Sec 4.13 – Hydrolysis
(notes)

- Reaction between a **salt** (**ion** or **ions** in a salt) and **water** to produce an *acidic* or *basic* solution.

- Net ionic equations for ***hydrolysis***:

An ion + water → a molecule or ion + $\overset{A}{H_3O^+}$ or $\overset{B}{OH^-}$

SPECTATORS- ions which do **NOT** hydrolyze (need periodic table and acid table to find these)

Spectator **Cations**

Group 1 (Alkali Metal ions) eg. Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+
Group 2 (Alkaline Earth ions) eg. Be^+, Mg^{2+}, Ca^{2+}, Ba^{2+}, Sr^{2+}, Ra^{2+}

Spectator **Anions** (look on acid table)

Conjugate bases of strong acids.

- ***Top 5 ions on the right*** side of table.
- ClO_4^- I^- Br^- Cl^- NO_3^-

(HSO_4^- is not a spectator – it is amphiprotic – will be dealt with later)

- **spectators are eliminated** in net ionic equations for hydrolysis!

Process – if given **salt** (dissociate → eliminate → evaluate)

1. Write **dissociation** equation
2. Eliminate **spectators**
3. Remaining ions → **left** side of table – undergo **acid** hydrolysis is – produce H_3O^+
   → **right** side of table – undergo **base** hydrolysis – produce OH^-
   → **amphiprotic** – determine $\mathbf{K_a}$ and $\mathbf{K_b}$ to find *dominant* hydrolysis.

Examples:

1. Is the salt NaF acidic, basic or neutral in water?

Dissociation : NaF → $\cancel{Na^+}$ + F^-

Spectator
(alkali cation)

Found on **right** side of acid table- forms a weak **base**.
--- so NaF is **basic ---**

2. Is the salt NH_4 NO_3 acidic, basic or neutral in aqueous solution?

Dissociation: NH_4NO_3 → NH_4^+ + $\cancel{NO_3^-}$ ← Spectator top 5 on right side of table

Found on **left** side of table – forms a weak **acid** **-** so NH_4NO_3 is **acidic**.

3. Is the salt KCl acidic, basic or neutral?

SA
HCl

Dissociation: KCl → $\cancel{K^+}$ + $\cancel{Cl^-}$ --- since **neither** ion undergoes hydrolysis, this salt is **NEUTRAL**.

4. Cations Which Hydrolyze

- **Hydrated cations**
  - i. metals from *center* of the periodic table (transition metals) are *smaller* ions and have *larger charges* - this attracts H_2O molecules

eg.) Fe^{3+}

Hydration: $Fe^{3+} + 6H_2O \rightarrow Fe(H_2O)_6^{3+}$

Fe

This ion acts as a *weak acid* (see it ~ 13th down on the acid table.)

The equation for the **hydrolysis** is:

$FeCl_3 \rightarrow Fe^{+3} + 3Cl^-$

$$Fe(H_2O)_6^{3+}{}_{(aq)} + H_2O_{(l)} \rightleftarrows H_3O^+_{(aq)} + Fe(H_2O)_5(OH)^{2+}{}_{(aq)}$$

on your chart

3 Common **Hydrated** cations (on ***left*** of acid chart):

iron(III) Fe^{3+} forms $Fe(H_2O)_6^{3+}$
Chromium(III) Cr^{3+} forms $Cr(H_2O)_6^{3+}$
Aluminum Al^{3+} forms $Al(H_2O)_6^{3+}$

} Act as **weak acids**.

Eg.) $AlCl_3$ is the same as $Al(H_2O)_6Cl_3$

$\rightarrow Al^{+3} + 3Cl^-$

$\rightarrow Al(H_2O)_5(OH)^{+2} + 3Cl^- + H_3O^+$

NH_4^+ *Hydrolysis* equation: $NH_4^{\pm}{}_{(aq)} + H_2O_{(l)} \leftrightarrows H_3O^+_{(aq)} + NH_{3(aq)}$

5. Anions which Hydrolyze

(−)

Looking on the **RIGHT** side of the **ACID TABLE**:

- Remember the TOP 5 DO NOT hydrolyze – they are spectators
- HSO_4^- is amphiprotic
- From IO_3^- to PO_4^{3-} under go base hydrolysis
- The BOTTOM 3 - act as STRONG BASES. They undergo 100% hydrolysis to form OH^- ions

Some examples of **net-ionic** ***hydrolysis equations*** for these would be:

$$IO_3^-{}_{(aq)} + H_2O_{(l)} \rightleftarrows HIO_{3\,(aq)} + OH^-_{(aq)}$$

B

$$CH_3COO^-_{(aq)} + H_2O_{(l)} \rightleftarrows CH_3COOH_{(aq)} + OH^-_{(aq)}$$

Eg.) Determine whether the salt sodium carbonate (Na_2CO_3) is acidic, basic or neutral in aqueous solution.

First dissociate the salt: $Na_2CO_3 \rightarrow \overset{spec}{2Na^+} + \overset{wB}{CO_3^{-2}}$

The **net-ionic equation** for the ***hydrolysis*** taking place in this salt would be:

$\underset{B}{CO_3^{2-}}{}_{(aq)} + \underset{A}{H_2O}{}_{(l)} \rightleftarrows HCO_3^- + OH^-$ and the salt would act as a *weak base* in water.

Remember that "net-ionic" means that any spectator ions have been removed!

Write the **net-ionic equation** for the ***hydrolysis*** taking place in aqueous magnesium sulphate:

$MgSO_4 \rightarrow Mg^{+2} + SO_4^{-2}$

$SO_4^{-2} + H_2O \rightleftarrows HSO_4^- + OH^-$

6. Hydrolysis When BOTH Cation and Anion hydrolyze

Eg. Is the salt ammonium nitrite NH_4NO_2 acidic, basic or neutral?

Of course we start out by *dissociating*: $NH_4NO_2 \rightarrow NH_4^+ + NO_2^-$

Remember that NH_4^+ produces H_3O^+ ($NH_4^+ + H_2O \rightleftarrows NH_3 + H_3O^+$) (equation 1)

And NO_2^- produces OH^- ($NO_2^- + H_2O \rightleftarrows HNO_2 + OH^-$) (equation 2)

- The Ka for NH_4^+ tells how much H_3O^+ it produces
- The Kb for NO_2^- tells how much OH^- it produces

The Ka for NH_4^+ is 5.6×10^{-10} (look up NH_4^+ on the left side of the table and it's Ka is on the right)

The Kb for NO_2^- must be calculated: $Kb_{(NO_2)} = \dfrac{Kw}{Ka_{(HNO_2)}} = \dfrac{1.0 \times 10^{-14}}{4.6 \times 10^{-4}} = 2.2 \times 10^{-11}$

Since the Ka of NH_4^+ > Kb of NO_2^- - We can say that this salt is **ACIDIC**

So, in summary:

If	Then the salt is:
Ka (cation) > Kb (anion)	***Acidic***
Kb (anion) > Ka (cation)	***Basic***
Ka (cation) = Kb (anion)	***Neutral***

Determine whether the salt NH_4CN (ammonium cyanide) is acidic, basic or neutral.

$NH_4CN \rightarrow \underset{WA}{NH_4^+{}_{(aq)}} + \underset{WB}{CN^-{}_{(aq)}}$

Ka of $NH_4^+ = 5.6 \times 10^{-10}$

Kb of $CN^- = \dfrac{1.0x10^{-14}}{4.9x10^{-10}} = 2.0x10^{-5}$

so since Kb of CN^- > Ka of NH_4^+ this solution is **basic.**

net ionic eq.

✓ $CN^- + H_2O \rightleftarrows HCN + OH^-$

7. Hydrolysis of Amphiprotic Anions

Amphiprotic Anions → Start with "H" and have a "**-**" charge.

Eg. HSO_4^- , HSO_3^- , $H_2PO_4^-$ HPO_4^{2-} HS^- etc.

Amphiprotic Anions hydrolyze as *acids* to produce H_3O^+ but they also hydrolyze as *bases* to produce OH^- So, how can we tell whether they are acidic or basic or neutral? We need to determine the ***predominant*** hydrolysis

Find the Ka of the ion. (Look for ion on the LEFT SIDE of the acid table, read Ka on the right.)

Find the Kb of the ion. (Look for the ion on the RIGHT SIDE of the table and use:

Kb = Kw/ Ka(conj. Acid)

If	Then the predominant hydrolysis is:	And, in aqueous solution, the ion:
Ka (the ion) > Kb (the ion)	***ACID HYDROLYSIS***	***Acts as an Acid***
Kb (the ion) > Ka (the ion)	***BASE HYDROLYSIS***	***Acts as a Base***

$K | HCO_3$

Eg. Find the predominant hydrolysis of the hydrogen carbonate ion (HCO_3^-) and write the net-ionic equation for it.

To find the Ka of HCO_3^-, look it up on the **left** side of table. It's Ka = 5.6×10^{-11}

To find the Kb of HCO_3^-, look it up of the **right** side of table.

(*It's conjugate acid is* H_2CO_3 *and the Ka of* $H_2CO_3 = 4.3 \times 10^{-7}$)

So we calculate the Kb of HCO_3^- using : $Kb(HCO_3^-) = \frac{Kw}{Ka(H_2CO_3)} = \frac{1.0 \times 10^{-14}}{4.3 \times 10^{-7}} = 2.3 \times 10^{-8}$

So, since Kb > Ka , the ion HCO_3^- predominantly undergoes BASE HYDROLYSIS.

And the net-ionic equation for the ***predominant hydrolysis*** is:

$$HCO_3^-{}_{(aq)} + H_2O_{(l)} \rightleftarrows H_2CO_3{}_{(aq)} + OH^-{}_{(aq)}$$

Read p. 144 – 147 in SW & Do Ex. 69 (a-f) and Ex. 70 (a – j), 71, 72 & 73 on p. 148.

Quiz 4.11 – 4.12 – 4.13

Thursday ?

Test 4.1 – 4.13 Tuesday

Sec 4.13 – Hydrolysis

(student notes)

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- Net ionic equations for ***hydrolysis***:

SPECTATORS- (need periodic table and acid table to find these)

Spectator **Cations**

Group 1 (Alkali Metal ions) eg. Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+
Group 2 (Alkaline Earth ions) eg. Be^+, Mg^{2+}, Ca^{2+}, Ba^{2+}, Sr^{2+}, Ra^{2+}

Spectator **Anions** (look on acid table)

- Conjugate bases of strong acids.
- ***Top 5 ions on the right*** side of table.
- ClO_4^- I^- Br^- Cl^- NO_3^-

(HSO_4^- is not a spectator – it is amphiprotic – will be dealt with later)

- ____________________________ in net ionic equations for hydrolysis!

Process – if given **salt** (_______________→_______________ → _______________)

1. Write **dissociation** equation
2. Eliminate **spectators**
3. Remaining ions → **left** side of table – undergo **acid** hydrolysis is – produce H_3O^+
   → **right** side of table – undergo **base** hydrolysis – produce OH^-
   → **amphiprotic** – determine $\mathbf{K_a}$ and $\mathbf{K_b}$ to find *dominant* hydrolysis.

Examples:

1. Is the salt NaF acidic, basic or neutral in water?

Dissociation : $NaF \quad \times\!\!\rightarrow Na^+ + F^-$

Found on **right** side of acid table- forms a weak **base**.
--- so NaF is __________ ---

2. Is the salt NH_4 NO_3 acidic, basic or neutral in aqueous solution?

Dissociation: $NH_4NO_3 \rightarrow \cancel{NH_4^+} + NO_3^-$

Found on **left** side of table – forms a ______________ - so NH_4NO_3 is ___________.

3. Is the salt KCl acidic, basic or neutral?

Dissociation: $KCl \rightarrow \cancel{K^+} + \cancel{Cl^-}$ --- since **neither** ion undergoes hydrolysis, this salt is ___________.

4. Cations Which Hydrolyze

- **Hydrated cations**
  - metals from *center* of the periodic table (transition metals) are *smaller* ions and have *larger charges* - this attracts H_2O molecules

eg.) Fe^{3+}

Hydration: $Fe^{3+} + 6H_2O \rightarrow Fe(H_2O)_6^{3+}$

This ion acts as a <u>*weak acid*</u> (see it ~ 13th down on the acid table.)

The equation for the **hydrolysis** is:

$$Fe(H_2O)_6^{3+}{}_{(aq)} + H_2O_{(l)} \rightleftarrows H_3O^+{}_{(aq)} + Fe(H_2O)_5(OH)^{2+}{}_{(aq)}$$

<u>3 Common **Hydrated** cations</u> (on ***left*** of acid chart):

$$\left.\begin{array}{ll}\text{Iron(III) } Fe^{3+} & \text{forms } Fe(H_2O)_6^{3+}\\ \text{Chromium(III) } Cr^{3+} & \text{forms } Cr(H_2O)_6^{3+}\\ \text{Aluminum } Al^{3+} & \text{forms } Al(H_2O)_6^{3+}\end{array}\right\}\quad \text{Act as } \underline{\textbf{weak acids}}.$$

Eg.) $AlCl_3$ is the same as $Al(H_2O)_6Cl_3$

NH_4^+ *Hydrolysis* equation: $NH_4^+{}_{(aq)} + H_2O_{(l)} \leftrightarrows H_3O^+{}_{(aq)} + NH_{3(aq)}$

5. Anions which Hydrolyze

Looking on the **RIGHT** side of the **ACID TABLE**:

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Some examples of **<u>net-ionic</u>** ***hydrolysis equations*** for these would be:

$IO_3^-{}_{(aq)} + H_2O_{(l)} \rightleftarrows$ ________________________

$CH_3COO^-{}_{(aq)} + H_2O_{(l)} \rightleftarrows$ ____________________________

Eg.) Determine whether the salt sodium carbonate (Na_2CO_3) is acidic, basic or neutral in aqueous solution.

First dissociate the salt: $Na_2CO_3 \rightarrow$ ______________________________

The **net-ionic equation** for the ***hydrolysis***-taking place in this salt would be:

$CO_3^{2-}{}_{(aq)} + H_2O_{(l)} \rightleftarrows$ _________________ and the salt would act as a *weak base* in water.

Remember that "net-ionic" means that any spectator ions have been removed!

Write the **net-ionic equation** for the ***hydrolysis*** taking place in aqueous magnesium sulphate:

6. Hydrolysis When BOTH Cation and Anion hydrolyze

Is the salt ammonium nitrite NH_4NO_2 acidic, basic or neutral?

Start out by *dissociating*: $NH_4NO_2 \rightarrow$ ______________________________

Remember that NH_4^+ produces H_3O^+ ($NH_4^+ + H_2O \rightleftarrows H_3O^+ + NH_3$) (equation 1)
And NO_2^- produces OH^- ($NO_2^- + H_2O \rightleftarrows HNO_2 + OH^-$) (equation 2)

- The Ka for NH_4^+ tells how much H_3O^+ it produces
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The Ka for NH_4^+ is ____________(look up NH_4^+ on the left side of the table and it's Ka is on the right)

The Kb for NO_2^- must be calculated: $Kb_{(NO_2)} = \dfrac{Kw}{Ka_{(HNO_2)}} =$ ___________

Since the Ka of NH_4^+ > Kb of NO_2^- - We can say that this salt is _________________

So, in summary:

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Ka (cation) > Kb (anion)	***Acidic***
Kb (anion) > Ka (cation)	***Basic***
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Determine whether the salt NH_4CN (ammonium cyanide) is acidic, basic or neutral.

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Ex. HSO_4^- , HSO_3^- , $H_2PO_4^-$ HPO_4^{2-} HS^- etc.

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If	**Then the predominant hydrolysis is:**	**And, in aqueous solution, the ion:**
Ka (the ion) > Kb (the ion)	***ACID HYDROLYSIS***	***Acts as an Acid***
Kb (the ion) > Ka (the ion)	***BASE HYDROLYSIS***	***Acts as a Base***

Ex. Find the predominant hydrolysis of the hydrogen carbonate ion (HCO_3^-) and write the net-ionic equation for it.

Read p. 144 – 147 in SW & Do Ex. 69 (a-f) and Ex. 70, 71, 72 & 73 on p. 148.

Sec 4.13 – Hydrolysis

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- **spectators are eliminated** in net ionic equations for hydrolysis!

Process – if given **salt** (dissociate → eliminate → evaluate)

1. Write **dissociation** equation
2. Eliminate **spectators**
3. Remaining ions
   → **left** side of table – undergo **acid** hydrolysis is – produce H_3O^+
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   → **amphiprotic** – determine K_a and K_b to find *dominant* hydrolysis.

Examples:

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Dissociation : $NaF \rightarrow \cancel{Na^+} + F^-$

Spectator
(alkali cation)

Found on **right** side of acid table- forms a weak **base**. --- so NaF is **basic** ---

2. Is the salt $NH_4\ NO_3$ acidic, basic or neutral in aqueous solution?

Dissociation: $NH_4NO_3 \rightarrow NH_4^+ + \cancel{NO_3^-}$

Spectator top 5 on right side of table

Found on **left** side of table – forms a weak **acid**

- so NH_4NO_3 is **acidic**.

3. Is the salt KCl acidic, basic or neutral?

Dissociation: $KCl \rightarrow \cancel{K^+} + \cancel{Cl^-}$ --- since **neither** ion undergoes hydrolysis, this salt is **NEUTRAL**.

4. Cations Which Hydrolyze

- **Hydrated cations**

  metals from *center* of the periodic table (transition metals) are *smaller* ions and have *larger charges* - this attracts H_2O molecules

eg.) Fe^{3+}

Hydration: $Fe^{3+} + 6H_2O \rightarrow Fe(H_2O)_6^{3+}$

This ion acts as a *weak acid* (see it ~ 13th down on the acid table.)

The equation for the **hydrolysis** is:

$$Fe(H_2O)_6^{3+}{}_{(aq)} + H_2O_{(l)} \rightleftarrows H_3O^+{}_{(aq)} + Fe(H_2O)_5(OH)^{2+}{}_{(aq)}$$

<u>3 Common **Hydrated** cations</u> (on ***left*** of acid chart):

Iron(III) Fe^{3+} forms $Fe(H_2O)_6^{3+}$
Chromium(III) Cr^{3+} forms $Cr(H_2O)_6^{3+}$
Aluminum Al^{3+} forms $Al(H_2O)_6^{3+}$

} Act as **<u>weak acids</u>**.

Eg.) $AlCl_3$ is the same as $Al(H_2O)_6Cl_3$

NH_4^+ *Hydrolysis* equation: $NH_4^+{}_{(aq)} + H_2O_{(l)} \leftrightarrows H_3O^+{}_{(aq)} + NH_{3(aq)}$

5. Anions which Hydrolyze

Looking on the **RIGHT** side of the **ACID TABLE**:

- Remember the TOP 5 DO NOT hydrolyze – they are spectators
- HSO_4^- is amphiprotic
- From IO_3^- to PO_4^{3-} under go base hydrolysis
- The BOTTOM 3 - act as STRONG BASES. They undergo 100% hydrolysis to form OH^- ions

Some examples of **<u>net-ionic</u>** ***hydrolysis equations*** for these would be:

$$IO_3^-{}_{(aq)} + H_2O_{(l)} \rightleftarrows HIO_{3\,(aq)} + OH^-{}_{(aq)}$$

$$CH_3COO^-{}_{(aq)} + H_2O_{(l)} \rightleftarrows CH_3COOH_{(aq)} + OH^-{}_{(aq)}$$

Eg.) Determine whether the salt sodium carbonate (Na_2CO_3) is acidic, basic or neutral in aqueous solution.

First dissociate the salt: $Na_2CO_3 \rightarrow 2\,Na^+{}_{(aq)} + CO_3^{2-}{}_{(aq)}$

The **<u>net-ionic equation</u>** for the ***hydrolysis*** taking place in this salt would be:

$CO_3^{2-}{}_{(aq)} + H_2O_{(l)} \rightleftarrows HCO^-_{3\,(aq)} + OH^-{}_{(aq)}$ and the salt would act as a *weak base* in water.

Remember that “net-ionic” means that any spectator ions have been removed!

Write the **net-ionic equation** for the ***hydrolysis*** taking place in aqueous magnesium sulphate:

$$MgSO_4\,(aq) \leftrightarrows Mg^{+2} + SO_4^{-2}$$

$$SO_4^{2-}{}_{(aq)} + H_2O_{(l)} \leftrightarrows HSO_4^{-}{}_{(aq)} + OH^{-}{}_{(aq)}$$

6. Hydrolysis When BOTH Cation and Anion hydrolyze

Ex. Is the salt ammonium nitrite NH_4NO_2 acidic, basic or neutral?

Of course we start out by *dissociating*: $NH_4NO_2 \rightarrow NH_4^{+}{}_{(aq)} + NO_2^{-}{}_{(aq)}$

Remember that NH_4^+ produces H_3O^+ ($NH_4^+ + H_2O \rightleftarrows H_3O^+ + NH_3$)
And NO_2^- produces OH^- ($NO_2^- + H_2O \rightleftarrows HNO_2 + OH^-$)

- The Ka for NH_4^+ tells how much H_3O^+ it produces
- The Kb for NO_2^- tells how much OH^- it produces

The Ka for NH_4^+ is 5.6×10^{-10} (look up NH_4^+ on the left side of the table and it's Ka is on the right)

The Kb for NO_2^- must be calculated: $Kb\,(NO_2) = \frac{Kw}{Ka\,(HNO_2)} = \frac{1.0 \times 10^{-14}}{4.6 \times 10^{-4}}$

$= 2.2 \times 10^{-11}$

Since the Ka of NH_4^+ **>** Kb of NO_2^- - We can say that this salt is **<u>ACIDIC</u>**

So, in summary:

If	**Then the salt is:**
Ka (cation) > Kb (anion)	***Acidic***
Kb (anion) > Ka (cation)	***Basic***
Ka (cation) = Kb (anion)	***Neutral***

Determine whether the salt NH_4CN (ammonium cyanide) is acidic, basic or neutral.

$NH_4CN \rightarrow NH_4{}^+{}_{(aq)} + CN^-{}_{(aq)}$

Ka of $NH_4{}^+ = 5.6 \times 10^{-10}$

$$\text{Kb of } CN^- = \frac{1.0x10^{-14}}{4.9x10^{-10}} = 2.0x10^{-5}$$

so since Kb of CN^- > Ka of $NH_4{}^+$ this solution <u>is **basic**.</u>

7. Hydrolysis of Amphiprotic Anions

Amphiprotic Anions → Start with “H” and have a “**-**“ charge.

Eg. $HSO_4{}^-$, $HSO_3{}^-$, $H_2PO_4{}^-$ $HPO_4{}^{2-}$ HS^- etc.

Amphiprotic Anions hydrolyze as *acids* to produce H_3O^+ but they also hydrolyze as *bases* to produce OH^-. So, how can we tell whether they are acidic or basic or neutral? We need to determine the <u>***predominant***</u> hydrolysis

- Find the Ka of the ion. (Look for ion on the LEFT SIDE of the acid table, read Ka on the right.)

- Find the Kb of the ion. (Look for the ion on the RIGHT SIDE of the table and use: Kb = Kw/ Ka(conj. Acid)

If	**Then the predominant hydrolysis is:**	**And, in aqueous solution, the ion:**
Ka (the ion) > Kb (the ion)	***ACID HYDROLYSIS***	***Acts as an Acid***
Kb (the ion) > Ka (the ion)	***BASE HYDROLYSIS***	***Acts as a Base***

Eg. Find the predominant hydrolysis of the hydrogen carbonate ion (HCO_3^-) and write the net-ionic equation for it.

To find the Ka of HCO_3^-, look it up on the **left** side of table.

It's $Ka = 5.6 \times 10^{-11}$

To find the Kb of HCO_3^-, look it up of the **right** side of table.

(*It's conjugate acid is* H_2CO_3 *and the Ka of* $H_2CO_3 = 4.3 \times 10^{-7}$)

So we calculate the Kb of HCO_3^- using : $Kb(HCO_3^-) = \dfrac{Kw}{Ka(H_2CO_3)} = \dfrac{1.0 \times 10^{-14}}{4.3 \times 10^{-7}}$

$= 2.3 \times 10^{-8}$

So, since Kb > Ka , the ion HCO_3^- predominantly undergoes BASE HYDROLYSIS.

And the net-ionic equation for the ***predominant*** ***hydrolysis*** is:

$$HCO_{3\,(aq)}^- + H_2O_{(l)} \rightleftarrows H_2CO_{3\,(aq)} + OH^-_{(aq)}$$

Read p. 144 – 147, Do Ex. 69 (a-f) and Ex. 70, 71, 72 & 73 on p. 148.