Acid Base Worksheet No. 3 — Key.

1. a. $HCN + H_2O \leftrightarrow CN^- + H_3O^+$

   b. CN^-

   c. $K_a = \frac{[CN^-][H_3O^+]}{[HCN]}$

   d. Let $x = [H_3O^+]$, then $[CN^-] = x$ and $[HCN] = 0.25M - x \approx 0.25M$ if x is small

   $K_a = 4.9 \times 10^{-10} = \frac{x^2}{0.25}$ $\quad x = [H_3O^+] = 1.1 \times 10^{-5} M$

   e. $pH = -\log[H_3O^+] = -\log(1.1 \times 10^{-5} M) = 4.96$

   f. $[H_3O^+][OH^-] = k_w \quad [OH^-] = \frac{1.00 \times 10^{-14}}{1.1 \times 10^{-5} M} = 9.0 \times 10^{-10} M$

   g. $[HCN]_{eqm} = [HCN]_{initial} - 1.1 \times 10^{-5} M = 0.25M$

   h. % dissociation $= \frac{1.1 \times 10^{-5} M}{0.25 M} \times 100 = 4.4 \times 10^{-3}$ %

2. $HA + H_2O \leftrightarrow A^- + H_3O^+$

   $K_a = \frac{[A^-][H_3O^+]}{[HA]}$

   $[H_3O^+] = \text{antilog}(-3.45) = 3.55 \times 10^{-4} M$

   $[A^-] = [H_3O^+] = 3.55 \times 10^{-4} M$

   $[HA] = 0.20M - 3.55 \times 10^{-4} M = 0.20 M$

   $K_a = \frac{(3.55 \times 10^{-4})^2}{0.20} = 6.3 \times 10^{-7}$

   % dissociation $= \frac{3.55 \times 10^{-4} M}{0.20 M} \times 100 = 1.8 \times 10^{-1}$ %

3. $HX + H_2O \leftrightarrow X^- + H_3O^+$

   $K_a = \frac{[X^-][H_3O^+]}{[HX]} = 1.0 \times 10^{-8}$

   Let $x = [H_3O^+]$, then $[X^-] = x$ and $[HX] = 1.0M - x \approx 1.0M$ if x is small

   $1.0 \times 10^{-8} = \frac{x^2}{1.0}$ $\quad x = [H_3O^+] = 1.0 \times 10^{-4} M$ $\quad pH = -\log[H_3O^+] = -\log(1.0 \times 10^{-4})$

   $pH = 4.00$

4. $HPO_4^{2-} + HCO_3^- \longleftrightarrow H_2PO_4^- + CO_3^{2-}$

5. $HNO_2 + H_2O \longleftrightarrow NO_2^- + H_3O^+$

   (a: HNO_2 / H_3O^+; b: H_2O / NO_2^-)

   Let $x = [H_3O^+]$, then $[NO_2^-] = x$ and $[HNO_2] = 0.40M - x \approx 0.40M$ if x is small

   $K_a = \frac{[NO_2^-][H_3O^+]}{[HNO_2]} = 4.6 \times 10^{-4}$

   $4.6 \times 10^{-4} = \frac{x^2}{0.40}$ $\quad x = [H_3O^+] = 1.4 \times 10^{-2} M$

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6. $HA + H_2O \longleftrightarrow A^- + H_3O^+$ (a, b, b, a)

$K_a = \frac{[A^-][H_3O^+]}{[HA]}$

$[H_3O^+] = 4.5 \times 10^{-4}\ M$

$[A^-] = [H_3O^+] = 4.5 \times 10^{-4}\ M$

$[HA] = 0.35 - 4.5 \times 10^{-4}\ M = 0.35\ M$

$K_a = \frac{(4.5 \times 10^{-4}\ M)^2}{0.35} = 5.8 \times 10^{-7}$

this acid is between H_2CO_3 and $Al(H_2O)_6^{3+}$ on the Strengths of Acids table.

7. $HCN + H_2O \longleftrightarrow CN^- + H_3O^+$ (a, b, b, a)

$K_a = \frac{[CN^-][H_3O^+]}{[HCN]} = 4.9 \times 10^{-10}$

let $x = [H_3O^+]$, then $[CN^-] = x$

and $[HCN] = \frac{1.6\ mols}{2.0\ L} - x \approx 0.80\ M$ if x is small

$4.9 \times 10^{-10} = \frac{x^2}{0.80}$

$x = [CN^-] = \underline{2.0 \times 10^{-5}\ M}$

8. $CH_3COOH + H_2O \longleftrightarrow CH_3COO^- + H_3O^+$

$K_a = \frac{[CH_3COO^-][H_3O^+]}{[CH_3COOH]} = 1.8 \times 10^{-5}$

$[H_3O^+] = \text{antilog}(-2.456) = 3.499 \times 10^{-3}\ M$

$[CH_3COO^-] = [H_3O^+] = 3.499 \times 10^{-3}\ M$

$[CH_3COOH] = [CH_3COOH]_{initial} - 3.499 \times 10^{-3}\ M$

$1.8 \times 10^{-5} = \frac{(3.499 \times 10^{-3})^2}{[CH_3COOH]_{ini} - 3.499 \times 10^{-3}\ M}$

$[CH_3COOH]_{initial} = 6.8 \times 10^{-1}\ M$

mols CH_3COOH = $0.68\ M \times 2.00\ L = 1.4\ mol$

mass CH_3COOH = $1.4\ mol \times 60.0\ g/mol = \underline{82\ g}$.

9. 0.1 M HCl

pH = 1.0

$\frac{1.0\ mL \times 0.1\ M}{100.\ mL} = 1.0 \times 10^{-3}\ M$ HCl

pH = 3.0

Changes by 2.0 pH units.

10. $HX + H_2O \longleftrightarrow X^- + H_3O^+$

$K_a = \frac{[X^-][H_3O^+]}{[HX]}$

$[H_3O^+] = \text{antilog}(-1.40) = 3.98 \times 10^{-2}\ M$

$[X^-] = [H_3O^+] = 3.98 \times 10^{-2}\ M$

$[HX] = 0.18\ M - 3.98 \times 10^{-2}\ M = 0.140\ M$

$K_a = \frac{(3.98 \times 10^{-2}\ M)^2}{0.140\ M} = \underline{1.1 \times 10^{-2}}$

11. $HX + H_2O \longleftrightarrow X^- + H_3O^+$

$K_a = \frac{[X^-][H_3O^+]}{[HX]}$

$[H_3O^+] = \text{antilog}(-4.26) = 5.50 \times 10^{-5}\ M$

$[X^-] = [H_3O^+] = 5.50 \times 10^{-5}\ M$

$[HX] = 1.0\ M - 5.50 \times 10^{-5}\ M = 1.0\ M$

$K_a = \frac{(5.50 \times 10^{-5})^2}{1.0} = \underline{3.0 \times 10^{-9}}$

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12. $HCN + H_2O \longleftrightarrow CN^- + H_3O^+$

$$K_a = \frac{[CN^-][H_3O^+]}{[HCN]} = 4.9 \times 10^{-10}$$

Let $[H_3O^+] = x$, then $[CN^-] = x$

and $[HCN] = 0.20M - x$
$\approx 0.20M$ if x is small

$$4.9 \times 10^{-10} = \frac{x^2}{0.20}$$

$[H_3O^+] = x = 9.90 \times 10^{-6} M$

$$\% \text{ dissociation} = \frac{9.90 \times 10^{-6} M}{0.20 M} \times 100 = \underline{4.9 \times 10^{-3} \%}$$

13. $HA + H_2O \longleftrightarrow A^- + H_3O^+$

$$K_a = \frac{[A^-][H_3O^+]}{[HA]}$$

$[H_3O^+] = 0.025\% \times 0.10M = 2.5 \times 10^{-5} M$

$[A^-] = [H_3O^+] = 2.5 \times 10^{-5} M$

$[HA] = 0.10M - 2.5 \times 10^{-5} M = 0.10M$

$$K_a = \frac{(2.5 \times 10^{-5})^2}{0.10} = \underline{6.3 \times 10^{-9}}$$

14. $HF + H_2O \longleftrightarrow F^- + H_3O^+$

$$k_a = \frac{[F^-][H_3O^+]}{[HF]} = 3.5 \times 10^{-4}$$

Let $x = [H_3O^+]$, then $[F^-] = x$

and $[HF] = 0.50M - x \approx 0.50M$ if x is small

$$3.5 \times 10^{-4} = \frac{x^2}{0.50}$$

$x = [H_3O^+] = 1.32 \times 10^{-2} M$

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

$pH = -\log (1.32 \times 10^{-2} M) = \underline{1.88}$

15. $HA + H_2O \longleftrightarrow A^- + H_3O^+$

$$K_a = \frac{[A^-][H_3O^+]}{[HA]}$$

$[H_3O^+] = \text{antilog}(-1.60) = 2.51 \times 10^{-2} M$

$[A^-] = [H_3O^+] = 2.51 \times 10^{-2} M$

$[HA] = 0.10M - 2.51 \times 10^{-2} M = 7.49 \times 10^{-2} M$

$$k_a = \frac{(2.51 \times 10^{-2})^2}{7.49 \times 10^{-2}} = \underline{8.4 \times 10^{-3}}$$

16. $pK_a = -\log K_a = -\log (1.5 \times 10^{-9}) = \underline{8.82}$

17. a) HIn_1 yellow — In_1^- pink

HIn_2 blue — In_2^- yellow

HIn_3 pink — In_3^- colorless

b) HA_1
HA_2
HIn_2
HA_2

18. $H_3PO_4 \longleftrightarrow H^+ + H_2PO_4^-$ $\quad k_{a_1} = \frac{[H^+][H_2PO_4^-]}{[H_3PO_4]} = 7.5 \times 10^{-3}$

$H_2PO_4^- \longleftrightarrow H^+ + HPO_4^{2-}$ $\quad k_{a_2} = \frac{[H^+][HPO_4^{2-}]}{[H_2PO_4^-]} = 6.2 \times 10^{-8}$

$HPO_4^{2-} \longleftrightarrow H^+ + PO_4^{3-}$ $\quad k_{a_3} = \frac{[H^+][PO_4^{3-}]}{[HPO_4^{2-}]} = 2.2 \times 10^{-13}$

overall:

$$H_3PO_4 \longleftrightarrow 3H^+ + PO_4^{3-} \quad K_T = \frac{[H^+]^3[PO_4^{3-}]}{[H_3PO_4]} = k_1 \times k_2 \times k_3 = \underline{1.0 \times 10^{-22}}$$

19. $[H^+] = \text{antilog}(-7.43) = 3.7 \times 10^{-8}\ M$

$[OH^-] = \frac{K_w}{[H^+]} = \frac{1.00 \times 10^{-14}}{3.7 \times 10^{-8}} = \underline{2.7 \times 10^{-7}\ M}$

20. HCl is a strong acid so $[H_3O^+] = [HCl] = 2.0\ M$

$pH = -\log [H_3O^+] = -\log(2.0) = \underline{-0.30}$

21. NaOH is highly soluble, so $[OH^-] = 0.15\ M$

$pOH = -\log [OH^-] = -\log(0.15\ M) = 0.824$

$pH + pOH = pK_w \quad pK_w = 14.000$ at 25°C

$pH = 14.000 - 0.824 = \underline{13.18}$

22. $Ba(OH)_2 \longrightarrow 2OH^- \qquad [OH^-] = 2 \times 0.025\ M = 0.050\ M$

$pOH = -\log [OH^-] = 1.301$

$pH = 14.000 - 1.301 = \underline{12.70}$