Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases Answer Key

Answer to Prediction

Acid	Base	Neutral
HCl(aq)	NaOH(aq)	NaCl(aq)
$CH_3COOH(aq)$	$NH_3(aq)$	$C_{12}H_{22}O_{11}(aq)$
$NaHCO_3(aq)$		

You might predict that $NaHCO_3(aq)$ is an acid, based on the Arrhenius theory, but it is actually a stronger base than acid. While $NH_3(aq)$ is not an Arrhenius base, it is a Brønsted-Lowry base.

Answers to Analysis Questions

1. NaOH(aq) = sodium hydroxide (IUPAC and Classical)
NaCl(aq) = sodium chloride (IUPAC and Classical)
$C_{12}H_{22}O_{11}(aq)$ = sucrose (IUPAC and Classical)
HCl(aq) = aqueous hydrogen chloride (IUPAC); hydrochloric acid (Classical)
$NH_3(aq)$ = ammonia (IUPAC and classical)
$CH_3COOH(aq)$ = ethanoic acid (IUPAC); acetic acid (Classical)
$NaHCO_3(aq)$ = sodium hydrogen carbonate (IUPAC); sodium bicarbonate (Classical)

2. The key to pH is not only the initial concentration of the acid or base, but also its degree of ionization. Weak acids and bases ionize only a little, giving them mild pH values, typically between 4.5 and 9.5. Approximate pH values follow:

0.10 mol/L NaOH(aq) has pH 12.5
0.10 mol/L NaCl(aq) has pH 7

This assumes that distilled water tests at a pH of 7. Dissolved carbon dioxide in the water may make it test at a pH less than 7.

0.10 mol/L $C_{12}H_{22}O_{11}(aq)$ has pH 7
0.10 mol/L HCl(aq) has pH 1.5
0.10 mol/L $NH_3(aq)$ has pH 8.5
0.10 mol/L $CH_3COOH(aq)$ has pH 4.5
0.10 mol/L $NaHCO_3(aq)$ has pH 7.5

Answer to Conclusion Question

3. (a) You may predict that $NaHCO_3(aq)$ is acidic since it has a hydrogen to donate. However, it is easier for $HCO_3^-(aq)$ to gain a hydrogen, allowing for the subsequent decomposition of the acid into water and carbon dioxide gas, than it is to lose a hydrogen and form the $CO_3^{2-}(aq)$ ion:

$$HCO_3^-(aq) + H_3O^+(aq) \rightarrow H_2CO_3\,(aq) + H_2O(\ell)$$
$$H_2CO_3\,(aq) \rightarrow H_2O(\ell) + CO_2(g)$$

If you were not already aware that ammonia is a base, your results for that substance may surprise you, since the molecule does not contain a hydroxide ion that can dissociate. You may also expect $C_{12}H_{22}O_{11}(aq)$ to be acidic since it has hydrogens in its chemical formula. The example of ethanoic acid illustrates that only hydrogens listed at the beginning or the end of a compound can act as acids.

Investigation 6.B: Testing the Arrhenius Theory of Acids and Bases Answer Key (continued)

(b) Acids dissociate to form hydrogen ions:

$$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$
$$CH_3COOH(aq) \rightarrow H^+(aq) + CH_3COO^-(aq)$$

Bases dissociate or react to form hydroxide ions:

$$NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)$$
$$NH_3(aq) + H_2O(\ell) \rightarrow NH_4^+(aq) + OH^-(aq)$$

It is impossible to explain the alkalinity of ammonia using only the Arrhenius theory of acids and bases, because ammonia has no hydroxide ion that can dissociate.

Soluble, neutral ionic substances dissociate in water, and soluble, neutral molecular substances dissolve in water, forming neither hydrogen ions nor hydroxide ions.

$$NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$$
$$C_{12}H_{22}O_{11}(s) \rightarrow C_{12}H_{22}O_{11}(aq)$$

Answer to Extension Question

4. Refer to Table 6.3 on p. 210 of the text. Avoid using litmus paper, since this simply repeats the use of a pH meter. A conductivity test could be used to help differentiate between strong and weak acids and bases. If magnesium and/or zinc strips are available, you could look for the characteristic hydrogen bubbles that form in reactions with acids.