CH 223 Chapter Fourteen Part I Concept Guide

1. Identifying Brønsted-Lowry Acids and Bases

Problem

Identify the Brønsted-Lowry acid (a reactant) and its conjugate base (a product) in each of the following reactions:

(a) $HNO_3(\ell) + H_2O(\ell) \rightleftarrows H_3O^+ + NO_3^-$
(b) $H_3O^+ + HS^- \rightleftarrows H_2S(aq) + H_2O(\ell)$
(c) $HF(aq) + OH^- \rightleftarrows H_2O(\ell) + F^-$

Solution

The Brønsted-Lowry acids are the species that donates the proton in each reaction. In the above reactions, the Brønsted-Lowry acids are:

(a) HNO_3
(b) H_3O^+
(c) HF

The conjugate base for each acid is the species formed by the removal of a proton from the acid:

(a) NO_3^-
(b) H_2O
(c) F^-

2. Ion Product Constant of Water

Question

What is the concentration of OH^- in a 0.04 M HCl solution?

Approach

Because HCl is a strong acid and is 100% ionized, the H_3O^+ concentration is equivalent to the molarity of the HCl solution, 0.04 M. To solve this problem, use the relationship between the concentrations of H_3O^+ and OH^- and water: $K_w = [H_3O^+] [OH^-]$.

Solution

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

Solving this for OH^- and substituting the known values of K_w and $[H_3O^+]$ gives

$$[OH^-] = \frac{K_w}{[H_3O^+]} = \frac{1.00 \times 10^{-14}}{0.04} = 3 \times 10^{-13}\ M$$

3. pH and pOH

Question

What are the pH and $[H_3O^+]$ of a solution that has $[OH^-] = 2.50 \times 10^{-5}$ M?

Solution

$pOH = -\log [OH^-] = -\log (2.50 \times 10^{-5}\ M) = 4.60$

$pH = 14.00 - pOH = 14.00 - 4.60 = 9.40$

$\log [H_3O^+] = -pH = -9.40$

$[H_3O^+] = 3.98 \times 10^{-10}$

4. K_a-K_b Relationship

Problem

The value of K_a for hydrocyanic acid (HCN) is 6.2×10^{-10}. Calculate the value of K_b for the conjugate base.

Solution

$HCN(aq) + H_2O(\ell) \rightleftharpoons H_3O^+ + CN^-$

In this reaction, the conjugate base is the cyanide ion, CN^-. The value of K_b for the reaction of CN^- as a base with water is:

$CN^- + H_2O(\ell) \longrightarrow HCN(aq) + OH^-$

$$K_b = \frac{K_w}{K_a} = \frac{1.00 \times 10^{-14}}{6.2 \times 10^{-10}} = 1.6 \times 10^{-5}$$

The value of K_b for the conjugate base, CN^-, is 1.6×10^{-5}.

5. Calculating pH

Question

If the hydronium ion concentration in vinegar is 1.8×10^{-3}, what is its pH?

Solution

$pH = -\log [H_3O^+] = -\log (1.8 \times 10^{-3}) = 2.74$

6. Calculating pH

Problem

Find the pH of a 0.052 M hypobromous acid (HBrO) solution.

$HBrO(aq) + H_2O(\ell) \rightleftharpoons H_3O^+ + BrO^-$ $\quad K_a = 2.2 \times 10^{-9}$

Approach

Write the corresponding equilibrium expression and identify what is unknown. Make a table to include the chemical equation, initial concentrations, changes in concentration, and equilibrium concentrations. Substitute the equilibrium concentrations from the table into the equilibrium expression and solve for the unknown (x). If an approximation was made, remember to check for validity. Finally, answer the question in the problem using some form of the value of x.

Solution

The unknown is $[H_3O^+]$ at equilibrium. Letting $x = [H_3O^+]$,

	$HBrO(aq) \rightleftharpoons$	**H_3O^+**	**$+ BrO^-$**
Initial	0.052 M	0 M	0 M
Change	- x	+ x	+ x
Equilibrium	0.052 - x	x	x

$$K_a = \frac{[H_3O^+][BrO^-]}{[HBrO]} = \frac{(x)(x)}{(0.052 - x)} = 2.2 \times 10^{-9}$$

$$\text{If } \frac{K_a[\text{initial}]}{1000}, \text{ then } K_a = \frac{x^2}{[\text{initial}] - x} \cong \frac{x^2}{[\text{initial}]}$$

Assuming that (0.052 - x) is approximately equal to 0.052,

$x^2 = (0.052)(2.2 \times 10^{-9}) = 1.1 \times 10^{-10}$ M

$x = 1.1 \times 10^{-5}$ M

$pH = - \log [H_3O^+] = \log (1.1 \times 10^{-5}) = 4.95$

The pH of this solution is 4.95.

7. Predicting the pH of Salt Solutions

Problem

Predict whether each salt listed below has a pH greater then, less than, or equal to 7.

(a) $FeCl_3$

(b) NH_4NO_3

(c) Na_2HPO_4

Solution

(a) Fe^{3+} ion is acidic and Cl^- ion is neutral. Therefore $FeCl_3$ is acidic, and the pH is less than 7.

(b) NH_4^+ is acidic and NO_3^- is neutral. Therefore, NH_4NO_3 is acidic, and the pH is less than 7.

(c) Na^+ is neutral and HPO_4^{2-} is basic. Therefore, Na_2HPO_4 is basic, and the pH is greater than 7.

8. Identifying Lewis Bases

Problem

Each of the following is a Lewis acid-base reaction:

(a) $Ni^{2+}(aq) + 4\ CN^-(aq) \rightarrow Ni(CN)_4^{2-}(aq)$

(b) $NH_3(aq) + H^+ \rightarrow NH_4^+$

(c) $BF_3(aq) + F^- \rightarrow BF_4^-$

(d) $H^+ + OH^- \rightarrow H_2O(\ell)$

Solution

(a) CN^- is the base. An electron pair is donated by the carbon atom to the nickel ion.

(b) In Lewis acid-base terms, the free hydrogen ion is thought of as the electron-pair acceptor. Here, NH_3 is the base and the electron-pair donor.

(c) The fluoride ion donates a pair of electrons to the boron atom and is therefore the base.

(d) The H^+ ion is an electron-pair acceptor, a Lewis acid. The OH^- ion is an electron-pair donor, a Lewis base. This shows that water-ion acids and bases are also Lewis acids and bases.

9. Lewis Acids and Bases

Problem

Determine whether each substance below should be classified as a Lewis acid or base.

(a) Mn^{2+}

(b) CH_3NH_2

(c) H_2NOH in the reaction: $H_2NOH(aq) + HCl(aq) \rightarrow [H_3NOH]Cl(aq)$

(d) SO_2 in the reaction: $SO_2(g) + BF_3(g) \rightarrow O_2S\text{-}BF_3(s)$

Solution

(a) Lewis acid. Mn^{2+} is expected to accept an electron pair because it is positively charged.

(b) Lewis base. CH_3NH_2 is anticipated to donate an electron pair. The N atom has a long electron pair with which it can form a bond with a Lewis acid.

(c) Lewis base. In the reaction, H_2NOH donates an electron pair to the H^+ ion of HCl to form the adduct, $[H_3NOH]Cl$.

(d) Lewis base. SO_2 has a lone electron pair on the central S atom. In the reaction, SO_2 donates an electron pair to form the adduct, $O_2S\text{-}BF_3$.

10. Classifying Lewis Acid-Base Reactions

Question

Which of the following reactions are Lewis acid-base reactions? Identify the Lewis base in each of the acid-base reactions.

(a) $Ag^+ + 2\ NH_3 \rightarrow [Ag(NH_3)_2]^+$

(b) $I^- + I_2 \rightarrow I_3^-$

(c) $H_3O^+ + OH^- \rightarrow 2\ H_2O$

(d) $H^+ + H_2O \rightarrow H_2 + OH^-$

Answer

All the above reactions are Lewis acid-base reactions. The Lewis bases, the species that donate an electron pair to form a bond with another species, are:

(a) NH_3

(b) I^-

(c) OH^-

(d) H_2O