

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

(a)  $\text{NH}_3$

(b)  $\text{HCO}_3^-$

(c)  $\text{Br}^-$

$\text{NH}_4^+$  (ammonium)

$\text{H}_2\text{CO}_3$  (hydrogen carbonate or bicarbonate)

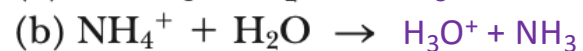
$\text{HBr}$  (hydrobromic acid)

6. Write balanced equations showing how the  $\text{HPO}_4^{2-}$  ion of sodium hydrogen phosphate,  $\text{Na}_2\text{HPO}_4$ , can be a Brønsted acid or a Brønsted base.

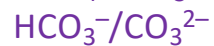
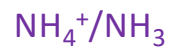
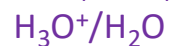
As a Brønsted acid:  $\text{HPO}_4^{2-} (\text{aq}) + \text{H}_2\text{O} (\text{l}) \rightleftharpoons \text{H}_3\text{O}^+ (\text{aq}) + \text{PO}_4^{3-}$

As a Brønsted base:  $\text{HPO}_4^{2-} (\text{aq}) + \text{H}_2\text{O} (\text{l}) \rightleftharpoons \text{OH}^- (\text{aq}) + \text{H}_2\text{PO}_4^-$

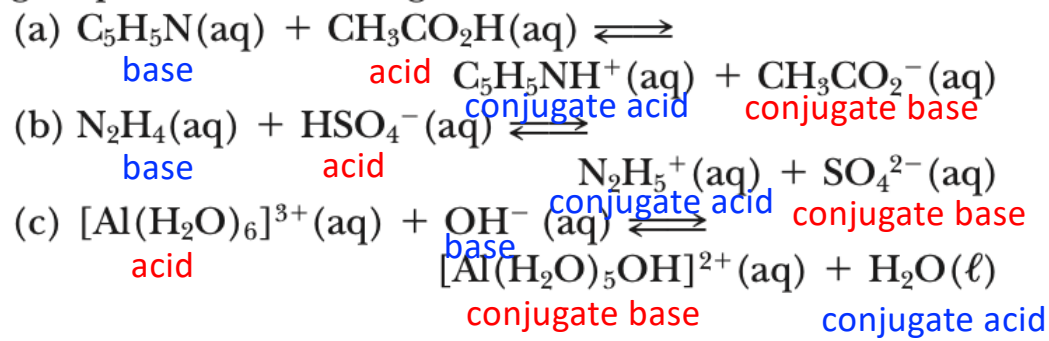
4. What are the products of each of the following acid–base reactions? Indicate the acid and its conjugate base and the base and its conjugate acid.



Acid/conjugate base:



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.



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

$$[\text{H}_3\text{O}^+] = 10^{-3.75} = 1.8 \times 10^{-4}$$

acidic

10. A saturated solution of milk of magnesia,  $\text{Mg}(\text{OH})_2$ , 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?

$$[\text{H}_3\text{O}^+] = 10^{-10.52} = 3.0 \times 10^{-11}$$
$$\text{pOH} = 14.00 - 10.52 = 3.48$$
$$[\text{OH}^-] = 10^{-3.48} = 3.3 \times 10^{-4}$$

basic

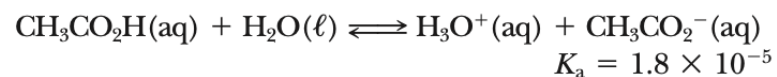
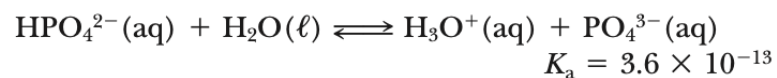
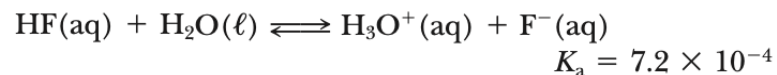
14. The pH of a solution of  $\text{Ba}(\text{OH})_2$  is 10.66 at 25 °C. What is the hydroxide ion concentration in the solution? If the solution volume is 125 mL, what mass of  $\text{Ba}(\text{OH})_2$  must have been dissolved?

$$\text{pOH} = 14.00 - 10.66 = 3.34$$

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

$$0.125 \text{ L} \times \frac{4.6 \times 10^{-4} \text{ mol OH}^-}{1 \text{ L}} \times \frac{1 \text{ mol Ba}(\text{OH})_2}{2 \text{ mol OH}^-} \times \frac{171.34 \text{ g}}{1 \text{ mol Ba}(\text{OH})_2} = \mathbf{4.9 \text{ mg Ba}(\text{OH})_2}$$

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



- (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.  $\text{F}^-$  is the weakest base (conjugate base of HF).

HF has the weakest conjugate base.

$\text{HPO}_4^{2-}$  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.





**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) $\text{Na}_2\text{S}$     | (d) $\text{NaF}$               |
| (b) $\text{Na}_3\text{PO}_4$  | (e) $\text{NaCH}_3\text{CO}_2$ |
| (c) $\text{NaH}_2\text{PO}_4$ | (f) $\text{AlCl}_3$            |

Acidic ions:  $\text{Al}^{3+}$  (really exists as  $\text{Al}(\text{H}_2\text{O})_6^{3+}$  in water,  $K_a = 7.9 \times 10^{-6}$ )

Neutral ions:  $\text{Na}^+$ ,  $\text{Cl}^-$

Basic ions (in order of increasing strength):  $\text{S}^{2-}$  ( $K_b = 1 \times 10^5$ )  $\text{PO}_4^{3-}$  ( $K_b = 2.8 \times 10^{-2}$ ),  $\text{CH}_3\text{COO}^-$  ( $K_b = 5.6 \times 10^{-10}$ ),  $\text{F}^-$  ( $K_b = 1.4 \times 10^{-11}$ )

$\text{H}_2\text{PO}_4^-$  is amphoteric. Its  $K_a$  is  $6.2 \times 10^{-8}$  and its  $K_b$  is  $1.3 \times 10^{-12}$ . Since its  $K_a > K_b$ , it is acidic.

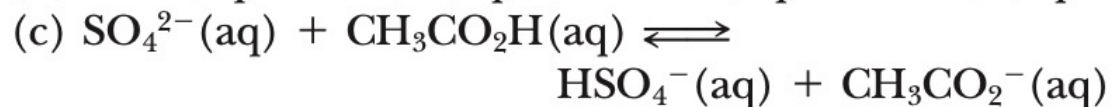
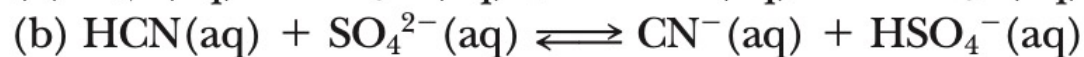
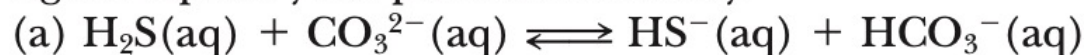
Given same concentration of salts (and acidic/basic cations and anions): the salt containing the ion with the highest  $K_a$  ( $\text{AlCl}_3$ ) would have the lowest pH. The salt containing the ion with the highest  $K_b$  ( $\text{Na}_2\text{S}$ ) would have the highest pH.

$\text{AlCl}_3 < \text{NaH}_2\text{PO}_4 < \text{NaF} < \text{NaCH}_3\text{COO} < \text{Na}_3\text{PO}_4 < \text{Na}_2\text{S}$

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.



$\text{H}_2\text{S}$  ( $K_a = 1 \times 10^{-7}$ ) is a stronger acid than  $\text{HCO}_3^-$  ( $K_a = 4.8 \times 10^{-11}$ ). Equilibrium lies to the **right**.

$\text{HCN}$  ( $K_a = 4.0 \times 10^{-10}$ ) is a weaker acid than  $\text{HSO}_4^-$  ( $K_a = 1.2 \times 10^{-2}$ ). Equilibrium lies to the **left**.

$\text{CH}_3\text{COOH}$  ( $K_a = 1.8 \times 10^{-5}$ ) is a weaker acid than  $\text{HSO}_4^-$  ( $K_a = 1.2 \times 10^{-2}$ ). 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,  $\text{CH}_3\text{CO}_2\text{H}$ , and 0.10 M KOH are mixed.
  - (b) 25 mL of 0.015 M  $\text{NH}_3$  is mixed with 25 mL of 0.015 M HCl.
  - (c) 150 mL of 0.20 M  $\text{HNO}_3$  is mixed with 75 mL of 0.40 M NaOH.

- a.  $\text{pH} > 7$  (product  $\text{CH}_3\text{COO}^-$  reacts with  $\text{H}_2\text{O}$  to produce  $\text{CH}_3\text{COOH}$  and  $\text{OH}^-$ )
- b.  $\text{pH} < 7$  (product  $\text{NH}_4^+$  reacts with  $\text{H}_2\text{O}$  to produce  $\text{NH}_3$  and  $\text{H}_3\text{O}^+$ )
- c.  $\text{pH} = 7$  (product neutral ions  $\text{Na}^+$  and  $\text{NO}_3^-$  and  $\text{H}_2\text{O}$ )

# 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.

	$C_6H_5COOH$	+ $H_2O$	$\rightleftharpoons$	$C_6H_5COO^-$	+ $H_3O^+$
I	0.020 M			0	0
C	$\sim 0$			+ x	+ x
E	$\sim 0.020$ M			x	x

$100(K_a) < A_0$ , so can ignore  $-x$

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

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

# pH of the solution of $\text{Na}_2\text{CO}_3$

The  $\text{CO}_3^{2-}$  ion is a base in water, forming the  $\text{HCO}_3^-$  ion, which in turn can form  $\text{H}_2\text{CO}_3$ .



What is the pH of a 0.10 M solution of  $\text{Na}_2\text{CO}_3$ ? What are the  $[\text{CO}_3^{2-}]$ ,  $[\text{HCO}_3^-]$  and  $[\text{H}_2\text{CO}_3]$ ?

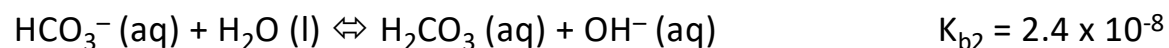
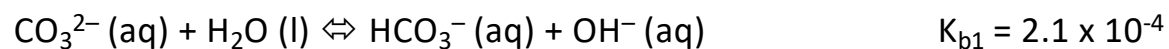
	$\text{CO}_3^{2-}$	+ $\text{H}_2\text{O}$	$\rightleftharpoons$	$\text{HCO}_3^-$	+ $\text{OH}^-$
I	0.10 M			0	0
C	$\sim 0$			+ x	+ x
E	0.10 M			x	x

$$K_{b1} = \frac{[\text{HCO}_3^-][\text{OH}^-]}{[\text{CO}_3^{2-}]} \rightarrow 2.1 \times 10^{-4} = \frac{x^2}{0.10} \rightarrow x = [\text{HCO}_3^-] = [\text{OH}^-] = 4.6 \times 10^{-3} \text{ M}$$

$$\text{pOH} = -\log(4.6 \times 10^{-3} \text{ M}) = 2.34 \rightarrow \text{pH} = 14.00 - 2.34 = 11.66$$

# pH of the solution of $\text{Na}_2\text{CO}_3$

The  $\text{CO}_3^{2-}$  ion is a base in water, forming the  $\text{HCO}_3^-$  ion, which in turn can form  $\text{H}_2\text{CO}_3$ .



What is the pH of a 0.10 M solution of  $\text{Na}_2\text{CO}_3$ ? What are the  $[\text{CO}_3^{2-}]$ ,  $[\text{HCO}_3^-]$  and  $[\text{H}_2\text{CO}_3]$ ?

	$\text{HCO}_3^-$	+ $\text{H}_2\text{O}$	$\rightleftharpoons$	$\text{H}_2\text{CO}_3$	+ $\text{OH}^-$
I	$4.6 \times 10^{-3} \text{ M}$			0	$4.6 \times 10^{-3}$
C	$\sim 0$			+ x	$\sim 0$
E	$4.6 \times 10^{-3} \text{ M}$			x	$4.6 \times 10^{-3}$

$$[\text{CO}_3^{2-}] \sim 0.10 \text{ M}$$

$$[\text{HCO}_3^-] \sim 4.6 \times 10^{-3} \text{ M}$$

$$[\text{H}_2\text{CO}_3] \sim 2.4 \times 10^{-8} \text{ M}$$

$$K_{b2} = \frac{[\text{H}_2\text{CO}_3][\text{OH}^-]}{[\text{HCO}_3^-]} \rightarrow 2.4 \times 10^{-8} = \frac{(4.6 \times 10^{-3})x}{4.6 \times 10^{-3}} \rightarrow x = [\text{H}_2\text{CO}_3] = [\text{OH}^-] = 2.4 \times 10^{-8} \text{ M}$$