

### 3.2.2 Combination reaction

We can use balanced chemical reactions to calculate the amount (in grams) of reactants and products for any chemical reaction. For example, in the **combination reaction** between sodium and chlorine, we find that 2 moles of sodium metal react with 1 mole of chlorine gas to give 2 moles of sodium chloride salt. Recall that a combination reaction occurs when two or more molecules combine to form a single product.

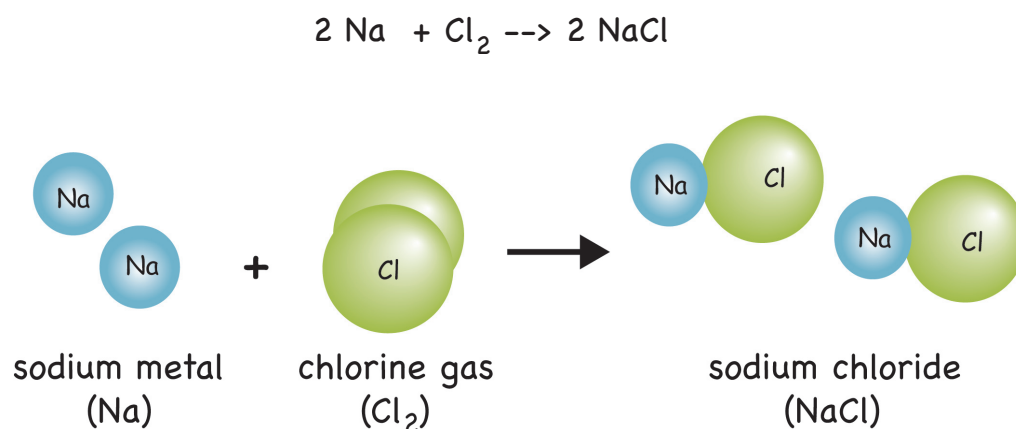


Figure 3.10: The **combination reaction** of sodium metal and chlorine gas to produce sodium chloride.

#### Sample Problem 3.1

(a) If we started with 2 moles of sodium metal, how many grams of chlorine gas would we need? (b) How many grams of sodium chloride salt will be made?

#### Answer

We know from the chemical equation that 2 moles of sodium metal react with 1 mole of chlorine gas to make 2 moles of sodium chloride. Since we need 1 mole of chlorine gas, we can calculate how many grams that is:

$$1 \text{ mole Cl}_2 = 2 \times 35 \text{ grams Cl} = \mathbf{70 \text{ grams Cl}_2}$$

(a) *We will need 70 grams of  $Cl_2$ .*

We also know from the chemical equation that we will make 2 moles of sodium chloride. We can calculate the amount of sodium chloride in grams.

$$2 \text{ moles NaCl} = (2 \times 23 \text{ grams Na}) + (2 \times 35 \text{ grams Cl}) = 116 \text{ grams NaCl}$$

(b) *We will make 116 grams of NaCl.*

So far, we have been converting moles to grams, but it is also possible to convert grams to moles. For example, we can also use chemical equations to calculate how many moles will be made from a given number of grams. Essentially, we do the calculation in the opposite order. Looking at Sample Problem 3.2, we see that grams of reactants can be converted to moles. From this we can calculate how many grams of product the reaction will produce.

### Sample Problem 3.2

(a) If we have 92 grams of sodium metal, how many moles of chlorine gas do we need? (b) How many grams of sodium chloride salt will this make?

#### Answer

First we need to find out how many moles of sodium metal equals 92 grams.

$$\begin{aligned} \text{moles Na metal} &= 92 \text{ grams Na metal} / 23 \text{ grams [mass of one Na]} \\ &= 4 \text{ moles} \end{aligned}$$

$$92 \text{ grams Na metal} = 4 \text{ moles}$$

Next, 1 mole of chlorine gas is needed for every 2 moles of sodium metal. We have 4 moles of sodium metal, so we will need 2 moles of chlorine gas.

$$2 \text{ moles Na metal} : 1 \text{ mole chlorine gas} \rightarrow$$

4 moles Na metal: 2 moles chlorine gas

(a) *We will need 2 moles of chlorine gas for 92 grams of sodium metal.*

Finally, we know that 2 moles of sodium metal give 2 moles of sodium chloride salt. So, if we have 4 moles of sodium metal, we will make 4 moles of sodium chloride salt.

2 moles Na metal: 2 moles sodium chloride salt

4 moles Na metal: 4 moles sodium chloride salt

Now we need to find out how many grams of sodium chloride salt equals 4 moles:

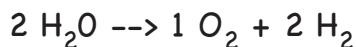
$$\begin{aligned} 4 \text{ moles NaCl} &= 4 \times 1 \text{ mole NaCl} = 4 \times [23 \text{ grams Na} + 35 \text{ grams Cl}] \\ &= 232 \text{ grams} \end{aligned}$$

(b) *We will get 232 grams of sodium chloride salt.*

### 3.2.3 Decomposition reaction

In the previous examples, we calculated the masses in grams needed for the acid-base reaction between acetic acid and sodium bicarbonate, and for the combination reaction between sodium metal and chlorine gas. However, we can calculate values for any kind of reaction.

For example the **decomposition reaction** for water is the following:



### Sample Problem 4.1

If 0.36 gram of HCl is added to 0.1 liters of water and if all of the HCl comes apart to release  $\text{H}^+$ , what will the pH be?

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#### Answer

mol. wt. HCl = (1 grams/mole H + 35 gram/mole Cl) = 36 grams per mole

*To find the number of moles in 0.36 grams HCl, divide the amount (0.36 grams) by the molecular weight.*

0.36 grams HCl / 36 grams per mole = 0.01 moles HCl

*To find the concentration, divide the number of moles by the volume (in liters).*

0.01 moles HCl / 0.1 liters = 0.1 moles per liter, or 0.1 M.

*Assume HCl completely dissociates, so there is 0.1 M  $\text{H}^+$  ions in solution.*

**The pH for a 0.1 M solution of HCl is 1. (See Table 4.3.)**

## 4.5 SUMMARY

Here are the main points to remember from this chapter:

- Acid-base reactions produce salts.
- An Arrhenius acid releases a **hydrogen ion** and an Arrhenius base releases a **hydroxide ion**.
- Monoprotic acids release a single proton.
- Polyprotic acids release more than one proton.

8. What is the hydrogen ion concentration of a solution that has a pH of 6?
9. What is the hydrogen ion concentration of a solution that has a pH of 9?

Challenge

10. The pH of water is 7. What is the hydrogen ion concentration? What is the hydroxyl ion ( $\text{OH}^-$ ) concentration? What is the pOH?

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**ANSWERS TO STUDY QUESTIONS**

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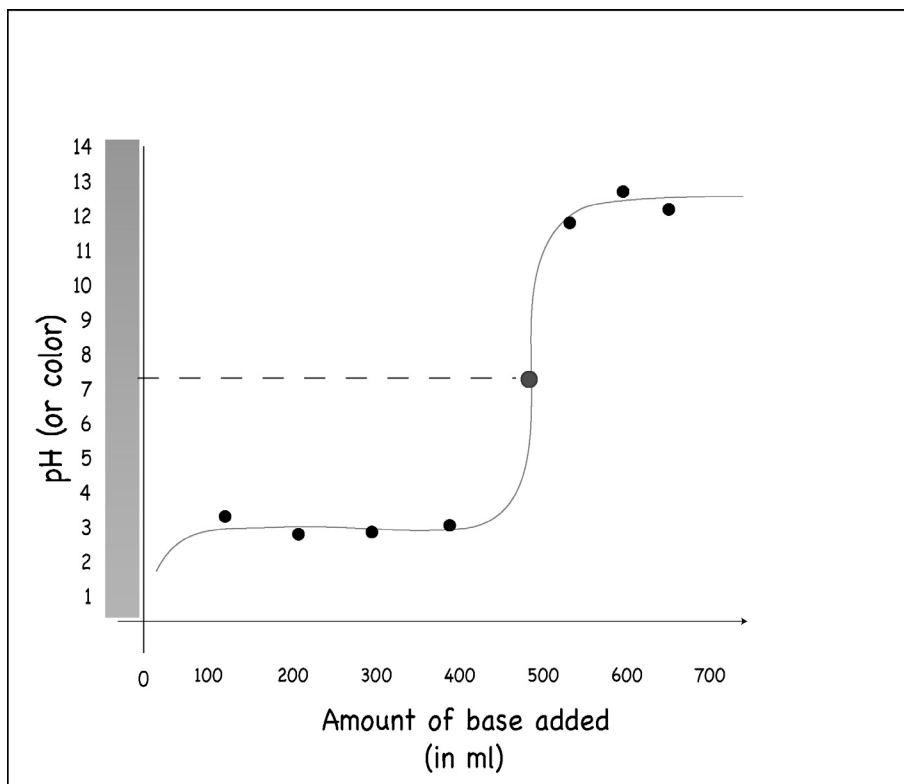
1. hydrochloric acid, HCl; hydrofluoric acid, HF; acetic acid CH<sub>3</sub>COOH.
2. phosphoric acid, H<sub>3</sub>PO<sub>4</sub>, carbonic acid, H<sub>2</sub>CO<sub>3</sub>; sulfuric acid, H<sub>2</sub>SO<sub>4</sub>.
3. An Arrhenius acid releases a proton, H<sup>+</sup>, and an Arrhenius base releases an OH<sup>-</sup>.
4. Molarity is defined as "moles per liter." Divide the number of moles by liters to find molarity. The symbol for molarity is "M."
  - a. 5 moles / 2 liters = 2.5 M
  - b. 2 moles / 1 liter = 2 M
  - c. 0.5 / 1 liter = 0.5 M
  - d. 18 grams of HCl = 1 mole HCl. 1 mole / 1 liter = 1 M
5. A strong acid or base ionizes more completely than a weak acid or base.
6. pH = 11. It is a base.  $1 \times 10^{-11}$  mol/liter.
7. pH = 1. It is an acid.
8.  $1 \times 10^{-6}$
9.  $1 \times 10^{-9}$

**Challenge**

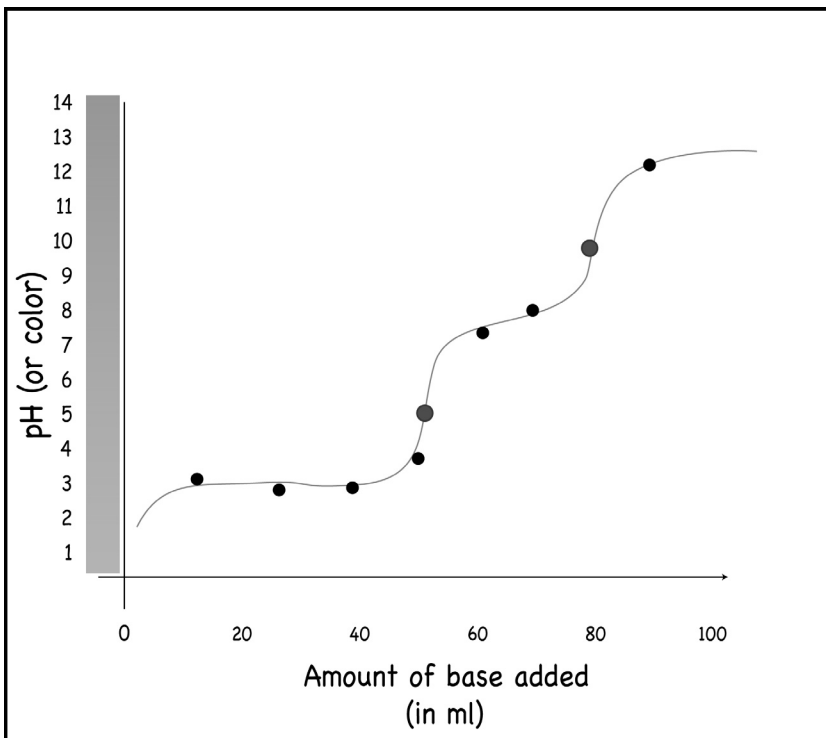
10. The hydrogen ion concentration is  $1 \times 10^{-7}$  mol/liter.  
The hydroxyl ion concentration is  $1 \times 10^{-7}$  mol/liter..  
The pOH is 7.

## ANSWERS TO STUDY QUESTIONS

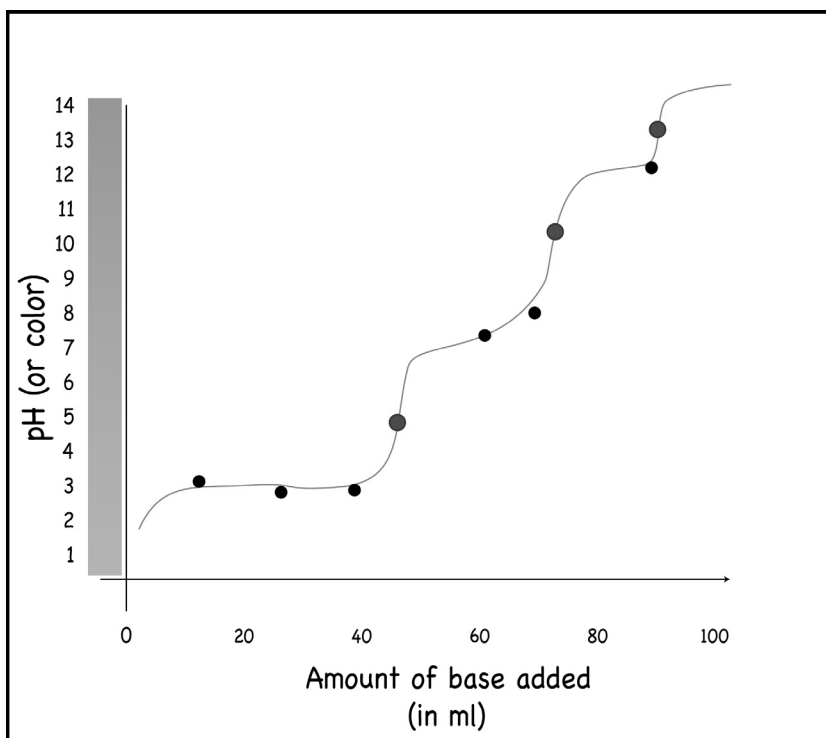
- 6 moles of NaOH?
- Give the molarity of the following solutions: [recall that molarity is moles per liter (the number of moles divided by the number of liters)]
  - 0.5 M [5 moles/10 liters = 0.5 M]
  - 0.25 M [2 moles/8 liters = 0.25 M]
  - 2 M [6 moles/3 liters = 2 M]
  - 5 M [5 moles/1 liter = 5 M]
- 0.2 moles [2 M x 100 ml = 2 M x 0.1 liter = 2 moles/liter x 0.1 liter (liters cancel) = 0.2 moles]
- 0.2 moles. (At the equivalence point the number of moles of base equals the number of moles of acid.)
- a. strong acid and a strong base
- c. strong acid and a weak base
- Titration curve for 500 ml of a 1 M solution of HCl with 1 M NaOH. pH is 7.



8. A general titration curve for  $\text{H}_2\text{SO}_4$  (a strong acid) with  $\text{NaOH}$  (a strong base).



9. A general titration curve for  $\text{H}_3\text{PO}_4$  (a polyprotic acid) titrated with  $\text{NaOH}$  (a strong base).



10. Draw a general titration curve for NaOH titrated with HCl.

