Acids & Bases

Ch12 in text

Please Write

Acids

1. Tastes sour.
2. Turns litmus red
3. React with metals to produce H_2 gas
4. Conduct electricity
5. pH < 7

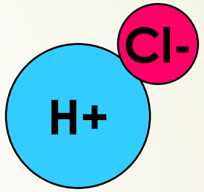
Bases

1. Taste bitter
2. Feel slippery
3. Turns litmus blue
4. Conduct electricity
5. pH > 7

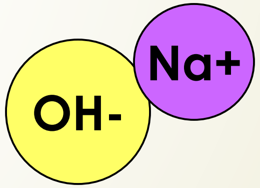
Definitions of Acids & Bases: *Please Write*

Arrhenius Acids & Bases:

- **Acid:**
  - produces H^+ ions in water
  - $HCl \rightarrow H^+ + Cl^-$



- **Base:**
  - produces OH^- ions in water
  - $NaOH \rightarrow Na^+ + OH^-$



- When combined they neutralize each other:
  - $NaOH + HCl \rightarrow NaCl + H_2O$

This definition is too limiting! It ignores ammonium NH_3 that is a base … and salts that can act as acids or bases but do not have H+ or OH-!

Please Write

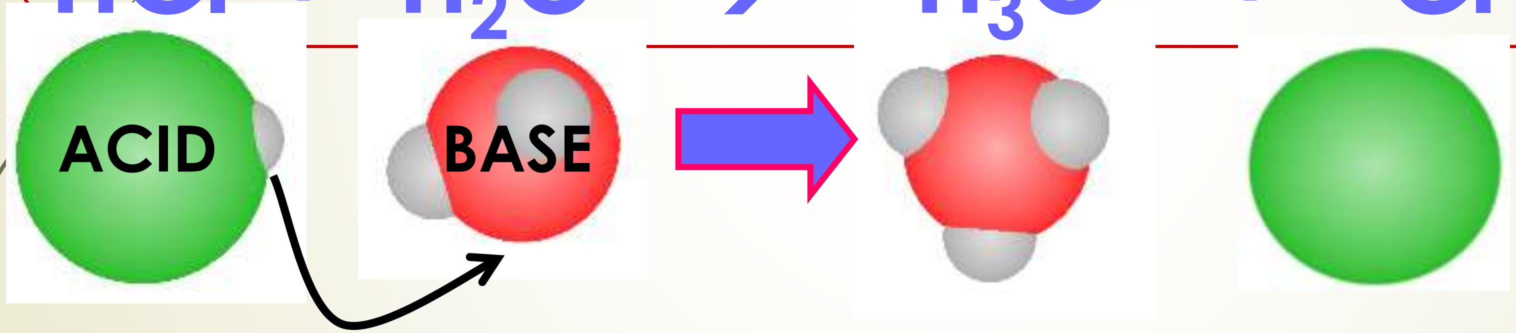
Brønsted-Lowry Acids & Bases:

- **Acids** donates H^+ ions
- **Bases** accept H^+ ions

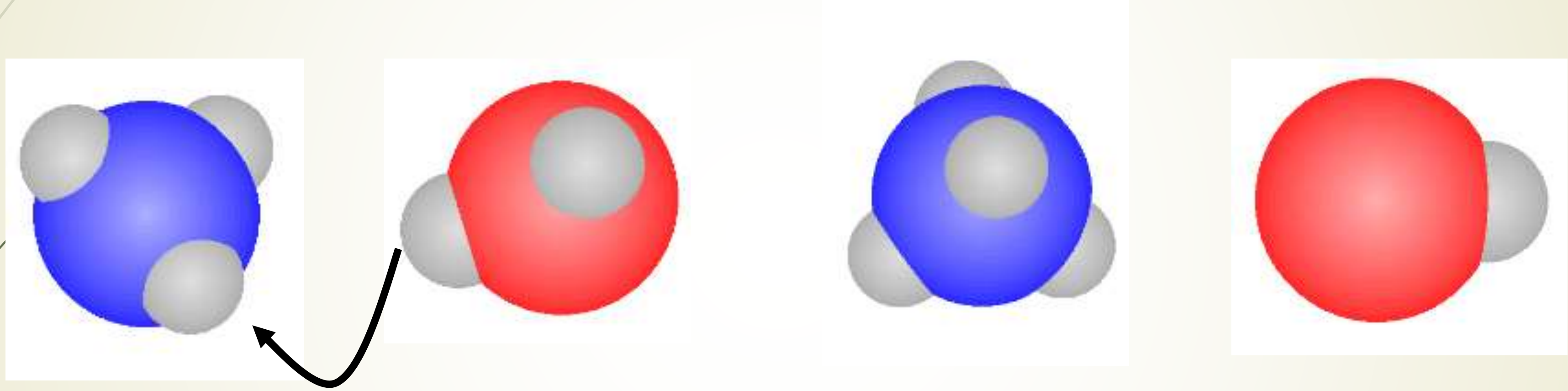
Hydronium Ion

Can be written as H^+

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$



$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$



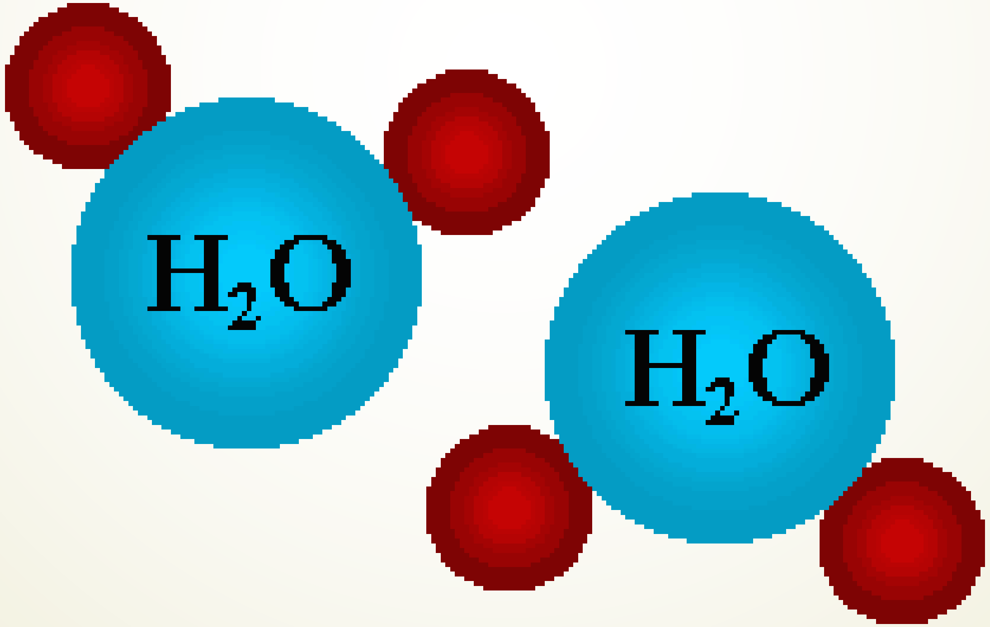
BASE **ACID**

Accepted H+ ion

Donated H+ ion

Water can accept & donate H^+

Water is "**amphoteric**", it can act like a **ACID** or a **BASE**



Please Write

- Each acid has a corresponding base conjugate. It is the particle that remains after the H^+ is lost.

- ...... base ....acid conjugate. It is the particle that is formed after the H^+ is gained.

Please Write

Conjugate Acid – Base Pair

$$HCl + H_2O \leftrightarrow H_3O^+ + Cl^-$$

ACID	BASE	Conjugate ACID	Conjugate BASE
Donates H+ ion	Accepts H+ ion	Donates H+ ion in reverse rxn	Accepts H+ ion in reverse rxn

Conjugate Acid – Base Pair

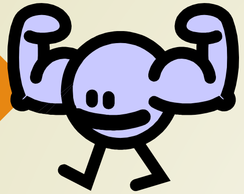
Conjugate Acid – Base Pair

$$CO_3^{2-} + 2H_2O \leftarrow\rightarrow 2OH^- + H_2CO_3$$

BASE	**ACID**	**Conjugate BASE**	**Conjugate ACID**
Accepts H+ ion	Donates H+ ion	Accepts H+ ion in reverse rxn	Donates H+ ion in reverse rxn

Conjugate Acid – Base Pair

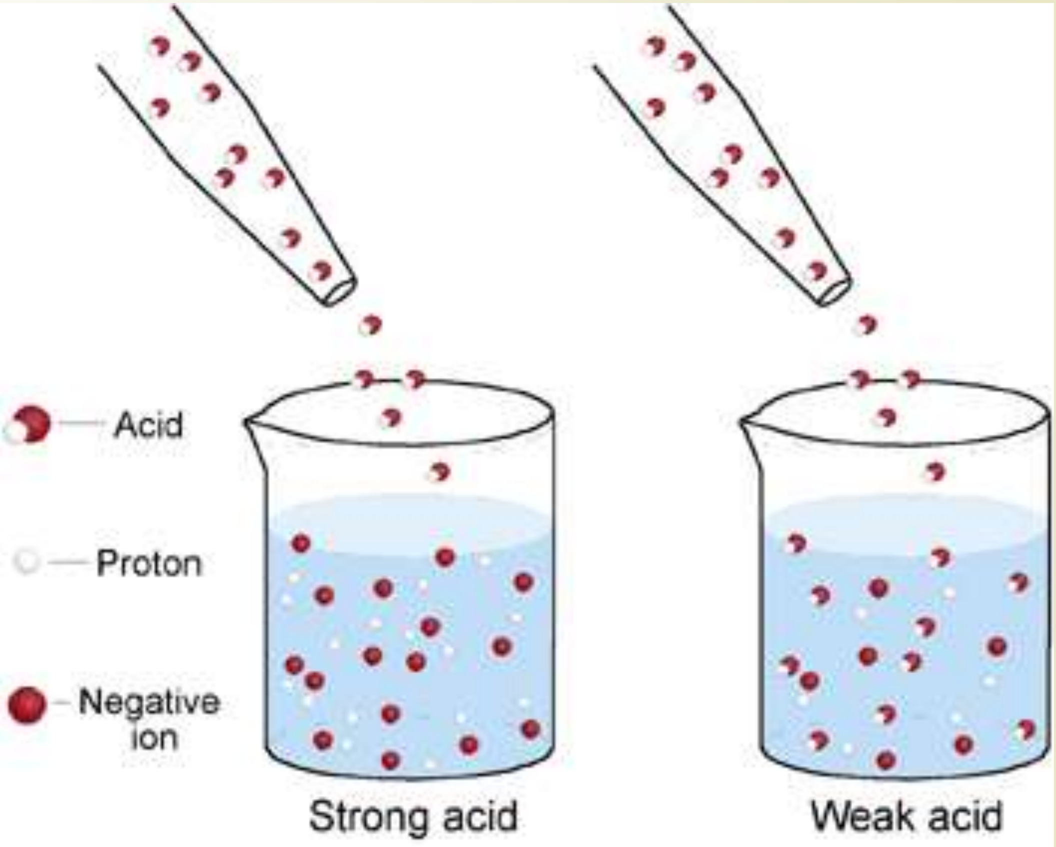
Please Write



Strength

- **A strong acid**
  - dissociates completely
    - $HCl \rightleftarrows H^+ + Cl^-$ large K_{eq}
- **A weak acid**
  - does not transfer <u>all</u> H^+
    - $CH_3COOH \rightleftarrows CH_3COO^- + H^+$

      small $K_{eq} = 1.8 \times 10^{-5}$



Please Write

- **A strong base**
  - has a high affinity for H^+ ions
  - ex. $NaOH \rightleftarrows Na^+ + OH^-$ large K_{eq} (many OH^- to accept H^+)
- **A weak base**
  - has a low affinity for H^+ ions
  - ex. $NH_3 + H_2O \rightleftarrows NH_4^+ + OH^-$ small K_{eq}

Kw:

Please Write

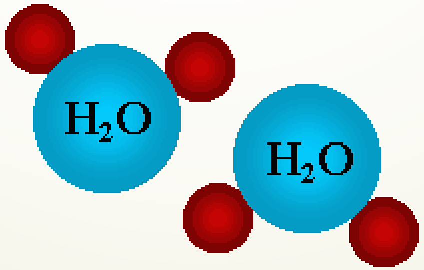
- Water is also in a equilibrium rxn:

$H_2O_{(l)} \rightleftarrows H^+_{(aq)} + OH^-_{(aq)}$ $K_w = [H^+][OH^-]$ = 1×10^{-14}

- Few molecules are ionized.
- $[H^+]=[H_3O^+]$ when water is present

$2H_2O$ + energy $\leftrightarrow$ H_3O^+ + OH^-

Can be simplified to



pH = 0	Battery acid
pH = 1	Sulfuric acid
pH = 2	Lemon juice, Vinegar
pH = 3	Orange juice, Soda
pH = 4	Acid rain (4.2-4.4)
	Acidic lake (4.5)
pH = 5	Bananas (5.0-5.3)
	Clean rain (5.6)
pH = 6	Healthy lake (6.5)
	Milk (6.5-6.8)
pH = 7	Pure water
pH = 8	Sea water, Eggs
pH = 9	Baking soda
pH = 10	Milk of Magnesia
pH = 11	Ammonia
pH = 12	Soapy water
pH = 13	Bleach
pH = 14	Liquid drain cleaner

- At 25°C

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

Please Write

$$[H^+] = 1.0 \times 10^{-7}\ M \qquad pH = 7$$

$$[OH^-] = 1.0 \times 10^{-7}\ M$$

- At other temperatures?

$$H_2O + E \rightleftarrows H^+ + OH^-$$

  - At lower temperatures K_w will be lower. (shift left, less products)
  - Higher temperatures K_w will be higher.

Practice

- If you add NaOH to water.
  - $[OH^-]$ goes up.
  - $[H^+]$ goes down.

- What is the pH of the solution if you add enough NaOH such that $[OH^-] = 1 \times 10^{-5}$ M what is the pH?

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

$$1.0 \times 10^{-14} = [H^+](1 \times 10^{-5})$$

$$[H^+] = 1 \times 10^{-9}$$

pH = 9

Please Write

	Strong acid	Weak acid	WATER	Weak base	Strong base
$[H^+]$	$1x10^{-1} = 0.1M$	$1x10^{-5}$	$1x10^{-7}$	$1x10^{-8}$	$1x10^{-12}$
$[OH^-]$	$1x10^{-13}$	$1x10^{-9}$	$1x10^{-7}$	$1x10^{-6}$	$1x10^{-2}$
pH	1	5	7	8	12
pOH	13	9	7	6	2

pH 2 vs pH 1 = 10x stronger

pH + pOH = 14

$$\boxed{\begin{array}{l}[H^+]=1x10^{-pH} \\ pH = -\log[H^+]\end{array}}$$

$$pOH = -\log[OH^-]$$

1. Find the $[H^+]$ and $[OH^-]$ of the following pH solutions **without** using a calculator:

A) pH=4 B) pH=12 C) pH=9 D) pH=7 E) pH=8

2. Find the pH of the following solutions **without** a calculator:

A) $[H^+]=1.0x10^{-8}$ mol/L B) $[OH^-]=1.0x10^{-3}$ $^{mol}/_{L}$

C) $[H^+]=1.0x10^{-5}$ mol/L D) $[OH^-]=1.0x10^{-9}$ $^{mol}/_{L}$

Practice

3. Find the $[H^+]$ of these solutions: **$[H^+]=10^{-pH}$**

A) pH=3.7 B) pH=9.8 C) pH=6.2 D) pH=4.0 E) pH=7.1

4. Find the pH of the following solutions: **pH= - *log* $[H^+]$.**

A) $[H^+]=4.5x10^{-3}$ mol/L B) $[H^+]=3.4x10^{-8}$ $^{mol}/_{L}$

C) $[H^+]=3.0x10^{-7}$mol/L D) $[H^+]=2.5x10^{-2}$ $^{mol}/_{L}$

Solutions to Problems 1- 4

Check answers.

1. Answers

   A) $[H^+]=1x10^{-4}$, $[OH^-]=1x10^{-10}$ mol/L B) $[H^+]=1x10^{-12}$, $[OH^-]=1x10^{-2}$ mol/L

   C) $[H^+]= 1x10^{-9}$, $[OH^-]=1x10^{-5}$ mol/L D) $[H^+]=1x10^{-7}$, $[OH^-]=1x10^{-7}$ mol/L

   E) $[H^+]=1x10^{-8}$, $[OH^-]1x10^{-6}$ mol/L

2. Answers:

   A) pH=8 B) $pOH^-=3 \rightarrow$ pH= 11 C) pH=5 D) $pOH^-=9 \rightarrow$ pH=5

3. Answers (in mol/L). remember: $\mathbf{[H^+]=10^{-pH}}$

   A) $10^{-3.7}=2.0x10^{-4}$ mol/L B) $10^{-9.8}=1.6x10^{-10}$ mol/L C) $6.3x10^{-7}$ mol/L

   D) $1.0x10^{-4}$ mol/L E) $7.9x10^{-8}$ mol/L

4. Answers: **pH= - *log* $[H^+]$.**

   A) pH= 2.3 ($-\log(4.5x10^{-3})$) B) pH=7.5 C) pH=6.5 D) pH=1.6

Ex #1:

Please Write

What is the $[H^+]$ of black coffee at 25°C if $[OH^-]$ is 1.3×10^{-9} M? What is the pH?

$$Kw = [H^+][OH^-]$$

$$1.0 \times 10^{-14} = [H^+]\,[1.3 \times 10^{-9}]$$

$$7.7 \times 10^{-6} = [H^+]$$

$$pH = -\log [H^+]$$

$$pH = -\log (7.7 \times 10^{-6})$$

$$pH = 5.1$$

ACIDIC

Please Write

$$CH_3COOH_{(aq)} \rightleftarrows CH_3COO^-_{(aq)} + H^+_{(aq)}$$

vinegar/acetic acid

- $K_a = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]}$
- K_a = small($\leq 10^{-5}$) = low $[H^+]$ = weak acid
- K_a = large = high $[H^+]$ = strong acid
- Nitrous acid Ka = 4.4×10^{-4} vs vinegar Ka = 1.8×10^{-5}

  Nitrous acid is stronger!
- Percent dissociation $\_\_\% = \frac{[H^+]}{[CH_3COOH]} \times 100$

Simplifying I.C.E. tables(the 5% rule)

When doing an ICE table you may have to subtract a **very small value** from a relatively large value…

for example 2.0 mol/L – 1.0×10^{-4} mol/L.

In this case, don't bother doing the subtraction, since by the time you change it to show significant digits, the result will be the same:

2.0 mol/L – 0.0001 mol/L = 1.9999 mol/L ≈ 2.0 mol/L.

SHORTCUT: If the number you subtract is less than 5% of the original number, you can usually skip the subtraction.

Please Write

Ex.2

Calculate the $[H^+]$ & pH of a 0.25M solution of CH_3COOH. $K_a = 1.80 \times 10^{-5}$.

$$CH_3COOH \leftrightarrow H^+ + CH_3COO^-$$

	CH_3COOH	H^+	CH_3COO^-
I	0.25	0	0
C	- x	+ x	+ x
E	0.25 – x	x	x

$$Ka = \frac{[H^+][CH_3COO^-]}{[CH_3COOH]}$$

$$1.80 \times 10^{-5} = \frac{[x][x]}{[0.25 - \cancel{x}]}$$

$$\boxed{[H^+] = 2.1 \times 10^{-3} M}$$

$$pH = -\log(2.1 \times 10^{-3})$$

$$\boxed{pH = 2.7}$$

How do you know?

x/0.25 $\leq$ 5% then the difference will be insignificant and the short cut is justified!

Please write

Ex.3

Calculate the $[H_3O^+]$ of a 0.55M HCN solution. Also calculate the % dissociation.

$Ka = 4.8 \times 10^{-10}$

$$HCN_{(aq)} + H_2O_{(l)} \leftrightarrow H_3O^+_{(aq)} + CN^-_{(aq)}$$

	HCN	H_3O^+	CN^-
I	0.55	0	0
C	- x	+ x	+ x
E	0.55 ~~– x~~	x	x

$$Ka = \frac{[H_3O^+][CN^-]}{[HCN]}$$

$$4.80 \times 10^{-10} = \frac{[x][x]}{[0.55 - \cancel{x}]}$$

$$\boxed{[H_3O^+] = 1.62 \times 10^{-5} M}$$

Shortcut? ☑

Please Write

$$\% \text{ Dissociation} = \frac{[H_3O^+]}{[HCN]} \times 100$$

$$\% \text{ Dissociation} = \frac{[1.62 \times 10^{-5}]}{[0.55]} \times 100$$

$$\boxed{\% \text{ Dissociation} = 2.94 \times 10^{-3}\ \%}$$

Very Small %
Weak Acid!

Please Write

$NH_{3\,(aq)} + H_2O_{(l)} \leftrightarrow NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$

ammonia

- $K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$
- K_b = small($\leq 10^{-5}$) = low $[OH^-]$ = weak base
- K_b = large = high $[OH^-]$ = strong base

  Hydrazine (N_2H_4)K_b= 1.7×10^{-6} vs ammonia K_b = 1.8×10^{-5}

  Ammonia is a stronger base!

- Percent dissociation $\_\_\% = \frac{[OH^-]}{[NH_3]} \times 100$

Please Write

Relationship between Ka & Kb:

$$CH_3COOH_{(aq)} + H_2O \rightleftarrows CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$$

$$CH_3COO^-_{(aq)} + H_2O \rightleftarrows CH_3COOH_{(aq)} + OH^-_{(aq)}$$

$$K_a = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]} \qquad K_b = \frac{[CH_3COOH][OH^-]}{[CH_3COO^-]}$$

$$K_a \times K_b = \frac{\cancel{[CH_3COO^-]}[H^+]}{\cancel{[CH_3COOH]}} \times \frac{\cancel{[CH_3COOH]}[OH^-]}{\cancel{[CH_3COO^-]}}$$

$$K_a \times K_b = [H^+] \times [OH^-] = K_W$$

$$\boxed{K_a \times K_b = K_w}$$

Please Write

Ex. 1 Calculate the K_b for CN^- acting as a base in water, if the K_a of HCN = 4.8×10^{-10}.

$$K_a \times K_b = K_w$$

$$K_b = \frac{K_w}{K_a}$$

$$K_b = \frac{1 \times 10^{-14}}{4.8 \times 10^{-10}}$$

$$K_b = 2.08 \times 10^{-5}$$

Please Write

Ex. 2.

HCO_3^{1-} is amphoteric.

If HCO_3^{1-} was placed in water, would the solution be acting as an acid or a base?

Step 1: Write out the equations acid & base rxns:

$HCO_3^{1-} + H_2O \leftrightarrow$ Ka = 4.7×10^{-11}

$HCO_3^{1-} + H_2O \leftrightarrow$ Kb = 2.13×10^{-4}

Step 2: Calculate Kb & compare to Ka

$K_a \times K_b = K_w \quad K_b = \frac{K_w}{K_a}$

$$Kb = \frac{1.0 \times 10^{-14}}{4.7 \times 10^{-11}}$$

$Kb = 2.13 \times 10^{-4}$

Kb > Ka Therefore solution is BASIC

Naming acids:

Please Write

- Arrhenious developed a naming method that indicates the # of ionization hydrogen.
  - Monoprotic $HCl \rightarrow H^+ + Cl^-$
  - Diprotic $H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$
  - Triprotic $H_3PO_4 \rightarrow 3H^+ + PO_4^{3-}$
- Rules:
  - H bonded with _____ide → hydro___ic acid.
    - Hydrogen chloride → hydrochloric acid (HCl)
  - H bonded with _____ate → ___ic acid.
    - Hydrogen sulphate → sulphuric acid (H_2SO_4)
  - H bonded with _____ite → ___ous acid.
    - Hydrogen sulphite → sulphurous acid (H_2SO_3)

Please Write

List the following acids from weakest to strongest.

ACID	Concentration (M)	pH
HX	0.10	2.1
HY	0.0010	3.1
HZ	0.10	3.1

$K_a = 6.9 \times 10^{-4}$

$K_a = 3.1 \times 10^{-3}$

$K_a = 6.4 \times 10^{-6}$

$$K_a = \frac{[H^+][X^-]}{[HX]}$$

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

$$= \frac{[x]^2}{[0.10 - x]}$$

$$[H^+] = 10^{-2.1}$$

$$= 7.943 \times 10^{-3}$$

$$= \frac{[7.943 \times 10^{-3}]^2}{[0.10 - 7.943 \times 10^{-3}]}$$

$$K_a = 6.854 \times 10^{-4}$$

HZ weakest

HX

HY strongest