zinc will form?
- 17) A solution of aluminum sulfate was treated with an excess of barium chloride solution. It was determined that 5.05 g of barium sulfate and 1.93 g of aluminum chloride were formed in the reaction. What mass of aluminum sulfate was in the original solution?
- 18) A 0.5273 g sample of impure silver sulfate was treated with excess sodium chloride solution. 0.3572 g of silver chloride was obtained. Calculate the percent purity of the silver sulfate sample.
- 19) 1.52 g of aluminum reacted with excess chlorine gas to give an 83.5% yield of aluminum chloride. Calculate this mass of aluminum chloride.
- 20) 2.350 g of a 72.5% pure sample of aluminum sulfate was treated with excess barium chloride solution. What mass of barium sulfate is formed?

Answers to Problems

- | | |
|---|---|
| 1) 18.3 g BaCl ₂ | 11) 0.404 g Zn(OH) ₂ |
| 2) 39.4 g Cl ₂ | 12) 0.793 g BaCl ₂ |
| 3) 1.35 g NaCl | 13) 0.145 g Al in sample; 77.5% pure |
| 4) 0.918 ton HCl | 14) BaCl ₂ is limiting; 16.8 g BaSO ₄ |
| 5) 19.78 lbs Al | 15) NaCl is limiting; 6.18 g AgCl |
| 6) 1.149 g AgCl; 95.04% | 16) ZnCl ₂ is limiting; 3.36 g Zn |
| 7) 317 g BaSO ₄ ; 94.7% | 17) 2.47 g Al ₂ (SO ₄) ₃ |
| 8) 13.4 g AlCl ₃ ; 93.3% | 18) 0.3885 g Ag ₂ SO ₄ in sample; 73.68% pure |
| 9) 20.2 g Zn; 93.7% | 19) 6.28 g AlCl ₃ |
| 10) 6.34 tons Al ₂ (SO ₄) ₃ | 20) 3.49 g BaSO ₄ |