Answers to Study Questions and Problems

1. a. $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

   base — weaker acid — acid — stronger base

   b. $HCN(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$

   acid — weaker base — acid — stronger base

   c. $NH_4^+(aq) + CO_3^-(aq) \rightleftharpoons NH_3(aq) + HCO_3^-(aq)$

   acid — stronger base — base — weaker acid

2. acid $\xrightarrow{\text{remove } H^+}$ conjugate base

	acid	conjugate base	
a.	HNO_2	NO_2^-	nitrite
b.	H_2SO_4	HSO_4^-	bisulfate
c.	$H_2PO_4^-$	HPO_4^{2-}	hydrogen phosphate
d.	HF	F^-	fluoride
e.	CH_3CO_2H	$CH_3CO_2^-$	acetate

3. a. $HSO_4^- + H_2O \rightleftharpoons H_3O^+ + SO_4^{2-}$

   acid — base — acid — base

   b. $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

   base — acid — acid — base

   c. $CN^- + H_2O \rightleftharpoons HCN + OH^-$

   base — acid — acid — base

   d. $H^- + H_2O \rightleftharpoons H_2 + OH^-$

   base — acid — acid — base

   e. $HClO_4 + H_2O \rightleftharpoons H_3O^+ + ClO_4^-$

   acid — base — acid — base

4. The HPO_4^{2-} ion is amphiprotic; it can donate or accept hydrogen ions:

   $H_2PO_4^- \rightleftharpoons HPO_4^{2-} \rightleftharpoons PO_4^{3-}$

   conjugate acid — conjugate base

5. $HNO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NO_3^-(aq)$ K_a = very large

$HSO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_4^-(aq)$ $K_a = 1.2 \times 10^{-2}$

$HCN(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CN^-(aq)$ $K_a = 4.0 \times 10^{-10}$

$H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^-(aq)$ $K_a = 4.2 \times 10^{-7}$

$NH_4^+(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NH_3(aq)$ $K_a = 5.6 \times 10^{-10}$

$HF(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + F^-(aq)$ $K_a = 7.2 \times 10^{-4}$

a. the strongest acid is HNO_3.
b. the acid that produces the lowest concentration of hydronium ions per mole of acid is the weakest acid: HCN.
c. the acid with the strongest conjugate base is the weakest acid: HCN.
d. the diprotic acid is H_2CO_3.
e. the strong acid is HNO_3.
f. the acid with the weakest conjugate base is the strongest acid: HNO_3.

The strongest acid is not necessarily a strong acid.

6. $CH_3CO_2H(aq) + NH_3(aq) \rightleftharpoons NH_4^+(aq) + CH_3CO_2^-(aq)$

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

$NH_4^+(aq) + OH^-(aq) \rightleftharpoons NH_3(aq) + H_2O(l)$

$H_3O^+(aq) + HCO_3^-(aq) \rightleftharpoons 2H_2O(l) + CO_2(g)$

$HClO_2(aq) + NH_3(aq) \rightleftharpoons NH_4^+(aq) + ClO_2^-(aq)$

$HPO_4^{2-}(aq) + CH_3CO_2H(aq) \rightleftharpoons H_2PO_4^-(aq) + CH_3CO_2^-(aq)$

Spectator ions are omitted–these are net ionic equations.

Each reaction involves the transfer of a proton from the acid to the base.

7. a. HCl is a strong acid, so 0.0010 M HCl solution contains 0.0010 M H_3O^+. The pH = $-\log[H^+] = -\log[0.0010] = 3.0$.

b. KOH is a strong base, so 0.15 M KOH solution contains 0.15 M OH^-. The pOH = $-\log[OH^-] = -\log[0.15] = 0.82$; pH = 13.2.

c. The total quantity of H^+ in the solution is initially 10^{-8} M from the HNO_3 plus 10^{-7} M from the water.
The total concentration of H^+ is approx. 1.1×10^{-7}. So the pH = 6.96.

The solution must be acidic, so the answer is not 8! The solution is slightly more acidic than pure water. There is always some H_3O^+ and OH^- in an aqueous solution due to the autoionization of water–usually insignificant but not in this case.

8. In increasing acid strength from bottom to top:

HCl	approx 10^7
H_3O^+	55
H_2SO_3	1.2×10^{-2}
HCO_2H	1.8×10^{-4}
$[Cu(H_2O)_6]^{2+}$	1.6×10^{-7}
$H_2PO_4^-$	6.2×10^{-8}
NH_4^+	5.6×10^{-10}
HCN	4.0×10^{-10}
H_2O	1.8×10^{-16}
NH_3	very small

For water at 25°C:

$[H_3O^+][OH^-] = K_w = 10^{-14}$

$pH + pOH = pK_w = 14$

9.

$[H_3O^+]$	$[OH^-]$	pH	pOH	acidic or basic
2.0×10^{-5}	5.0×10^{-10}	4.70	9.30	acidic
5.6×10^{-7}	1.8×10^{-8}	6.25	7.75	acidic
1.8×10^{-13}	5.6×10^{-2}	12.75	1.25	basic
1.6×10^{-5}	6.3×10^{-10}	4.80	9.20	acidic
8.7×10^{-10}	1.1×10^{-5}	9.06	4.94	basic

Molar mass of NaOH = 40 g/mol

10. Sodium hydroxide is a strong base.
Concentration of NaOH = 2.6 g/250 mL = 0.26 mol/L
The concentration of OH^- ions is therefore the same = 0.26 M
pOH = −log[OH] = 0.585
pH = 13.4

$[OH^-]$ is much lower than $[H^+]$; the solution is acidic.

11. $pH = -\log[H^+] = 4.62$
$[H^+] = 2.4 \times 10^{-5}$
$[OH^-] = 4.2 \times 10^{-10}$

Learn how to take an antilog on your calculator.

12. pH = 4.26 at 25°C
$[H_3O^+] = 5.50 \times 10^{-5}$

$$K_a = \frac{[H_3O^+]^2}{0.12} = 2.52 \times 10^{-8}.$$

13. $$K_b = 6.6 \times 10^{-9} = \frac{[OH^-]^2}{[NH_2OH]} = \frac{[OH^-]^2}{0.36}$$

$[OH^-]= 4.87\times 10^{-5}$
pOH = 4.31 and the pH = 9.69.

14.

		$C_6H_5CO_2H + H_2O \rightleftharpoons$	$H_3O^+(aq)$ +	$C_6H_5CO_2^-(aq)$
I	Initial	0.15	0	0
C	Change	−x	+x	+x
E	Equilibrium	0.15−x	x	x

(0.15−x) is approximately equal to 0.15. Actually 0.147.

Solving the quadratic yields a value for x = 0.00304.

K_a for benzoic acid = $6.3 \times 10^{-5} = x^2/(0.15-x) = x^2/0.15$; x = 0.00307M

a. the concentration of benzoic acid at equilibrium = 0.147M
b. the concentration of hydronium ion = 0.0031 M
c. the concentration of benzoate anion = 0.0031 M
d. the pH of the solution = 2.51

Determine the acid and base used to make the salt.
But look out for acid salts (the anions of polyprotic acids).

No calculations are necessary.

15.

a.	sodium acetate	K_a for acetic acid = 1.8×10^{-5}; basic
b.	potassium chloride	strong acid : strong base : neutral solution
c.	sodium bisulfate	bisulfate ionizes ($K_a = 1.2 \times 10^{-2}$) lowest pH
d.	magnesium nitrate	strong acid : strong base : neutral solution
e.	potassium cyanide	K_a for HCN = 4.0×10^{-10}; basic

16.	a. $NaNO_3$	strong acid	strong base	neutral
	b. NH_4I	strong acid	weak base	acidic
	c. $NaHCO_3$	weak acid	strong base	basic
	d. NH_4CN	weaker acid	weak base	slightly basic
	e. NaOCl	weak acid	strong base	basic
	f. KCH_3CO_2	weak acid	strong base	basic

17. a. K_a for the acid and K_b for the conjugate base are related:

$K_a \times K_b = K_w$.
If $K_a = 3.5 \times 10^{-4}$ for cyanic acid HOCN,
then K_b for cyanate $= 10^{-14}/3.5 \times 10^{-4} = 2.86 \times 10^{-11}$.

b. Phenol is a relatively weak acid, $K_a = 1.3 \times 10^{-10}$.
K_b for its conjugate base $= 10^{-14}/1.3 \times 10^{-10} = 7.7 \times 10^{-5}$.

For comparison:
ammonia $K_b = 1.8 \times 10^{-5}$ (about the same)
acetate $K_b = 5.6 \times 10^{-10}$ (much weaker)
sodium hydroxide K_b = very large (much stronger).

18. a. $K_{a1} = \frac{[H_3O^+][HSO_3^-]}{[H_2SO_3]} = \frac{[H_3O^+]^2}{[H_2SO_3]} = 1.7 \times 10^{-2}$ $[H_3O^+] = 0.108$
pH = 0.97

Solve the quadratic to obtain the hydronium ion concentration.

b. $[SO_3^{2-}] = K_{a2} = 6.4 \times 10^{-8}$

c. Nothing; the $[SO_3^{2-}]$ is independent of $[H_2SO_3]$.

See review question 17.

19. a. Boron trichloride (acid) accepts a pair of electrons from chloride (base).

b. Nickel (acid) accepts a pair of electrons from carbon monoxide (base).

c. Ammonia (base) donates a pair of electrons to the proton (acid) from acetic acid.

d. Sodium ions (acid) are solvated by water (base).

The Lewis base donates the electron pair; the Lewis acid accepts the electron pair.

20. $CN^-(aq) + H_2O(l) \rightleftharpoons HCN(aq) + OH^-(aq)$

$$K_b = \frac{[HCN][OH^-]}{[CN^-]} = \frac{[OH^-]^2}{[CN^-]} = \frac{[OH^-]^2}{0.35} = 4.0 \times 10^{-10}$$

$[OH^-] = 1.18 \times 10^{-5}$
pOH = 4.93
pH = 9.07