13. The three solutions are tested with bromocresol green indicator. The pH 3.5 solution is the only solution that is yellow in bromocresol green indicator. The two remaining solutions are tested with cresol red indicator. The pH 7.8 solution is the only solution that is red in cresol red indicator. The remaining solution must be pH 5.8. This can be verified by testing the solution with litmus and bromophenol blue. It should be red in litmus and blue–violet in bromophenol blue.
14. From strongest to weakest: nitric and hydrochloric acid are identical, hydrofluoric acid, methanoic acid, acetic acid, and hydrocyanic acid.

8.5 BUFFERS

PRACTICE

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Understanding Concepts

1. (a) A good buffer solution maintains a nearly constant pH when diluted or when a strong acid or base is added.
   (b) A buffer contains equimolar amounts of a weak acid and its conjugate base.
2. (a) (i) $NH_{4(aq)}^{+} \rightleftharpoons H_{(aq)}^{+} + NH_{3(aq)}$
   (ii) $HC_7H_5O_{2(aq)} \rightleftharpoons H_{(aq)}^{+} + C_7H_5O_{2(aq)}^{-}$
   (b) The equilibrium will shift in the direction of the conjugate acid:
   $NH_{4(aq)}^{+} \rightarrow NH_{3(aq)} + H_{(aq)}^{+}$
3.
$$[CO_2H_{(aq)}^{-}] = 1.5 \text{ mol/L}$$
$$[HCO_2H_{(aq)}] = 1.5 \text{ mol/L}$$
$$HCO_2H_{(aq)} \rightleftharpoons H_{(aq)}^{+} + CO_2H_{(aq)}^{-}$$
$$\frac{[H_{(aq)}^{+}][CO_2H_{(aq)}^{-}]}{[HCO_2H_{(aq)}]} = 1.8 \times 10^{-4}$$
$$[H_{(aq)}^{+}] = K_a \frac{[HCO_2H_{(aq)}]}{[CO_2H_{(aq)}^{-}]}$$
$$= 1.8 \times 10^{-4} \times \frac{1.5 \text{ mol/L}}{1.5 \text{ mol/L}}$$
$$[H_{(aq)}^{+}] = 1.8 \times 10^{-4}$$
$$pH = -\log[1.8 \times 10^{-4}]$$
$$pH = 3.74$$
The addition of $H_{(aq)}^{+}$ …
$$[H_{(aq)}^{+}]_{added} = 0.13 \text{ mol/L}$$
$$[HCO_2H_{(aq)}]_{final} = (1.5 + 0.13) \text{ mol/L}$$
$$[HCO_2H_{(aq)}]_{final} = 1.63 \text{ mol/L}$$
$$[CO_2H_{(aq)}^{-}]_{final} = (1.5 - 0.13) \text{ mol/L}$$
$$[CO_2H_{(aq)}^{-}]_{final} = 1.37 \text{ mol/L}$$
$$[H_{(aq)}^{+}] = K_a \frac{[HCO_2H_{(aq)}]}{[CO_2H_{(aq)}^{-}]}$$
$$= 1.8 \times 10^{-4} \times \frac{1.63}{1.37}$$
$$[H_{(aq)}^{+}] = 2.1 \times 10^{-4}$$
$$pH = 3.67$$

$$\Delta pH = 3.74 - 3.67$$

$$\Delta pH = 0.07$$

The change in pH is 0.07.

SECTION 8.5 QUESTIONS

(Page 620)

Understanding Concepts

1. A buffer is a mixture of a conjugate acid–base pair that maintains a nearly constant pH when diluted or when a strong acid or base is added.
2. Phosphate and carbonate buffers help maintain a normal pH level in the human body.
3. (a) $H_2CO_{3(aq)} \rightarrow H^+_{(aq)} + HCO^-_{3(aq)}$

   (b) $H^+_{(aq)} + HCO^-_{3(aq)} \rightarrow H_2CO_{3(aq)}$

   (c) $H_2CO_{3(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)} + HCO^-_{3(aq)}$
4. A large excess of strong acid or base can drive the buffer equilibrium to completion. For example, the addition of $HCl_{(aq)}$ to the carbonate buffer shifts the equilibrium in question 3(a) completely to the left.
5. $HC_2H_3O_{2(aq)} \rightleftharpoons H^+_{(aq)} + C_2H_3O^-_{2(aq)}$

   (a) The addition of a small amount of $HCl_{(aq)}$ shifts the equilibrium to the left, consuming some acetate.

   (b) $NaOH_{(aq)}$ consumes $H^+_{(aq)}$, which causes the equilibrium to shift to the right.
6. (a) base
   (b) acid
   (c) neutral
   (d) base
   Lowest pH: (b), (c), (d), (a)
7. (a) and (c) will not form effective buffers because they consist of strong acids and bases. Conversely, (b) and (d) will form buffer systems because these mixtures consist of weak acids and their conjugate bases.
8. (a) The pH of nitric acid is much lower than that of nitrous acid.
   (b) Nitric acid is such a strong acid that it completely donates its hydrogen to water:

   $$HNO_{3(aq)} + H_2O_{(l)} \xrightarrow{100\%} H_3O^+_{(aq)} + NO^-_{3(aq)}$$

   Nitrous acid only partially donates its hydrogen to water. Some molecular nitrous acid remains.

   $$HNO_{2(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + NO^-_{2(aq)}$$
9. $$[C_2H_3O^-_{2(aq)}] = 0.25 \text{ mol/L}$$

   $$[HC_2H_3O_{2(aq)}] = 0.25 \text{ mol/L}$$

   $$HC_2H_3O_{2(aq)} \rightleftharpoons H^+_{(aq)} + C_2H_3O^-_{2(aq)}$$

   $$\frac{[H^+_{(aq)}][C_2H_3O^-_{2(aq)}]}{} = 1.8 \times 10^{-5}$$

   $$[H^+_{(aq)}] = K_a \frac{[HC_2H_3O_{2(aq)}]}{[C_2H_3O^-_{2(aq)}]}$$

   $$= 1.8 \times 10^{-5} \times \frac{0.25 \text{ mol/L}}{0.25 \text{ mol/L}}$$

   $$= 1.8 \times 10^{-5}$$

   $$pH = -\log[1.8 \times 10^{-5}]$$

   $$pH = 4.74$$

   The addition of hydroxide …

$$[OH^-_{(aq)}]_{added} = 0.15 \text{ mol/L}$$
$$[HC_2H_3O_{2(aq)}]_{final} = (0.25 - 0.15) \text{ mol/L}$$
$$[HC_2H_3O_{2(aq)}]_{final} = 0.10 \text{ mol/L}$$
$$[C_2H_3O^-_{2(aq)}]_{final} = (0.25 + 0.15) \text{ mol/L}$$
$$[C_2H_3O^-_{2(aq)}]_{final} = 0.40 \text{ mol/L}$$
$$[H^+_{(aq)}] = K_a \frac{[HC_2H_3O_{2(aq)}]}{[C_2H_3O^-_{2(aq)}]}$$
$$= 1.8 \times 10^{-5} \times \frac{0.10}{0.40}$$
$$[H^+_{(aq)}] = 4.5 \times 10^{-6}$$
$$pH = 5.35$$
$$\Delta pH = 5.35 - 4.74$$
$$\Delta pH = 0.61$$

The change in pH is 0.61.

8.6 CASE STUDY: THE SCIENCE OF ACID DEPOSITION

PRACTICE

(Page 624)

Understanding Concepts

1. Acid deposition is suspected as one of the causes of forest decline, particularly in forests at high altitudes and colder latitudes. (Sample table)

Evidence of acid rain damage	Alternative interpretations
The evidence clearly demonstrates that the Black Forest, for example, receives as much as 30 times more acid than if the rain fell through clean air. Damage to the trees includes yellowing, premature needle loss, and eventual death. Study of the tree rings shows that trees grow more slowly in areas subject to acid deposition.	Other scientists question the link between tree growth and acid deposition. They propose conflicting evidence that seedlings actually grow better in an acidic environment. They counter that the reduction in tree growth rate is more directly due to the reduction in mean annual temperature in the regions in question. This hypothesis is supported by empirical data. Other researchers indicate that ground-level ozone, rather than acid deposition, is implicated in the damage to the forests.

2. (a) Scientific research on catalysis assisted the development of catalytic converter technology.
   (b) Sensitive detection devices have helped scientific research in the reduction of sulfur oxide emissions.
   (c) The technology that produces sulfur oxides (smelting and power generating) has a harmful impact on human health.
   (d) Society provides the resources, through government funding, that enable scientific research on the causes and effects of acid deposition.
   (e) Society affects technology by purchasing its products, such as cars with catalytic converters.