2. Write the formula and give the name of the conjugate acid of each of the following bases.

(a) NH_3 (b) HCO_3^- (c) Br^-

NH_4^+ (ammonium)

H_2CO_3 (hydrogen carbonate or bicarbonate)

HBr (hydrobromic acid)

6. Write balanced equations showing how the HPO_4^{2-} ion of sodium hydrogen phosphate, Na_2HPO_4, can be a Brønsted acid or a Brønsted base.

As a Brønsted acid: HPO_4^{2-} (aq) + H_2O (l) ⇔ H_3O^+ (aq) + PO_4^{3-}

As a Brønsted base: HPO_4^{2-} (aq) + H_2O (l) ⇔ OH^- (aq) + $H_2PO_4^-$

4. What are the products of each of the following acid–base reactions? Indicate the acid and its conjugate base and the base and its conjugate acid.

(a) $HClO_4 + H_2O \rightarrow H_3O^+ + ClO_4^-$

(b) $NH_4^+ + H_2O \rightarrow H_3O^+ + NH_3$

(c) $HCO_3^- + OH^- \rightarrow H_2O + CO_3^{2-}$

Acid/conjugate base:

$HClO_4/ClO_{4-}$

H_3O^+/H_2O

NH_4^+/NH_3

HCO_3^-/CO_3^{2-}

H_2O/OH^-

8. In each of the following acid–base reactions, identify the Brønsted acid and base on the left and their conjugate partners on the right.

(a) $C_5H_5N(aq) + CH_3CO_2H(aq) \rightleftharpoons C_5H_5NH^+(aq) + CH_3CO_2^-(aq)$

base acid conjugate acid conjugate base

(b) $N_2H_4(aq) + HSO_4^-(aq) \rightleftharpoons N_2H_5^+(aq) + SO_4^{2-}(aq)$

base acid conjugate acid conjugate base

(c) $[Al(H_2O)_6]^{3+}(aq) + OH^-(aq) \rightleftharpoons [Al(H_2O)_5OH]^{2+}(aq) + H_2O(\ell)$

acid base conjugate base conjugate acid

9. An aqueous solution has a pH of 3.75. What is the hydronium ion concentration of the solution? Is it acidic or basic?

$[H_3O^+]=10^{-3.75} = 1.8 \times 10^{-4}$

acidic

10. A saturated solution of milk of magnesia, $Mg(OH)_2$, has a pH of 10.52. What is the hydronium ion concentration of the solution? What is the hydroxide ion concentration? Is the solution acidic or basic?

$[H_3O^+]=10^{-10.52} = 3.0 \times 10^{-11}$

pOH = 14.00 – 10.52 = 3.48

$[OH^-] = 10^{-3.48} = 3.3 \times 10^{-4}$

basic

14. The pH of a solution of $Ba(OH)_2$ is 10.66 at 25 °C. What is the hydroxide ion concentration in the solution? If the solution volume is 125 mL, what mass of $Ba(OH)_2$ must have been dissolved?

pOH = 14.00 – 10.66 = 3.34

$[OH^-] = 10^{-3.34} = 4.6 \times 10^{-4}$

$$0.125\ L \times \frac{4.6\times10^{-4}\ mol\ OH^-}{1\ L} \times \frac{1\ mol\ Ba(OH)_2}{2\ mol\ OH^-} \times \frac{171.34\ g}{1\ mol\ Ba(OH)_2} = \mathbf{4.9\ mg\ Ba(OH)_2}$$

16. Several acids are listed here with their respective equilibrium constants.

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

$$HPO_4^{2-}(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + PO_4^{3-}(aq) \qquad K_a = 3.6 \times 10^{-13}$$

$$CH_3CO_2H(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + CH_3CO_2^-(aq) \qquad K_a = 1.8 \times 10^{-5}$$

(a) Which is the strongest acid? Which is the weakest acid?
(b) What is the conjugate base of the acid HF?
(c) Which acid has the weakest conjugate base?
(d) Which acid has the strongest conjugate base?

HF is the strongest acid. F^- is the weakest base (conjugate base of HF).
HF has the weakest conjugate base.
HPO_4^{2-} has the strongest conjugate base.

Sodium carbonate is a base derived from a diprotic acid. Write a chemical equilibrium expression for each of the two successive base reactions with water.

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

HCO_3^- (aq) + H_2O (l) ⇔ H_2CO_3 (aq) + OH^- (aq)

21. If each of the salts listed here were dissolved in water to give a 0.10 M solution, which solution would have the highest pH? Which would have the lowest pH?

(a) Na_2S
(b) Na_3PO_4
(c) NaH_2PO_4
(d) NaF
(e) $NaCH_3CO_2$
(f) $AlCl_3$

Acidic ions: Al^{3+} (really exists as $Al(H_2O)_6^{3+}$ in water, $K_a = 7.9 \times 10^{-6}$)
Neutral ions: Na^+, Cl^-
Basic ions (in order of increasing strength): S^{2-} ($K_b = 1 \times 10^5$) PO_4^{3-} ($K_b = 2.8 \times 10^{-2}$), CH_3COO^- ($K_b = 5.6 \times 10^{-10}$), F^- ($K_b = 1.4 \times 10^{-11}$)
$H_2PO_4^-$ is amphiprotic. Its K_a is 6.2×10^{-8} and its K_b is 1.3×10^{-12}. Since its $K_a > K_b$, it is acidic.

Given same concentration of salts (and acidic/basic cations and anions): the salt containing the ion with the highest K_a ($AlCl_3$) would have the lowest pH. The salt containing the ion with the highest K_b (Na_2S) would have the highest pH.

$AlCl_3 < NaH_2PO_4 < NaF < NaCH_3COO < Na_3PO_4 < Na_2S$
Lowest pH **highest pH**

36. For each of the following reactions, predict whether the equilibrium lies predominantly to the left or to the right. Explain your predictions briefly.

(a) $H_2S(aq) + CO_3^{2-}(aq) \rightleftharpoons HS^-(aq) + HCO_3^-(aq)$

(b) $HCN(aq) + SO_4^{2-}(aq) \rightleftharpoons CN^-(aq) + HSO_4^-(aq)$

(c) $SO_4^{2-}(aq) + CH_3CO_2H(aq) \rightleftharpoons HSO_4^-(aq) + CH_3CO_2^-(aq)$

H_2S ($K_a = 1 \times 10^{-7}$) is a stronger acid than HCO_3^- ($K_a = 4.8 \times 10^{-11}$). Equilibrium lies to the **right**.
HCN ($K_a = 4.0 \times 10^{-10}$) is a weaker acid than HSO_4^- ($K_a = 1.2 \times 10^{-2}$). Equilibrium lies to the **left**.
CH_3COOH ($K_a = 1.8 \times 10^{-5}$) is a weaker acid than HSO_4^- ($K_a = 1.2 \times 10^{-2}$). Equilibrium lies to the **left**.

63. For each of the following cases, decide whether the pH is less than 7, equal to 7, or greater than 7.

(a) Equal volumes of 0.10 M acetic acid, CH_3CO_2H, and 0.10 M KOH are mixed.

(b) 25 mL of 0.015 M NH_3 is mixed with 25 mL of 0.015 M HCl.

(c) 150 mL of 0.20 M HNO_3 is mixed with 75 mL of 0.40 M NaOH.

a. **pH > 7** (product CH_3COO^- reacts with H_2O to produce CH_3COOH and **OH^-**)
b. **pH < 7** (product NH_4^+ reacts with H_2O to produce NH_3 and **H_3O^+**)
c. **pH = 7** (product neutral ions Na^+ and NO_3^- and H_2O)

Calculations with K_a and K_b

- Calculate the pH of a 0.020 M solution of benzoic acid (C_6H_5COOH) given that $K_a = 6.3 \times 10^{-5}$ for the acid.

	C_6H_5COOH	$+ H_2O$	⇔	$C_6H_5COO^-$	$+ H_3O^+$
I	0.020 M			0	0
C	~ 0			+ x	+ x
E	~ 0.020 M			x	x

$100(K_a) < A_0$, so can ignore – x

$$K_a = \frac{[C_6H_5COO^-][H_3O^+]}{[C_6H_5COOH]} \rightarrow 6.3 \times 10^{-5} = \frac{x^2}{0.020} \rightarrow x = [H_3O^+] = 1.1 \times 10^{-3}\ \text{M}$$

pH = $-\log[H_3O^+]$ = 2.95

pH of the solution of Na_2CO_3

The CO_3^{2-} ion is a base in water, forming the HCO_3^- ion, which in turn can form H_2CO_3.

CO_3^{2-} (aq) + H_2O (l) ⇔ HCO_3^- (aq) + OH^- (aq) $K_{b1} = 2.1 \times 10^{-4}$

HCO_3^- (aq) + H_2O (l) ⇔ H_2CO_3 (aq) + OH^- (aq) $K_{b2} = 2.4 \times 10^{-8}$

What is the pH of a 0.10 M solution of Na_2CO_3? What are the $[CO_3^{2-}]$, $[HCO_3^-]$ and $[H_2CO_3]$?

	CO_3^{2-}	+ H_2O	⇔	HCO_3^-	+ OH^-
I	0.10 M			0	0
C	~0			+ x	+ x
E	0.10 M			x	x

$$K_{b1} = \frac{[HCO_3^-][OH^-]}{[CO_3^{2-}]} \rightarrow 2.1\times10^{-4} = \frac{x^2}{0.10} \rightarrow \boldsymbol{x = [HCO_3^-] = [OH^-] = 4.6\times10^{-3}\ M}$$

pOH = –log(4.6 x 10^{-3} M) = 2.34 → **pH = 14.00 – 2.34 = 11.66**

pH of the solution of Na_2CO_3

The CO_3^{2-} ion is a base in water, forming the HCO_3^- ion, which in turn can form H_2CO_3.

CO_3^{2-} (aq) + H_2O (l) ⇔ HCO_3^- (aq) + OH^- (aq) $K_{b1} = 2.1 \times 10^{-4}$

HCO_3^- (aq) + H_2O (l) ⇔ H_2CO_3 (aq) + OH^- (aq) $K_{b2} = 2.4 \times 10^{-8}$

What is the pH of a 0.10 M solution of Na_2CO_3? What are the $[CO_3^{2-}]$, $[HCO_3^-]$ and $[H_2CO_3]$?

	HCO_3^-	+ H_2O	⇔	H_2CO_3	+ OH^-
I	4.6×10^{-3} M			0	4.6×10^{-3}
C	~0			+ x	~0
E	4.6×10^{-3} M			x	4.6×10^{-3}

$[CO_3^{2-}]$ ~ 0.10 M

$[HCO_3^-]$ ~ 4.6×10^{-3} M

$[H_2CO_3]$ ~ 2.4×10^{-8} M

$$K_{b2} = \frac{[H_2CO_3][OH^-]}{[HCO_3^-]} \rightarrow 2.4\times10^{-8} = \frac{(4.6\times10^{-3})x}{4.6\times10^{-3}} \rightarrow \boldsymbol{x = [H_2CO_3] = [OH^-] = 2.4\times10^{-8}\ M}$$