Calculations Involving Acids

Section 8.4

Homework
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Pg. 520 #1, 2
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Pg. 525 #1-10a

Types of Calculations

- K_a
- pH
- % ionization

…or some combination of all of the above!

Solutions of Strong Acids

Complete ionization occurs:

$$HA \xrightarrow{100\%} H^+ + A^-$$

HA	H⁺	A⁻
(before ionization) 1.0 mol	(after ionization) 1.0 mol	(after ionization) 1.0 mol

Therefore, $[HA] = [H^+] = [A^-]$

Example 1. Find the $[H^+]$, $[OH^-]$, pH and pOH of a 0.042 mol/L $HNO_{3\,(aq)}$ solution.

This reaction proceeds according to the equation:

$$HNO_{3\,(aq)} \rightarrow H^+_{(aq)} + NO_3^-{}_{(aq)}$$

Before getting started, consider the MAJOR entities in solution:

H^+ NO_3^- H_2O

There are actually TWO processes that can contribute to $[H^+]$:
(1) ionization of HNO_3 K_a = infinitely large
~~(2) autoionization of water: $H_2O \rightarrow H^+ + OH^-$ $K_w = 1.0 \times 10^{-14}$~~

Ignore process (2) because
K_a of HNO_3 is so much larger
∴ HNO_3 is a much stronger acid;
contribution of H_2O is negligible

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Strategy for strong acid calculations:
1. Assume that $[H^+] = [HA]$
2. Perform necessary calculations using $[H^+]$

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❶ *Find $[H^+]$*
Since HNO_3 is a strong acid,
$\mathbf{[H^+] = [HNO_3] = 0.042\ M}$

❷ *Find pH*
$pH = -\log[H^+] = -\log(0.042)$
pH = 1.38

❸ *Find pOH*
pH + pOH = 14.00
pOH = 14.00 – pH
pOH = 14.00 – 1.38
pOH = 12.62

❹ *Find $[OH^-]$*
$[OH^-] = 10^{-pOH}$
$= 10^{-12.62}$
$\mathbf{[OH^-] = 2.4 \times 10^{-13}\ mol/L}$

Practice.
Pg. 513 #1, 2

1. Find $[OH^-]$ of a 0.0700 mol/L HCl solution. Ans: 1.43×10^{-13} M
2. A 2.00-L HBr solution contains 0.070 mol of acid. Find pH and pOH. Ans: pH = 1.46, pOH = 12.54

Solutions of Weak Acids

Weak acids only partially ionize in water.
- **Percent ionization** describes how much of the original acid ionizes to produce H^+.

For the general weak acid ionization reaction $HA \rightleftharpoons H^+ + A$

$$\%\ \text{ionization} = \frac{[H^+]}{[HA]_0} \times 100\%$$

where $[H^+]$ is the concentration of ionized acid, and $[HA]_0$ is the **initial** acid concentration.

Example 2. Finding % Ionization Using pH
Calculate the percent ionization of propanoic acid, $HC_3H_5O_2$, if a 0.050 mol/L solution has a pH of 2.78.

❶ Write the ionization equation

$$HC_3H_5O_2 \rightleftharpoons H^+ + C_3H_5O_2^-$$

❷ Use pH to find $[H^+]$

$[H^+] = 10^{-2.78}$
$[H^+] = 1.7 \times 10^{-3}$ mol/L ← the quantity of H^+ from the ionization of $HC_3H_5O_2$.

❸ Calculate % ionization

$$\%\ \text{ionization} = \frac{[H^+]}{[HC_3H_5O_2]_0} \times 100\%$$

$$= \frac{1.7 \times 10^{-3}}{0.050} \times 100\%$$

% ionization = 3.3%

Example 3. Finding K_a using % Ionization
Calculate the K_a of hydrofluoric acid, HF, if a 0.100 mol/L solution at equilibrium has a percent ionization of 7.8%.

❶ Write the ionization equation

$$HF \xleftrightarrow{7.8\%} H^+ + F^-$$

❷ Write K_a expression

$$K_a = \frac{[H^+][F^-]}{[HF]}$$

Requires all concentrations at equilibrium

❸ Set up ICE table

	HF	H^+	F^-
I	0.100	0	0
C	- x	+ x	+ x
E	0.100 – x	x	x

Given: % ionization = 7.8%

RTF: K_a

	HF	H^+	F^-
I	0.100	0	0
E	0.100 – x	x	x
	0.0922 mol/L	0.0078 mol/L	0.0078 mol/L

❹ Use % ionization to find $[H^+]$ and $[F^-]$

$x = 0.078 \times 0.100$ mol/L
$x = 0.0078$ mol/L $= [H^+] = [F^-]$

❺ Use x to find [HF]

$[HF] = 0.100 - x = 0.0922$ mol/L

❻ Plug values into K_a

$$K_a = \frac{[H^+][F^-]}{[HF]} = \frac{(0.0078)(0.0078)}{(0.0922)}$$

$K_a = 6.6 \times 10^{-4}$

Example 4. Calculating the pH of a weak acid solution

Calculate the hydrogen ion concentration and pH of a 0.10 mol/L acetic acid solution. K_a is 1.8×10^{-5}.

❶ Write the ionization equation $HC_2H_3O_2 \rightleftharpoons H^+ + C_2H_3O_2^-$

❷ Consider all major entities, and reactions that contribute to pH.

Major entities in solution:
$HC_2H_3O_2$ H^+ $C_2H_3O_2^-$ H_2O

Contributing reactions:
(1) $HC_2H_3O_2 \rightleftharpoons H^+ + C_2H_3O_2^-$ $K_a = 1.8 \times 10^{-5}$
~~(2) $H_2O \rightleftharpoons H^+ + OH^-$ $K_w = 1.0 \times 10^{-14}$~~

❸ Set up ICE table

	$HC_2H_3O_2$	H^+	$C_2H_3O_2^-$
I	0.10	0	0
C	- x	+ x	+ x
E	0.10 – x	x	x

❹ Use K_a to solve for x

$$K_a = \frac{[H^+][C_2H_3O_2^-]}{[HC_2H_3O_2]}$$

$$1.8 \times 10^{-5} = \frac{(x^2)}{(0.10-x)}$$ ⇐ $\frac{0.10}{K_a}$ >> 100

$$1.8 \times 10^{-5} \cong \frac{(x^2)}{(0.10)}$$

$$x^2 \cong 1.8 \times 10^{-6}$$

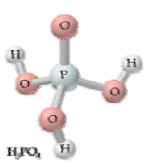
$$x \cong 1.3 \times 10^{-3} \text{ mol/L}$$ ⇐ $\frac{x}{0.10}$ = 1.3% Assumption was valid!

❺ Use $[H^+]$ to find pH

pH = -log $[H^+]$
pH = -log (1.3×10^{-3}) = **1.87**

Polyprotic acids have more than one ionisable proton.

e.g., phosphoric acid, H_3PO_4



$H_3PO_4 \rightleftharpoons H^+ + H_2PO_4^-$ $K_{a1} = 7.1 \times 10^{-3}$

$H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$ $K_{a2} = 6.3 \times 10^{-8}$

$HPO_4^{2} \rightleftharpoons H^+ + PO_4^{3-}$ $K_{a3} = 4.2 \times 10^{-13}$

What trend do you notice for the value of each successive K_a?

Only the FIRST ionization step contributes a considerable amount of H^+.

Treat polyprotic acid problems like monoprotic acids, where you only consider the first step!

Example 5. Calculate the pH a 0.20 mol/L solution of ascorbic acid, $H_2C_6H_6O_6$.

$K_{a1} = 7.9 \times 10^{-5}$
$K_{a2} = 1.6 \times 10^{-12}$

❶ Compare the K_a values:
Does the second ionization contribute much H^+?

$K_{a2} << K_{a1}$
Only the **first step** contributes an appreciable amount of H^+

❷ Write the ionization equation $H_2C_6H_6O_6 \rightleftharpoons H^+ + HC_6H_6O_6^-$

❸ Consider all major entities, and reactions that contribute to pH.

Major entities in solution:
$H_2C_6H_6O_6$ H^+ $HC_6H_6O_6^-$ H_2O

Contributing reactions:
(1) $H_2C_6H_6O_6 \rightleftharpoons H^+ + HC_6H_6O_6^-$ $K_a = 7.9 \times 10^{-5}$
~~(2) $H_2O \rightleftharpoons H^+ + OH^-$ $K_w = 1.0 \times 10^{-14}$~~

❸ Set up ICE table

	$H_2C_6H_6O_6$	H^+	$HC_6H_6O_6^-$
I	0.20	0	0
C	- X	+ x	+ x
E	0.20 – x	x	x

❹ Use K_a to solve for x

$$K_a = \frac{[H^+][HC_6H_6O_6^-]}{[H_2C_6H_6O_6]}$$

$$7.9 \times 10^{-5} = \frac{(x^2)}{(0.20-x)} \cong \frac{(x^2)}{(0.20)}$$ ⇐ $\frac{0.20}{K_a}$ >> 100

$$x \cong 4.0 \times 10^{-3} \text{ mol/L}$$ ⇐ $\frac{x}{0.20}$ = 2% Assumption was valid!

❺ Use $[H^+]$ to find pH

pH = -log $[H^+]$
pH = -log (4.0×10^{-3}) = **2.40**

Summary

- Strong acids ionize completely, so [H+] can be obtained directly from [HA].
- For weak acids, % ionization describes the percentage of the original acid that ionizes to produce H+.
- Weak acid problems are equilibrium problems. Set up an ICE table, and apply simplifying assumptions where appropriate.
- Polyprotic acids can be treated as weak monoprotic acids, since the contribution of the second/third ionizations is so miniscule.

Homework

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Pg. 525 #1-10a