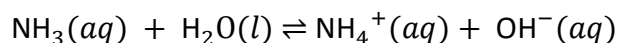


Acid-Base Equilibria

Section 91 – Bronsted-Lowry Acids and Bases

- 91-1 Write an equation that shows NH_3 acting as a base in aqueous solution. What is the conjugate acid of NH_3 ?

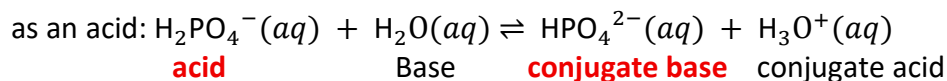
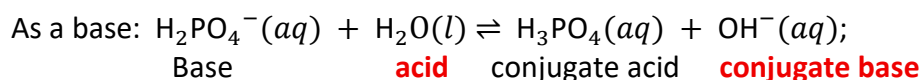
Solution



The conjugate acid is the ammonium ion, NH_4^+ .

- 91-2 Write equations that show H_2PO_4^- acting both as an acid and as a base in aqueous solution. For each equation, indicate the conjugate acid/base pairs.

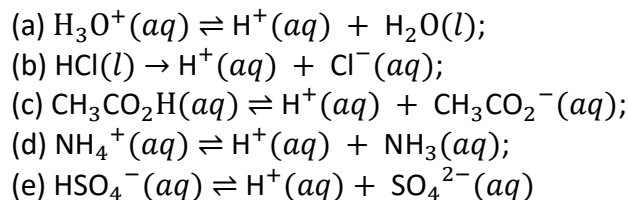
Solution



- 91-3 Show by suitable net ionic equations that each of the following species can act as a Brønsted-Lowry acid in aqueous solution:

- (a) H_3O^+
- (b) HCl
- (c) $\text{CH}_3\text{CO}_2\text{H}$
- (d) NH_4^+
- (e) HSO_4^-

Solution



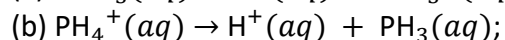
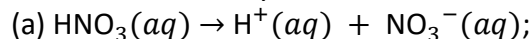
- 91-4 Show by suitable net ionic equations that each of the following species can act as a Brønsted-Lowry acid.

- (a) HNO_3
- (b) PH_4^+
- (c) H_2S

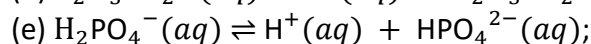
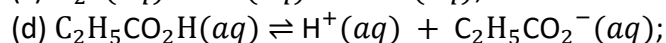
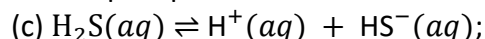
- (d) $\text{CH}_3\text{CH}_2\text{COOH}$
- (e) H_2PO_4^-

Solution

In a Brønsted-Lowry acid, the acid must supply an H^+ .



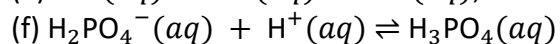
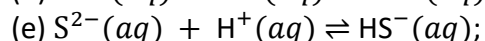
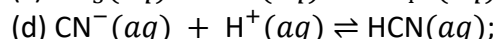
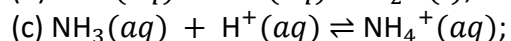
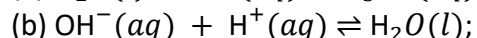
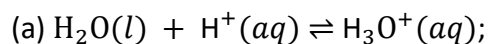
Note: the phosphonium ion, PH_4^+ , is a strong acid, and will completely dissociate in water to form phosphine, PH_3 . Phosphine is a toxic, flammable gas. There are important applications that use phosphine but it is very dangerous to work with. Thus, the phosphonium ion is not listed in our table of "common acids".



- 91-5 Show by suitable net ionic equations that each of the following species can act as a Brønsted-Lowry base in aqueous solution:

- (a) H_2O
- (b) OH^-
- (c) NH_3
- (d) CN^-
- (e) S^{2-}
- (f) H_2PO_4^-

Solution



- 91-6 Show by suitable net ionic equations that each of the following species can act as a Brønsted-Lowry base:

- (a) HS^-
- (b) PO_4^{3-}
- (c) NH_2^-
- (d) $\text{C}_2\text{H}_5\text{OH}$
- (e) O^{2-}
- (f) H_2PO_4^-

Solution

In a Brønsted-Lowry base, the base must accept an H^+ .

- (a) $\text{HS}^- + \text{H}^+ \rightleftharpoons \text{H}_2\text{S}$;
- (b) $\text{PO}_4^{3-} + \text{H}^+ \rightleftharpoons \text{HPO}_4^{2-}$;
- (c) $\text{NH}_2^- + \text{H}^+ \rightleftharpoons \text{NH}_3$
- (d) $\text{C}_2\text{H}_5\text{OH} + \text{H}^+ \rightleftharpoons \text{C}_2\text{H}_5\text{OH}_2^+$;
- (e) $\text{O}^{2-} + \text{H}^+ \rightleftharpoons \text{OH}^-$;
- (f) $\text{HPO}_4^{2-} + \text{H}^+ \rightleftharpoons \text{H}_2\text{PO}_4^-$

91-7 What is the conjugate acid of each of the following? What is the conjugate base of each?

- (a) OH^-
- (b) H_2O
- (c) HCO_3^-
- (d) NH_3
- (e) HSO_4^-
- (f) H_2O_2
- (g) HS^-
- (h) H_5N_2^+

Solution

Note that to form the conjugate acid, you just add an H^+ ; to form the conjugate base you remove an H^+ . Be careful to balance the charge.

- (a) H_2O , O^{2-} ;
- (b) H_3O^+ , OH^- ;
- (c) H_2CO_3 , CO_3^{2-} ;
- (d) NH_4^+ , NH_2^- ;
- (e) H_2SO_4 , SO_4^{2-} ;
- (f) H_3O_2^+ , HO_2^- ;
- (g) H_2S ; S^{2-} ;
- (h) $\text{H}_6\text{N}_2^{2+}$, H_4N_2

91-8 What is the conjugate acid of each of the following? What is the conjugate base of each?

- (a) H_2S
- (b) H_2PO_4^-
- (c) PH_3
- (d) HS^-
- (e) HSO_3^-
- (f) H_3O_2^+
- (g) H_4N_2
- (h) CH_3OH

Solution

- (a) H_3S^+ , HS^- ;
- (b) H_3PO_4^- , HPO_4^{2-} ;
- (c) PH_4^+ , PH_2^- ;
- (d) H_2S , S^{2-} ;

- (e) H_2SO_3 , SO_3^{2-} ;
(f) $\text{H}_4\text{O}_2^{2+}$, H_2O_2 ;
(g) H_5N_2^+ , H_3N_2^- ;
(h) CH_3OH_2^+ , CH_3O^-

91-9 Identify and label the Brønsted-Lowry acid, its conjugate base, the Brønsted-Lowry base, and its conjugate acid in each of the following equations:

- (a) $\text{HNO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{NO}_3^-$
(b) $\text{CN}^- + \text{H}_2\text{O} \rightarrow \text{HCN} + \text{OH}^-$
(c) $\text{H}_2\text{SO}_4 + \text{Cl}^- \rightarrow \text{HCl} + \text{HSO}_4^-$
(d) $\text{HSO}_4^- + \text{OH}^- \rightarrow \text{SO}_4^{2-} + \text{H}_2\text{O}$
(e) $\text{O}^{2-} + \text{H}_2\text{O} \rightarrow 2\text{OH}^-$
(f) $[\text{Cu}(\text{H}_2\text{O})_3(\text{OH})]^+ + [\text{Al}(\text{H}_2\text{O})_6]^{3+} \rightarrow [\text{Cu}(\text{H}_2\text{O})_4]^{2+} + [\text{Al}(\text{H}_2\text{O})_5(\text{OH})]^{2+}$
(g) $\text{H}_2\text{S} + \text{NH}_2^- \rightarrow \text{HS}^- + \text{NH}_3$

Solution

The labels are Brønsted-Lowry acid = BA; its conjugate base = CB; Brønsted-Lowry base = BB; its conjugate acid = CA.

- (a) HNO_3 (BA), H_2O (BB), H_3O^+ (CA), NO_3^- (CB);
(b) CN^- (BB), H_2O (BA), HCN (CA), OH^- (CB);
(c) H_2SO_4 (BA), Cl^- (BB), HCl (CA), HSO_4^- (CB);
(d) HSO_4^- (BA), OH^- (BB), SO_4^{2-} (CB), H_2O (CA);
(e) O^{2-} (BB), H_2O (BA), OH^- (CB and CA);
(f) $[\text{Cu}(\text{H}_2\text{O})_3(\text{OH})]^+$ (BB), $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$ (BA), $[\text{Cu}(\text{H}_2\text{O})_4]^{2+}$ (CA), $[\text{Al}(\text{H}_2\text{O})_5(\text{OH})]^{2+}$ (CB); (g)
 H_2S (BA), NH_2^- (BB), HS^- (CB), NH_3 (CA)

91-10 Identify and label the Brønsted-Lowry acid, its conjugate base, the Brønsted-Lowry base, and its conjugate acid in each of the following equations:

- (a) $\text{NO}_2^- + \text{H}_2\text{O} \rightarrow \text{HNO}_2 + \text{OH}^-$
(b) $\text{HBr} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Br}^-$
(c) $\text{HS}^- + \text{H}_2\text{O} \rightarrow \text{H}_2\text{S} + \text{OH}^-$
(d) $\text{H}_2\text{PO}_4^- + \text{OH}^- \rightarrow \text{HPO}_4^{2-} + \text{H}_2\text{O}$
(e) $\text{H}_2\text{PO}_4^- + \text{HCl} \rightarrow \text{H}_3\text{PO}_4 + \text{Cl}^-$
(f) $[\text{Fe}(\text{H}_2\text{O})_5(\text{OH})]^{2+} + [\text{Al}(\text{H}_2\text{O})_6]^{3+} \rightarrow [\text{Fe}(\text{H}_2\text{O})_6]^{3+} + [\text{Al}(\text{H}_2\text{O})_5(\text{OH})]^{2+}$
(g) $\text{CH}_3\text{OH} + \text{H}^- \rightarrow \text{CH}_3\text{O}^- + \text{H}_2$

Solution

The labels are Brønsted-Lowry acid = BA; its conjugate base = CB; Brønsted-Lowry base = BB; and its conjugate acid = CA.

- (a) NO_2^- (BB), H_2O (BA), HNO_2 (CA), OH^- (CB);
- (b) HBr (BA), H_2O (BB), H_3O^+ (CA), Br^- (CB);
- (c) HS^- (BB), H_2O (BA), H_2S (CA), OH^- (CB);
- (d) H_2PO_4^- (BA), OH^- (BB), HPO_4^{2-} (CB), H_2O (CA);
- (e) H_2PO_4^- (BB), HCl (BA), H_3PO_4 (CA), Cl^- (CB);
- (f) $[\text{Fe}(\text{H}_2\text{O})_5(\text{OH})]^{2+}$ (BB), $[\text{Al}(\text{H}_2\text{O})_6]^{3+}$ (BA), $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ (CA), $[\text{Al}(\text{H}_2\text{O})_5(\text{OH})]^{2+}$ (CB);
- (g) CH_3OH (BA), H^- (BB), CH_3O^- (CB), H_2 (CA)

91-11 What are amphiprotic species? Illustrate with suitable equations.

Solution

Amphiprotic species may either gain or lose a proton in a chemical reaction, thus acting as a base or an acid. An example is H_2O . As an acid: $\text{H}_2\text{O}(l) + \text{NH}_3(aq) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)$. As a base: $\text{H}_2\text{O}(l) + \text{HCl}(aq) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{Cl}^-(aq)$

91-12 State which of the following species are amphiprotic and write chemical equations illustrating the amphiprotic character of these species:

- (a) H_2O
- (b) H_2PO_4^-
- (c) S^{2-}
- (d) CO_3^{2-}
- (e) HSO_4^-

Solution

amphiprotic:

- (a) $\text{H}_2\text{O}(l) + \text{HBr}(aq) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{Br}^-(aq)$,
 $\text{H}_2\text{O}(l) + \text{CN}^-(aq) \rightleftharpoons \text{HCN}(aq) + \text{OH}^-(aq)$;
- (b) $\text{H}_2\text{PO}_4^-(aq) + \text{HBr}(aq) \rightleftharpoons \text{H}_3\text{PO}_4(aq) + \text{Br}^-(aq)$,
 $\text{H}_2\text{PO}_4^-(aq) + \text{OH}^-(aq) \rightleftharpoons \text{HPO}_4^{2-}(aq) + \text{H}_2\text{O}(l)$;
- (e) $\text{HSO}_4^-(aq) + \text{HClO}_4(aq) \rightleftharpoons \text{H}_2\text{SO}_4(aq) + \text{ClO}_4^-(aq)$,
 $\text{HSO}_4^-(aq) + \text{OH}^-(aq) \rightleftharpoons \text{SO}_4^{2-}(aq) + \text{H}_2\text{O}(l)$;

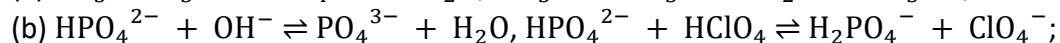
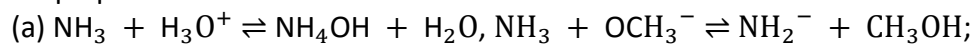
not amphiprotic (neither has a proton to donate, and so cannot serve as an acid): (c) S^{2-} , (d) CO_3^{2-}

91-13 State which of the following species are amphiprotic and write chemical equations illustrating the amphiprotic character of these species.

- (a) NH_3
- (b) HPO_4^{2-}
- (c) Br^-
- (d) NH_4^+
- (e) ASO_4^{3-}

Solution

Amphiprotic:



not amphiprotic: (c) Br^- ; (d) NH_4^+ ; (e) AsO_4^{3-}

91-14 Which of the following does not fit the definition of a Brønsted Acid?

- (a) H_3PO_4
- (b) H_2PO_4^-
- (c) H_2O
- (d) NH_4^+
- (e) CO_2

Solution: A Brønsted Acid can donate a proton. All of compounds (a) – (d) have protons that they can donate in aqueous solution. CO_2 does not have any protons, and thus it cannot directly act as a Brønsted

91-15 Which of the following does not fit the definition of a Brønsted Base?

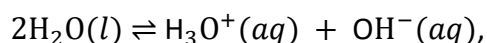
- (a) NH_3
- (b) H_2O
- (c) NH_4^+
- (d) HCO_3^-
- (e) CO_3^{2-}

Solution: A Brønsted Base can accept a proton. All of the compounds except ammonium ion (NH_4^+) can accept a proton, and so ammonium ion is the only one that cannot act as a Brønsted Base.

91-16 Is the self-ionization of water endothermic or exothermic? The ionization constant for water (K_w) is 2.9×10^{-14} at 40 °C and 9.3×10^{-14} at 60 °C.

Solution

The equation for the self-ionization of water is



You are given that the K_w increases with increasing temperature – i.e., when more heat is available, the reaction shifts to the product side. According to Le Châtelier's principle, the system will try to resist the change (added heat), and so it will shift in the direction that uses up heat. Therefore, the reaction is endothermic.