11. Problem

In which direction will the following reactions proceed? Explain why in each case.

(a) $H_2PO_4^-{}_{(aq)} + NH_4^+{}_{(aq)} \rightarrow H_2PO_4^-{}_{(aq)} + NH_{3(aq)}$

(b) $H_2SO_{4(aq)} + H_2O_{(l)} \rightarrow HSO_4^-{}_{(aq)} + H_3O^+{}_{(aq)}$

(c) $H_2S_{(aq)} + NH_{3(aq)} \rightarrow HS^-{}_{(aq)} + NH_4^+{}_{(aq)}$

Solution

Using Figure 14.12, identify the weaker acid and the weaker base. The reaction will proceed towards the formation of these two species.

(a) $H_2PO_4^-{}_{(aq)}$ is a weaker base than $NH_{3(aq)}$ and $NH_4^+{}_{(aq)}$ is a weaker acid than $H_3PO_{4(aq)}$.

This reaction proceeds to the left or reactants are favoured..

(b) $H_3O^+{}_{(aq)}$ is a weaker acid than $H_2SO_{(aq)}$ and $HSO_4^-{}_{(aq)}$ is a weaker base than $H_2O_{(l)}$ The reaction will proceed to the right or products are favoured.

(c) $HS^-{}_{(aq)}$ is a weaker base than $NH_{3(aq)}$ and $NH_4^+{}_{(aq)}$ is as weaker acid than $H_2S_{(aq)}$ The reaction proceeds to the right or products are favoured.

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12. Problem

Determine $[H_3O^+]$ and $[OH^-]$ in each solution.

(a) 0.45 mol/L hydrochloric acid

(b) 1.1 mol/L sodium hydroxide

Solution

You know that hydrochloric acid is a strong acid and sodium hydroxide is a strong base. Since both dissociate completely in aqueous solutions, you can use their molar concentrations to determine $[H_3O^+]$ or $[OH^-]$. You can find the concentration of the other ion using K_w as shown below:

$K_w = 1.0 \times 10^{-14} = [H_3O^+][OH^-]$

(a) $[HCl] = 0.45$ mol/L, so $[H_3O^+] = 0.45$ mol/L

$$[OH^-] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{0.45}$$
$$= 2.2 \times 10^{-14} \text{ mol/L}$$

(b) $[NaOH] = 1.1$ mol/L

Therefore, $[OH^-] = 1.1$ mol/L

$$[H_3O^+] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{1.1}$$
$$= 9.1 \times 10^{-15} \text{ mol/L}$$

Check Your Solution

Solution (a) is a strong acid. Therefore, $[H_3O^+]$ should be greater than 1.0×10^{-7}, and $[OH^-]$ should be less than 1.0×10^{-7}. For a solution of a strong base, as in (b), $[OH^-]$ should be greater than 1.0×10^{-7}, and $[H_3O^+]$ should be less than 1.0×10^{-7}.

13. Problem

Determine $[H_3O^+]$ and $[OH^-]$ in each solution.

(a) 0.95 mol/L hydrobromic acid

(b) 0.012 mol/L calcium hydroxide

Solution

You know that hydrobromic acid is a strong acid and calcium hydroxide is a strong base. Since both dissociate completely in aqueous solutions, you can use their molar concentrations to determine $[H_3O^+]$ or $[OH^-]$. You can find the concentration of the other ion using K_w, as shown below:

$K_w = 1.0 \times 10^{-14} = [H_3O^+][OH^-]$

(a) $[HBr] = 0.95$ mol/L, so $[H_3O^+] = 0.95$ mol/L

$$[OH^-] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{0.95}$$
$$= 1.1 \times 10^{-14} \text{ mol/L}$$

(b) $[Ca(OH)_2] = 0.12$ mol/L

Each mole of $Ca(OH)_2$ in solution forms two moles of OH^- ions.

Therefore, $[OH^-] = 2 \times 0.012$ mol/L $= 0.024$ mol/L

$$[H_3O^+] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{0.024}$$
$$= 4.2 \times 10^{-13} \text{ mol/L}$$

Check Your Solution

Solution (a) is a strong acid. Therefore, $[H_3O^+]$ should be greater than 1.0×10^{-7}, and $[OH^-]$ should be less than 1.0×10^{-7}. For a solution of a strong base, as in (b), $[OH^-]$ should be greater than 1.0×10^{-7}, and $[H_3O^+]$ should be less than 1.0×10^{-7}.

14. Problem

$[OH^-]$ is 5.6×10^{-14} mol/L in a solution of hydrochloric acid. What is the molar concentration of the $HCl_{(aq)}$?

Solution

You know $[OH^-] = 5.6 \times 10^{-14}$ mol/L. You can find $[H_3O^+]$ using K_w as shown below:

$K_w = 1.0 \times 10^{-14} = [H_3O^+][OH^-]$

Hydrochloric acid is a strong acid. Therefore, $[H_3O^+] = [HCl]$

$$[H_3O^+] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{5.6 \times 10^{-14}}$$
$$= 0.18 \text{ mol/L}$$

Therefore, $[HCl] = 0.18$ mol/L

Check Your Solution

For a solution with $[OH^-]$ less than 1.0×10^{-7}, the $[H_3O^+]$ must be greater than 1.0×10^{-7}.

15. Problem

$[H_3O^+]$ is 1.7×10^{-14} in a solution of calcium hydroxide. What is the molar concentration of the $Ca(OH)_{2(aq)}$?

Solution

You know $[H_3O^+] = 1.7 \times 10^{-14}$ mol/L. You can find $[OH^-]$ using K_w, as shown below:

$K_w = 1.0 \times 10^{-14} = [H_3O^+][OH^-]$

Calcium hydroxide is a strong base. Each mole of $Ca(OH)_2$ forms two moles of OH^- ions. Therefore, $[Ca(OH)_2] = \frac{1}{2} \times [OH^-]$

$$[OH^-] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{1.7 \times 10^{-14}}$$
$$= 0.588 \text{ mol/L}$$

Therefore, $[Ca(OH)_2] = \frac{1}{2} \times 0.588 \text{ mol/L} = 0.29 \text{ mol/L}$

Check Your Solution

For a solution with $[H_3O^+]$ less than 1.0×10^{-7}, the $[OH^-]$ must be greater than 1.0×10^{-7}.

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16. Problem

Calculate the pH of each solution, given the hydronium ion concentration.

(a) $[H_3O^+] = 0.0027$ mol/L

(b) $[H_3O^+] = 7.28 \times 10^{-8}$ mol/L

(c) $[H_3O^+] = 9.7 \times 10^{-5}$ mol/L

(d) $[H_3O^+] = 8.27 \times 10^{-12}$ mol/L

What Is Required?

You need to calculate the solution pH for the hydronium ion concentrations listed.

What Is Given?

The $[H_3O^+]$ is given for each solution.

Plan Your Strategy

Apply the equation: $pH = -\log [H_3O^+]$

Act on Your Strategy

(a) $pH = -\log 0.0027 = 2.57$

(b) $pH = -\log 7.28 \times 10^{-8} = 7.14$

(c) $pH = -\log 9.75 \times 10^{-5} = 4.01$

(d) $pH = -\log 8.27 \times 10^{-12} = 11.08$

Check Your Solution

(a) $[H_3O^+] > 1.0 \times 10^{-7}$ mol/L, therefore the pH should be less than 7 and the solution should be acidic, which it is at 2.57.

(b) $[H_3O^+]$ is slightly lower than 1.0×10^{-7} mol/L, therefore the pH of the solution should be just above neutral, which it is at 7.14.

(c) $[H_3O^+] > 1.0 \times 10^{-7}$ mol/L, therefore the pH should be less than 7 and the solution should be acidic, which it is at 4.01.

(d) $[H_3O^+] < 1.0 \times 10^{-7}$ mol/L, therefore pH should be more than 7 and the solution should be basic, which it is at 11.08.

17. Problem

$[H_3O^+]$ in a cola drink is about 5.0×10^{-3} mol/L. Calculate the pH of the drink. State whether the drink is acidic or basic.

What Is Required?

You have to calculate the pH of a cola drink.

What Is Given?

$[H_3O^+] = 5.0 \times 10^{-3}$ mol/L

Plan Your Strategy

Use the equation: $pH = -\log [H_3O^+]$

Act on Your Strategy

$pH = -\log 5.0 \times 10^{-3} = 2.30$. Therefore, the cola drink is acidic.

Check Your Solution
$[H_3O^+] > 1.0 \times 10^{-7}$ mol/L, therefore the pH should be less than 7 and the cola drink should be acidic, which it is at 2.3.

18. Problem
A glass of orange juice has $[H_3O^+]$ of 2.9×10^{-4} mol/L. Calculate the pH of the juice. State whether the result is acidic or basic.

What Is Required?
You have to calculate the pH of a sample of orange juice.

What Is Given?
$[H_3O^+] = 2.9 \times 10^{-4}$ mol/L

Plan Your Strategy
Use the equation: $pH = -\log [H_3O^+]$

Act on Your Strategy
$pH = -\log 2.9 \times 10^{-4} = 3.54$. Therefore, the orange juice is acidic.

Check on Your Solution
$[H_3O^+] > 1.0 \times 10^{-7}$ mol/L, therefore the pH should be less than 7 and the juice should be acidic, which it is at 3.54.

19. Problem
(a) $[H_3O^+]$ in a dilute solution of nitric acid, HNO_3, is 6.3×10^{-3} mol/L. Calculate the pH of the solution.
(b) $[H_3O^+]$ of a solution of sodium hydroxide is 6.59×10^{-10} mol/L. Calculate the pH of the solution.

What Is Required?
You have to calculate the pH of the nitric acid and sodium hydroxide solutions.

What Is Given?
$[H_3O^+] = 6.3 \times 10^{-3}$ mol/L for HNO_3
$[H_3O^+] = 6.59 \times 10^{-10}$ mol/L for NaOH

Plan Your Strategy
Use the equation: $pH = -\log [H_3O^+]$

Act on Your Strategy
(a) $pH = -\log 6.3 \times 10^{-3} = 2.2$, therefore, the solution is acidic.
(b) $pH = -\log 6.59 \times 10^{-10} = 9.18$, therefore, the solution is basic.

Check Your Solution
(a) $[H_3O^+] > 1.0 \times 10^{-7}$ mol/L, therefore the pH should be less than 7 and the solution should be acidic, as would be expected for nitric acid.
(b) $[H_3O^+] < 1.0 \times 10^{-7}$ mol/L, therefore the pH should be more than 7 and the solution should be basic, as would be expected for NaOH.

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20. Problem
$[H_3O^+]$ of a sample of milk is found to be 3.98×10^{-7} mol/L. Is the milk acidic, neutral, or basic? Calculate the pH and $[OH^-]$ of the sample.

Solution
Compare $[H_3O^+]$ in the milk with $[H_3O^+]$ in neutral water.

$[H_3O^+] = 3.98 \times 10^{-7}$ mol/L, which is greater than 1.0×10^{-7} mol/L.
Therefore, the milk is acidic.
Use the equation $pH = -\log[H_3O^+]$ to find the pH.

$$pH = -\log 3.98 \times 10^{-7}$$
$$= 6.400$$

Use the following equation to find the hydroxide ion concentration:

$$[OH^-] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{[H_3O^+]}$$

$$[OH^-] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{3.98 \times 10^{-7}}$$
$$= 2.51 \times 10^{-8} \text{ mol/L}$$

Check Your Solution

The ion product is
$[H_3O^+] \times [OH^-] = 3.98 \times 10^{-7} \times 2.51 \times 10^{-8} = 9.99 \times 10^{-15}$
This is equal to the value of K_w 1.0×10^{-14}, within the error introduced by mathematical rounding.

21. Problem

A sample of household ammonia has a pH of 11.9. What is the pOH and $[OH^-]$ of the sample?

Solution

Use the following equation to find the pOH:
$pH + pOH = 14.0$
Then calculate $[OH^-]$ using the following equation:
$[OH^-] = 10^{-pOH}$

$$pOH = 14.0 - 11.9$$
$$= 2.1$$

$$[OH^-] = 10^{-2.1}$$
$$= 8 \times 10^{-3} \text{ mol/L}$$

Check Your Solution

The ammonia solution has pH greater than 7, and is therefore basic. The $[OH^-]$ is greater than 1×10^{-7} mol/L.

22. Problem

Phenol, C_6H_5OH, is used as a disinfectant. An aqueous solution of phenol was found to have a pH of 4.72. Is phenol acidic, neutral, or basic? Calculate $[H_3O^+]$, $[OH^-]$, and pOH of the solution.

Solution

Compare the pH of the solution with the pH of neutral water. pH = 4.72, which is less than 7. Therefore, the solution is acidic.
Use the following equation to find the $[H_3O^+]$:

$$[H_3O^+] = 10^{-pH}$$
$$[H_3O^+] = 10^{-4.72}$$
$$= 1.9 \times 10^{-5} \text{ mol/L}$$

Use the following equation to find the hydroxide ion concentration:

$$[OH^-] = \frac{1.0 \times 10^{-14}\ \text{mol/L}}{[H_3O^+]}$$

$$[OH^-] = \frac{1.0 \times 10^{-14}\ \text{mol/L}}{1.9 \times 10^{-5}}$$

$$= 5.3 \times 10^{-10}\ \text{mol/L}$$

Calculate pOH using the following equation:

$pOH = -\log [OH^-]$

$pOH = -\log 5.3 \times 10^{-10}$

$= 9.28$

Check Your Solution

$pH + pOH = 4.72 + 9.28 = 14.00$

23. Problem

At normal body temperature, 37°C, the value of K_w for water is 2.5×10^{-14}. Calculate $[H_3O^+]$ and $[OH^-]$ at this temperature. Is pure water at 37°C acidic, neutral, or basic?

Solution

$H_2O_{(\ell)} + H_2O_{(\ell)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$

Therefore, $[H_3O^+] = [OH^-]$

Let x represent $[H_3O^+]$.

Find the hydronium ion concentration using:

$K_w = [H_3O^+][OH^-]$

$2.5 \times 10^{-14} = x^2$

$x = \pm 1.6 \times 10^{-7}$

The negative root is not physically possible.

Therefore, $[H_3O^+] = [OH^-] = 1.6 \times 10^{-7}$ mol/L

Water is neutral at 37°C since $[H_3O^+] = [OH^-]$

Check Your Solution

K_w is an equilibrium constant. Every equilibrium constant depends on temperature. Since the water is pure, it must be neutral.

24. Problem

A sample of baking soda was dissolved in water and the pOH of the solution was found to be 5.81 at 25°C. Is the solution acidic, basic or neutral? Calculate the pH, $[H_3O^+]$, and $[OH^-]$ of the solution.

Solution

Compare the pOH of the solution with the pOH of neutral water at 25°C. The pOH is 5.81, which is less than 7. Therefore, the solution is basic.

Use the following equation to find the pH:

$pH + pOH = 14.00$

$pH = 14.00 - 5.81$

$= 8.19$

$[H_3O^+] = 10^{-pH}$

$= 10^{-8.19}$

$= 6.5 \times 10^{-9}$ mol/L

Use the following equation to find the hydroxide ion concentration:

$$[OH^-] = \frac{1.0 \times 10^{-14}\ mol/L}{[H_3O^+]}$$

$$[OH^-] = \frac{1.0 \times 10^{-14}\ mol/L}{6.5 \times 10^{-9}}$$

$$= 1.5 \times 10^{-6}\ mol/L$$

Check Your Solution

$$[H_3O^+][OH^-] = (6.5 \times 10^{-9}) \times (1.5 \times 10^{-6})$$

$$= 9.8 \times 10^{-15}$$

This is equal to the value of K_w, 1.0×10^{-14}, within the error introduced by mathematical rounding.

25. Problem

A chemist dissolved some Aspirin™ in water. The chemist then measured the pH of the solution and found it to be 2.73 at 25°C. What are the $[H_3O^+]$ and $[OH^-]$ of the solution?

Solution

Find the hydronium ion concentration using the following equation:

$$[H_3O^+] = 10^{-pH}$$

$$[H_3O^+] = 10^{-2.73} = 1.9 \times 10^{-3}\ mol/L$$

Use the following equation to find the hydroxide ion concentration:

$$[OH^-] = \frac{1.0 \times 10^{-14}\ mol/L}{[H_3O^+]}$$

$$[OH^-] = \frac{1.0 \times 10^{-14} mol/L}{1.9 \times 10^{-3}}$$

$$= 5.3 \times 10^{-12}\ mol/L$$

Check Your Solution

$$[H_3O^+][OH^-] = (1.9 \times 10^{-3}) \times (5.3 \times 10^{-12})$$

$$= 1.0 \times 10^{-14}$$

This is equal to the value of K_w at 25°C.

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26. Problem

Calculate the pH of a $HNO_{3(aq)}$ solution which is formed by diluting 45 mL of 0.0115 mol/L $HNO_{3(aq)}$ to a final volume of 2.00 L.

What is Required?

You must determine the final pH of a solution after a dilution was carried out.

What is Given?

Initial: $V_i = 45$ mL, $c_i = 0.0115$ mol/L, $V_f = 2.00$ L

Plan Your Strategy

Step 1 Calculate c_f using the equation $c_i V_i = c_f V_f$

Step 2 Since $HNO_{3(aq)}$ is a strong acid containing one H^+ ion per mol of $HNO_{3(aq)}$, c_f for the $HNO_{3(aq)} = c_f$ for $H_3O^+_{(aq)}$ and $pH = -\log[H_3O^+_{(aq)}]$