Unit 7, Lesson 05: Answers to Working with Ka, Kb and Kw

4. For each of the following acids:
- write the ionization reaction in water and the Ka expression
- write the ionization reaction for its conjugate base and Kb expression
- calculate the value of Kb for the conjugate base

a) benzoic acid

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

$C_6H_5COOH\ (aq) \quad + \quad H_2O\ (l) \quad \leftrightarrow \quad C_6H_5COO^{1-}\ (aq) \quad + \quad H_3O^{1+}\ (aq)$

$$Ka = \frac{[C_6H_5COO^{1-}]\,[H_3O^{1+}]}{[C_6H_5COOH]}$$

$= 6.3 \times 10^{-5}$ (from page 597)

The K_b equation shows the ionization and dissociation of the base to form OH^- in water:

$C_6H_5COO^-\ (aq) \quad + \quad H_2O\ (l) \quad \leftrightarrow \quad C_6H_5COOH\ (aq) \quad + \quad OH^-\ (aq)$

$$Kb = \frac{[C_6H_5COOH]\,[OH^{1-}]}{[C_6H_5COO^-]}$$

$= Kw / Ka$

$= 1.0 \times 10^{-14} / 6.3 \times 10^{-5}$

$= 1.6 \times 10^{-10}$

b) hydrofluoric acid

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

$HF\ (aq) \quad + \quad H_2O\ (l) \quad \leftrightarrow \quad F^{1-}\ (aq) \quad + \quad H_3O^{1+}\ (aq)$

$$Ka = \frac{[F^{1-}]\,[H_3O^{1+}]}{[HF]}$$

$= 6.3 \times 10^{-4}$ (from page 597)

The K_b equation shows the ionization and dissociation of the base to form OH^- in water:

$F^-\ (aq) \quad + \quad H_2O\ (l) \quad \leftrightarrow \quad HF\ (aq) \quad + \quad OH^-\ (aq)$

$$Kb = \frac{[HF]\,[OH^{1-}]}{[F^-]}$$

$= Kw / Ka$

$= 1.0 \times 10^{-14} / 6.3 \times 10^{-4}$

$= 1.6 \times 10^{-11}$

c) iodic acid HIO_3

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

HIO_3 (aq) + H_2O (l) ↔ IO_3^{1-} (aq) + H_3O^{1+} (aq)

$$Ka = \frac{[IO_3^{1-}][H_3O^{1+}]}{[HIO_3]}$$

$= 1.7 \times 10^{-1}$ (from page 597)

The K_b equation shows the ionization and dissociation of the base to form OH^- in water:

IO_3^- (aq) + H_2O (l) ↔ HIO_3 (aq) + OH^- (aq)

$$Kb = \frac{[HIO_3][OH^{1-}]}{[IO_3^-]}$$

$= Kw / Ka$

$= 1.0 \times 10^{-14} / 1.7 \times 10^{-1}$

$= 5.9 \times 10^{-14}$

d) $H_2BO_3^{1-}$ (aq)

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

$H_2BO_3^{1-}$ (aq) + H_2O (l) ↔ HBO_3^{2-} (aq) + H_3O^{1+} (aq)

$$Ka = \frac{[HBO_3^{2-}][H_3O^{1+}]}{[H_2BO_3^{1-}]}$$

$< 1.0 \times 10^{-14}$ (from table E.10 on page 597)

The K_b equation shows the ionization and dissociation of the base to form OH^- in water:

HBO_3^{2-} (aq) + H_2O (l) ↔ $H_2BO_3^{1-}$ (aq) + OH^- (aq)

$$Kb = \frac{[H_2BO_3^{1-}][OH^{1-}]}{[HBO_3^{2-}]}$$

$= Kw / Ka$

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

> 1 (so HBO_3^{2-} is a very strong base)

e) HCO_3^{1-} (aq)

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

HCO_3^{1-} (aq) + H_2O (l) ↔ CO_3^{2-} (aq) + H_3O^{1+} (aq)

$$Ka = \frac{[CO_3^{2-}][H_3O^{1+}]}{[HCO_3^{1-}]}$$

$= 4.7 \times 10^{-11}$ (from table E.10 on page 597)

The K_b equation shows the ionization and dissociation of the base to form OH^- in water:

CO_3^{2-} (aq) + H_2O (l) ↔ HCO_3^{1-} (aq) + OH^- (aq)

$$Kb = \frac{[HCO_3^{1-}][OH^{1-}]}{[CO_3^{2-}]}$$

$= Kw / Ka$

$= 1.0 \times 10^{-14} / 4.7 \times 10^{-11}$

$= 2.1 \times 10^{-4}$

5. For each of the following bases:
- write the ionization reaction in water and the Kb expression
- write the ionization reaction for its conjugate acid and Ka expression
- calculate the value of Ka for the conjugate acid

a) hydroxlamine

The K_b equation shows the ionization and dissociation of the base to form OH^- in water. Add a hydrogen ion (H+) to the original compound:

NH_2OH (aq) + H_2O (l) ↔ NH_3OH^+ (aq) + OH^- (aq)

$$Kb = \frac{[NH_3OH^+][OH^{1-}]}{[NH_2OH]}$$

$= 8.8 \times 10^{-9}$ (from table E.11 on page 597)

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

NH_3OH^+ (aq) + H_2O (l) ↔ NH_2OH (aq) + H_3O^{1+} (aq)

$$Ka = \frac{[NH_2OH][H_3O^{1+}]}{[NH_3OH^+]}$$

$= Kw / Kb$

$= 1.0 \times 10^{-14} / 8.8 \times 10^{-9}$

$= 1.1 \times 10^{-6}$

b) ethanamine

The K_b equation shows the ionization and dissociation of the base to form OH^- in water. Add a hydrogen ion (H+) to the original compound:

$C_2H_5NH_2$ (aq) + H_2O (l) ↔ $C_2H_5NH_3^+$ (aq) + OH^- (aq)

$$Kb = \frac{[C_2H_5NH_3^+]\,[OH^{1-}]}{[C_2H_5NH_2]}$$

$= 4.5 \times 10^{-4}$ (from table E.11 on page 597)

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

$C_2H_5NH_3^+$ (aq) + H_2O (l) ↔ $C_2H_5NH_2$ (aq) + H_3O^{1+} (aq)

$$Ka = \frac{[C_2H_5NH_2]\,[H_3O^{1+}]}{[C_2H_5NH_3^+]}$$

$= Kw / Kb$

$= 1.0 \times 10^{-14} / 4.5 \times 10^{-4}$

$= 2.2 \times 10^{-11}$

c) urea

The K_b equation shows the ionization and dissociation of the base to form OH^- in water. Add a hydrogen ion (H+) to the original compound:

NH_2CONH_2 (aq) + H_2O (l) ↔ $NH_2CONH_3^+$ (aq) + OH^- (aq)

$$Kb = \frac{[NH_2CONH_3^+]\,[OH^{1-}]}{[NH_2CONH_2]}$$

$= 1.3 \times 10^{-14}$ (from table E.11 on page 597)

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

$NH_2CONH_3^+$ (aq) + H_2O (l) ↔ NH_2CONH_2 (aq) + H_3O^{1+} (aq)

$$Ka = \frac{[NH_2CONH_2]\,[H_3O^{1+}]}{[NH_2CONH_3^+]}$$

$= Kw / Kb$

$= 1.0 \times 10^{-14} / 1.3 \times 10^{-14}$

$= 0.77$ (quite a strong acid)

d) $H_2BO_3^{1-}$ (aq)

The K_b equation shows the ionization and dissociation of the base to form OH^- in water. Add a hydrogen ion (H+) to the original compound:

$H_2BO_3^{1-}$ (aq) + H_2O (l) ↔ H_3BO_3 (aq) + OH^- (aq)

$$Kb = \frac{[H_3BO_3]\,[OH^{1-}]}{[H_2BO_3^{1-}]}$$

We only know the Ka for H_3BO_3 (aq) = 5.4×10^{-10} (from table E.10 on page 597), so we can calculate Kb using this value:

Kb = Kw / Ka

= 1.0×10^{-14} / 5.4×10^{-10}

= 1.85×10^{-5} or 1.9×10^{-5} (2 sd)

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

H_3BO_3 (aq) + H_2O (l) ↔ $H_2BO_3^{1-}$ (aq) + H_3O^{1+} (aq)

$$Ka = \frac{[H_2BO_3^{1-}]\,[H_3O^{1+}]}{[H_3BO_3\,]}$$

= 5.4×10^{-10} (from table E.10 on page 597)

e) HCO_3^{1-} (aq)

The K_b equation shows the ionization and dissociation of the base to form OH^- in water. Add a hydrogen ion (H+) to the original compound:

HCO_3^{1-} (aq) + H_2O (l) ↔ H_2CO_3 ((aq) + OH^- (aq)

$$Kb = \frac{[H_2CO_3]\,[OH^{1-}]}{[HCO_3^{1-}]}$$

We only know the Ka for H_2CO_3 (aq) = 4.5×10^{-7} (from table E.10 on page 597), so we can calculate Kb using this value:

Kb = Kw / Ka

= 1.0×10^{-14} / 4.5×10^{-7}

= 2.2×10^{-8}

The K_a equation shows the ionization and dissociation of the acid to form H_3O^+ in water:

H_2CO_3 (aq) + H_2O (l) ↔ HCO_3^{1-} (aq) + H_3O^{1+} (aq)

$$Ka = \frac{[HCO_3^{1-}]\,[H_3O^{1+}]}{[H_2CO_3\,]}$$

= 4.5×10^{-7} (from table E.10 on page 597)

6. Given the relationship $K_a \cdot K_b = K_w$, complete the following statements:

a) If the K_a for an acid is large, the K_b for its conjugate base is: small

b) If the K_a for an acid is small, the K_b for its conjugate base is: **large**

c) If the K_b for a base is large, the K_a for its conjugate acid is: **small**

d) If the K_b for a base is small, the K_a for its conjugate acid is: **large**