STATION 1 – CALCULATIONS

Formulas on your formula sheet:

$$pH = -\log[H^+],\ pOH = -\log[OH^-]$$
$$14 = pH + pOH$$
$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14} \text{ at } 25°C$$
$$= K_a \times K_b$$

Formulas NOT on your formula sheet:

$[H^+] = 10^{-pH}$ $[OH^-] = 10^{-pOH}$

Calculate the pH for each solution below with the specified conditions.

1. $[H^+] = 1.0 \times 10^{-8}$ M
2. $[H^+] = 5.91 \times 10^{-6}$ M
3. pOH = 3.50
4. $[OH^-] = 1.0 \times 10^{-10}$ M
5. $[NaOH] = 4.28 \times 10^{-3}$ M
6. $[Ca(OH)_2] = 9.2 \times 10^{-7}$ M

<u>Sig figs for logs</u>

The number of sig figs will equal the number of decimal places in pH and pOH values.

Example) pH = 2.564 has three decimal places, thus three sig figs

Calculate the $[H^+]$ for each solution below with the specified conditions.

7. pH = 6.000
8. pH = 4.882
9. $[OH^-] = 6.1 \times 10^{-5}$ M
10. pOH = 10.22

A lesson in MENTAL MATH

It will be helpful if you can estimate logs in your head without a calculator. Here are a few tips.

- log of 1 is always zero

  Example 1) $\log_{10}(1) = 0$ Example 2) $\log_3(1) = 0$ Example 3) $\ln(1) = 0$

- When the base of the log matches the base inside, the exponent is the answer. Other than ln, you will only encounter logs with a base of 10 in this class. When there is no base written, it is assumed to be base 10.

$$\log_b(b^a) = a$$

  Example 4) $\log_{10}(10^2) = 2$ Example 5) $\log(10^5) = 5$ Example 6) $\log(10^7) = 7$

- When taking the log of (1×10^a), ignore the 1 since $\log(1) = 0$.
  Example 7) $\log(1 \times 10^8) = 8$ Example 8) $\log(1 \times 10^{-3}) = -3$

- Taking the pH formula into consideration.
  Example 9) $-\log(1 \times 10^{-3}) = +3$ Example 10) $-\log(1 \times 10^{-7}) = +7$

<u>You try without a calculator.</u>

11. $pH = -\log(1 \times 10^{-4})$
12. $pH = -\log(1 \times 10^{-11})$

- What happens when the numbers aren't so nice?

Example 11) $-\log(2 \times 10^{-9}) = ?$

To accurately solve this…you would need to know the log of 2. If it's an FRQ, then use your calculator. However, for multiple choice, just approximate the answer.

Here's how…

2×10^{-9} is a value between the numbers 1×10^{-8} and 1×10^{-9}

$-\log(1 \times 10^{-8}) = 8$ and $-\log(1 \times 10^{-9}) = 9$

$\therefore -\log(2 \times 10^{-9})$ must be between 8 and 9 (verify w/ calculator = 8.699)

Example 12) $-\log(5 \times 10^{-3}) = ?$

$-\log(1 \times 10^{-2}) = 2$ and $-\log(1 \times 10^{-3}) = 3$

$\therefore -\log(5 \times 10^{-3})$ = between 2 and 3 (verify w/ calculator = 2.301)

<u>You try without a calculator.</u>

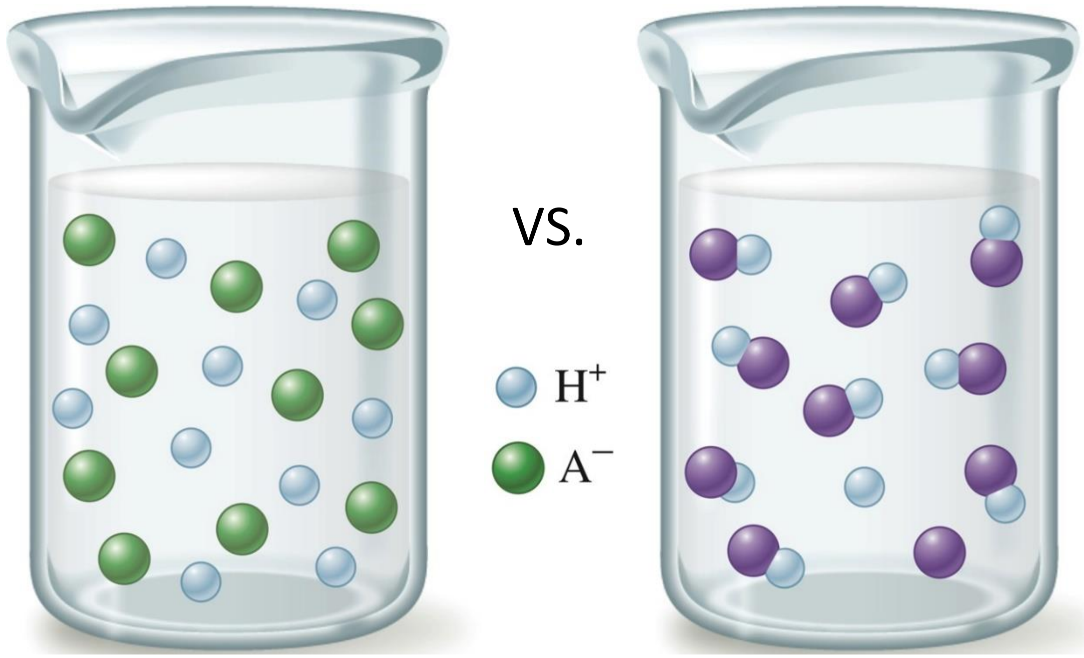
13. pH = $-\log(7 \times 10^{-5})$
14. pH = $-\log(3.11 \times 10^{-12})$

STATION 2 – STRONG ACID VS. WEAK ACID

STRONG ACID

VS.

WEAK ACID



Ionization Equation:

$HA(aq) \rightarrow H^+(aq) + A^-(aq)$

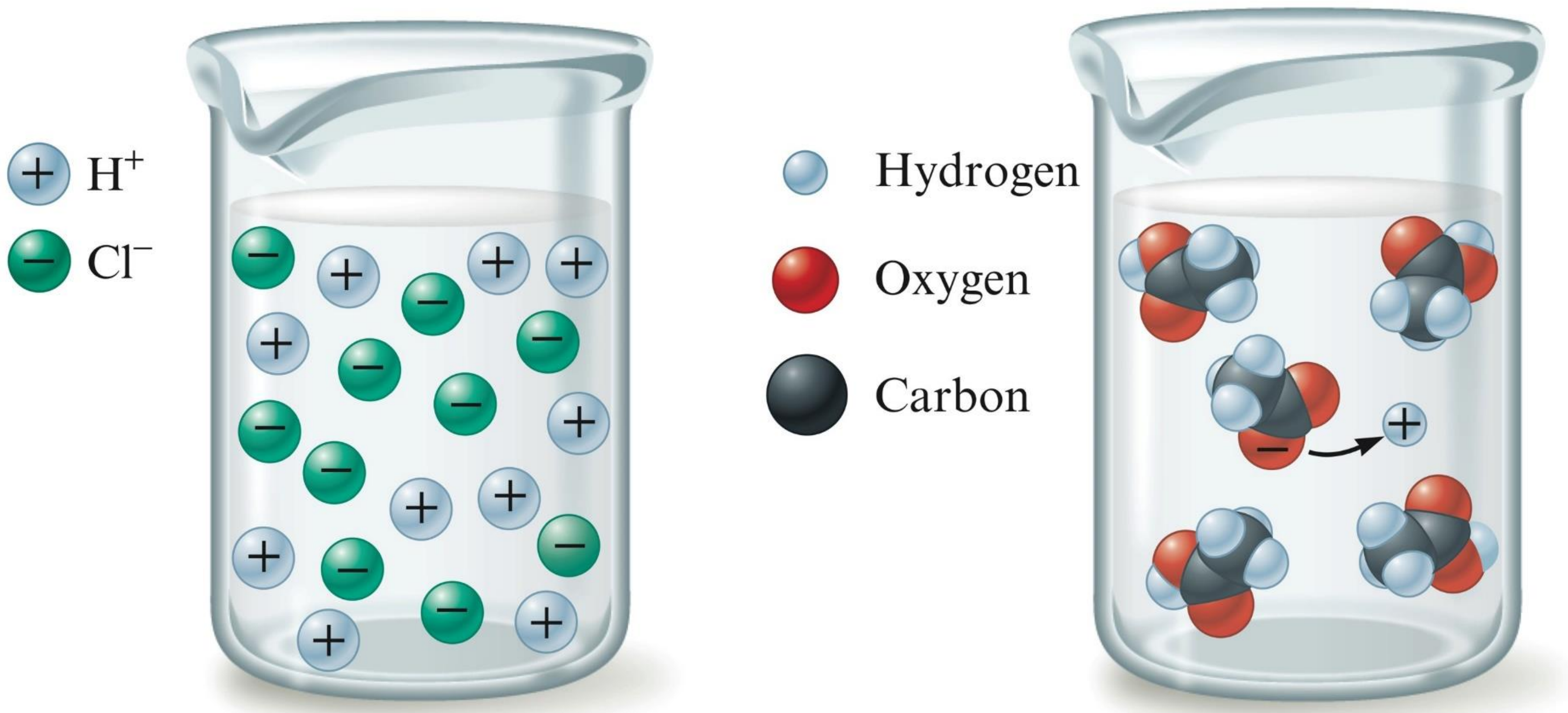
$HA(aq) \leftrightarrow H^+(aq) + A^-(aq)$

1. What do both acids have in common?
2. What is different between strong and weak acids?

3. Examine the two solutions below.

a. Identify each as either a strong acid or weak acid.

b. Write the ionization equation for each.



HCl(aq) $HC_2H_3O_2$(aq)

4. If both solutions above are at the same concentration of 3.0×10^{-5} M, then predict:

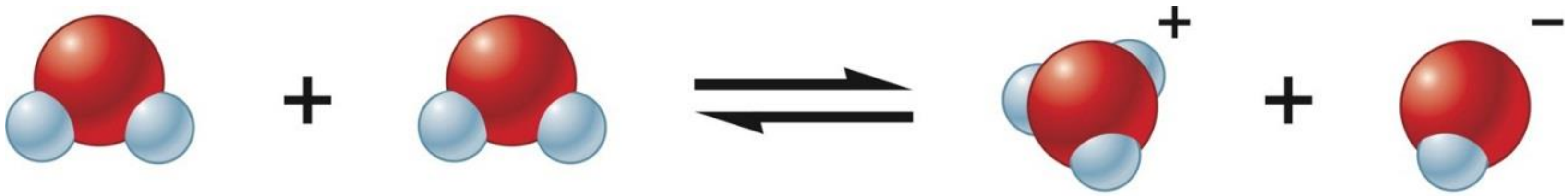
a. the solution with the higher concentration of H^+. Explain your reasoning.

b. the solution with the higher pH. Explain your reasoning.

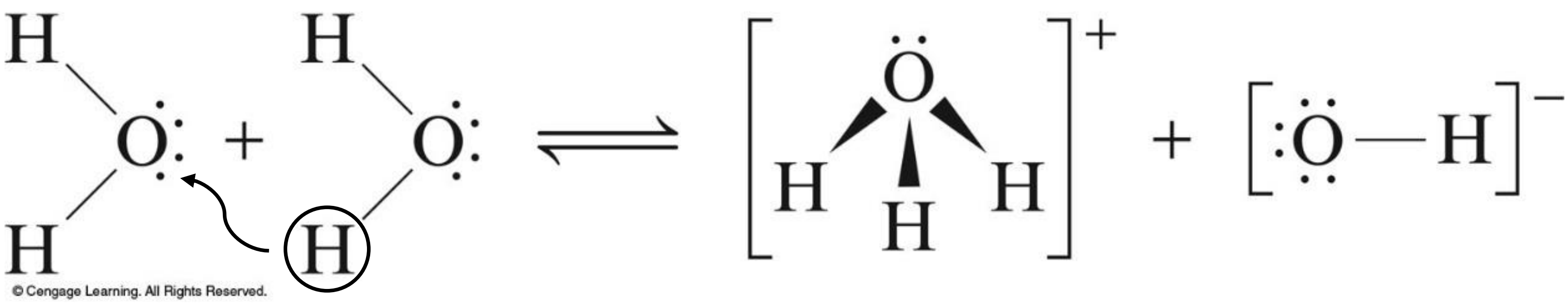
STATION 3 – WATER

Water can give or take a proton (i.e. H^+), meaning water can be either an acid or base. This is a property known as amphoteric or amphiprotic.

Water molecules autoionize into H_3O^+ and OH^- ions as shown below.



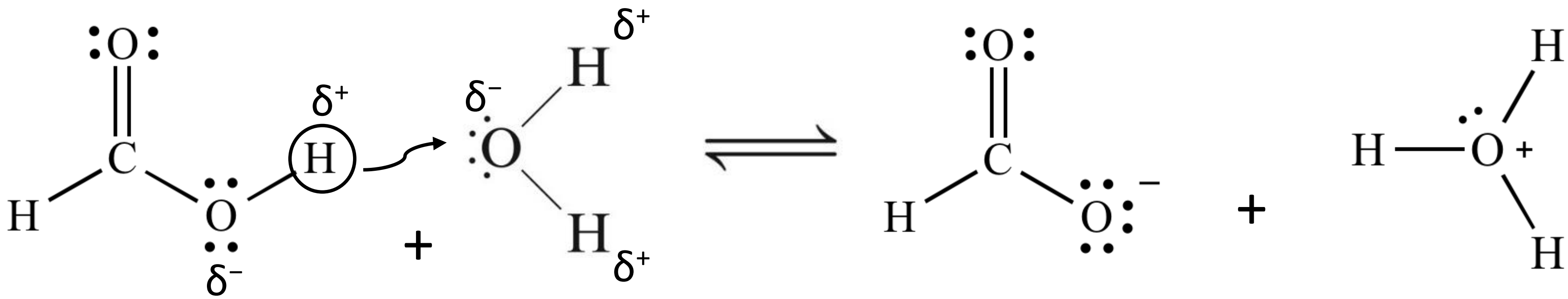
$H_2O(l)$ $H_2O(l)$ $H_3O^+(aq)$ $OH^-(aq)$



H_2O takes H^+ H_2O donates H^+ $H_3O^+(aq)$ $OH^-(aq)$

BASE ACID

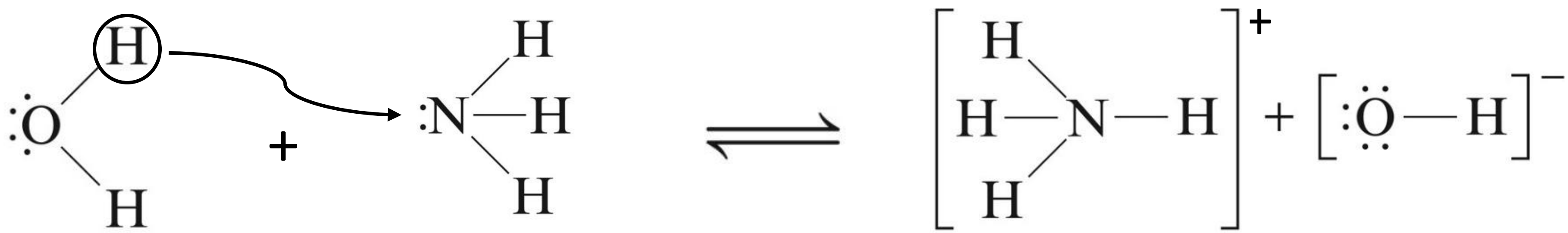
WATER as a weak **BASE**



Methanoic Acid	Water	Methanoate ion	Hydronium ion
HCOOH	**H_2O**	**$HCOO^-$**	**H_3O^+**
Acid	Base	Conjugate base of methanoic acid	Conjugate acid of water

1. Look at the structure of a water molecule. What makes water capable of taking an H^+ ion? In other words, what allows water to act as a base?
2. Look at the structure of a methanoic acid molecule. The hydrogen that is taken is the one bonded to the oxygen. Why is it not the hydrogen bonded to the carbon?
3. What ion do you think will always be produced when an acid dissociates in water?

WATER as a weak **ACID**



Water	Ammonia	Ammonium ion	Hydroxide ion
H_2O	**NH_3**	**NH_4^+**	**OH^-**
Acid	Base	Conjugate acid of ammonia	Conjugate base of water

4. Look at the structure of an ammonia, NH_3, molecule. What makes ammonia capable of taking an H^+ ion?
5. What ion do you think will always be produced when a base dissociates in water?
6. Classify each substance below as an acid or base. Then write its ionization/hydrolysis equation.
   a. $CH_3CH_2COOH(aq)$
   b. $C_2H_5NH_2(aq)$
   c. $CH_3NH_2(aq)$
   d. $NO_2^-(aq)$
   e. $NH_4^+(aq)$

STATION 4 – THE MEANING OF NEUTRAL

Pure water is a neutral substance. We often think of neutral water as having a pH of 7. However, this only holds true if the temperature of water is 25°C.

The true meaning of neutral is $[H^+] = [OH^-]$.

Consider the ionization of water as represented in the equation below.

$$H_2O(l) + H_2O(l) \leftrightarrow H_3O^+(aq) + OH^-(aq)$$

We can write an equilibrium constant, K_w, expression for the ionization of water.

$$K_w = [H_3O^+][OH^-]$$

$$K_w = 1.0 \times 10^{-14} \text{ at } 25°C$$

Thus, we can complete the following ICE chart for the ionization of water.

	$H_2O(l)$ + $H_2O(l)$ $\leftrightarrow$	$H_3O^+(aq)$ +	$OH^-(aq)$
I		0	0
C		+ x	+ x
E		x	x

$\therefore$ the equilibrium $[H^+] = [OH^-] = x$

$\therefore$ water is neutral

Calculating the concentration of H^+ in water at 25°C…

$$K_w = x^2$$
$$1.0 \times 10^{-14} = x^2$$
$$x = 1.0 \times 10^{-7}\ M = [H^+]$$

Calculating the pH of water at 25°C…

$$pH = -\log [H^+]$$
$$pH = -\log (1.0 \times 10^{-7})$$
$$pH = 7.00$$

Unless otherwise stated, we can assume a temperature of 25°C. Caution…K_w is temperature dependent, just like all other equilibrium constants. <u>When temperature changes, K_w will change, thus $[H^+]$ and pH change with temperature.</u>

Consider the following K_w values at various temperatures.

Temperature	K_w
0°C	0.11×10^{-14}
10°C	0.31×10^{-14}
100°C	7.50×10^{-14}

1. Calculate the $[H^+]$ at each temperature.
2. Calculate the pH at each temperature.
3. Is water acidic, basic, or neutral at 100°C? Justify your answer.
4. Based on how the K_w value changes with temperature, is the ionization of water endothermic or exothermic? Explain your reasoning.

STATION 5 – CONJUGATE ACID-BASE PAIRS

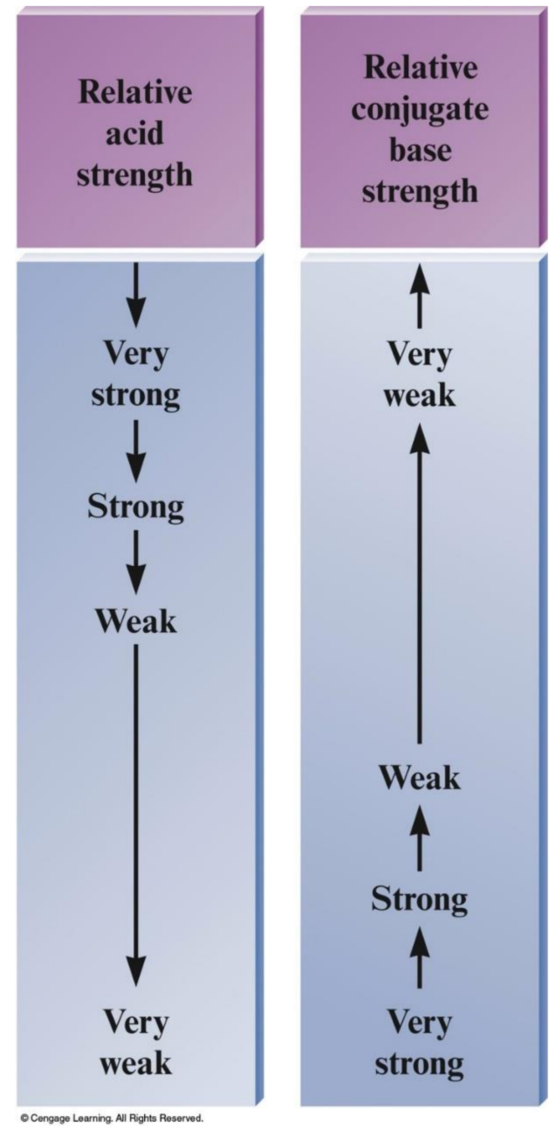
<u>Conjugate acid-base pair</u> – two compounds that differ by the presence of one H^+ unit.

Example) $HClO_2$ (acid) and ClO_2^- (conjugate base)

Identify the conjugate acid-base pairs in each equation below.

1. $HNO_3 + H_2O \rightarrow H_3O^+ + NO_3^-$
2. $CN^- + HC_2H_3O_2 \leftrightarrow HCN + C_2H_3O_2^-$
3. $NH_4^+ + F^- \leftrightarrow HF + NH_3$
4. $PO_4^{3-} + H_2O \leftrightarrow HPO_4^{2-} + OH^-$

For any given conjugate acid-base pair, we can compare relative strength of the acid vs. its conjugate base. Consider the diagram to the right. The stronger the acid, the weaker its conjugate base. Likewise, the weaker the acid, the stronger its conjugate base.



The extent to which an acid ionizes (i.e. creates ions) determines the strength of the acid. The easier it is for an acid to ionize the larger its equilibrium acid dissociation constant, Ka, value.

Example) The acid HClO ionizes according to the following equation.

$$HClO(aq) + H_2O(l) \leftrightarrow H_3O^+(aq) + ClO^-(aq)$$

The equilibrium constant, Ka, expression would be:

$$Ka = \frac{[H_3O^+]\,[ClO^-]}{[HClO]}$$

∴ the stronger the acid, the more H_3O^+ ions, the larger its Ka value

To compare the relative strength of HClO to its conjugate base, ClO^-, we will need the Kb value of ClO^-.

The base ClO^- hydrolyzes with water according to the following equation.

$$ClO^-(aq) + H_2O(l) \leftrightarrow HClO(aq) + OH^-(aq)$$

The equilibrium constant, Kb, expression would be:

$$Kb = \frac{[HClO][OH^-]}{[ClO^-]}$$

∴ the stronger the base, the more OH^- ions, the larger its Kb value

Looking up Ka/Kb values…

Ka of HClO = 4.0×10^{-8}

Kb of ClO^- = 2.5×10^{-7} ∴ ClO^- is a stronger base than HClO is an acid

For any given conjugate acid-base pair:

$$Ka \times Kb = 1.0 \times 10^{-14}$$

For each acid below, write the formula of its conjugate base and calculate the base's Kb value.

5. $HC_3H_5O_3$ $Ka = 1.38 \times 10^{-4}$
6. HCN $Ka = 6.2 \times 10^{-10}$
7. H_2CO_3 $Ka = 4.3 \times 10^{-7}$

For each base below, write the formula of its conjugate acid and calculate the acid's Ka value.

8. C_5H_5N $Kb = 1.7 \times 10^{-9}$
9. CH_3NH_2 $Kb = 4.38 \times 10^{-4}$
10. $(C_2H_5)_3N$ $Kb = 4.0 \times 10^{-4}$