THE INSTITUTE OF EDUCATION

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TOPIC: Acids and Bases

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Acids and Bases

Arrhenius

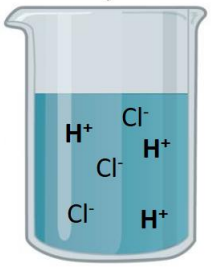
Arrhenius
(1859-1927)

Q: Define an acid, according to the Arrhenius theory

- An acid is a substance that **dissociates in water to produce H^+ ions**

Examples:

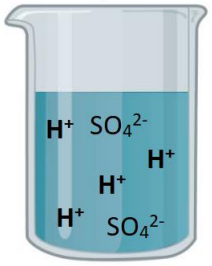
Add HCl to water



$HCl \longrightarrow H^+ + Cl^-$

Notice:
HCl is a **monobasic acid** – each molecule dissociates to produce **one H^+ ion** in solution

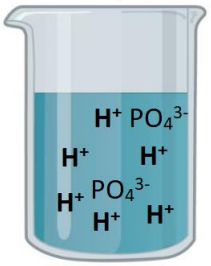
Add H_2SO_4 to water



$H_2SO_4 \longrightarrow 2H^+ + SO_4^{2-}$

Notice:
H_2SO_4 is a **dibasic acid** – each molecule dissociates to produce **two H^+ ions** in solution

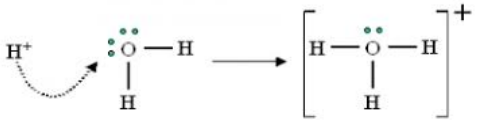
Add H_3PO_4 to water



$H_3PO_4 \longrightarrow 3H^+ + PO_4^{3-}$

Notice:
H_3PO_4 is a **tribasic acid** – each molecule dissociates to produce **three H^+ ions** in solution

Important: In reality, the H^+ ion formed reacts with a molecule of water to form H_3O^+ (Hydronium ion)



Hydronium ion

Q: Write an equation to show the dissociation of hydrogen chloride in water

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

Q: Write an equation to show the dissociation of ethanoic acid in water

$$CH_3COOH + H_2O \longrightarrow CH_3COO^- + H_3O^+$$

Q: Write an equation to show the dissociation of sulfuric acid in water

$$H_2SO_4 + 2H_2O \longrightarrow SO_4^{2-} + 2H_3O^+$$

Note: Sulfuric acid is dibasic – it dissociates in two stages:

1st dissociation: $H_2SO_4 + H_2O \longrightarrow HSO_4^- + H_3O^+$

2nd dissociation: $HSO_4^- + H_2O \longrightarrow SO_4^{2-} + H_3O^+$

Q: Write an equation to show the dissociation of phosphoric acid in water

$$H_3PO_4 + 3H_2O \longrightarrow PO_4^{3-} + 3H_3O^+$$

Note: Phosphoric acid is tribasic – it dissociates in three stages:

1st dissociation: $H_3PO_4 + H_2O \longrightarrow H_2PO_4^- + H_3O^+$

2nd dissociation: $H_2PO_4^- + H_2O \longrightarrow HPO_4^{2-} + H_3O^+$

3rd dissociation: $HPO_4^{2-} + H_2O \longrightarrow PO_4^{3-} + H_3O^+$

Note: The dissociation of an acid HA in water can be represented in general as:

$$HA + H_2O \longrightarrow A^- + H_3O^+$$

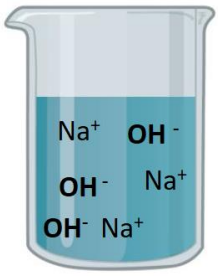
Q: Define a base, according to the Arrhenius theory

- A base is a substance that **dissociates in water to produce OH^- (hydroxide) ions**

Note: A **base dissolved in water** in **known as an alkali**

Examples:

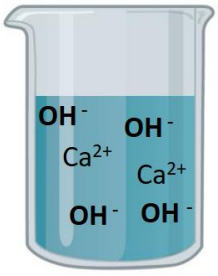
Add NaOH to water



$NaOH \longrightarrow Na^+ + OH^-$

Notice:
NaOH is a **monobasic base** – each molecule dissociates to produce **one OH^- ion** in solution

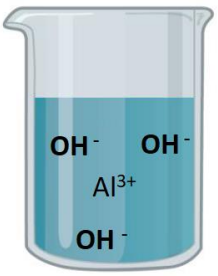
Add $Ca(OH)_2$ to water



$Ca(OH)_2 \longrightarrow Ca^{2+} + 2OH$

Notice:
$Ca(OH)_2$ is a **dibasic base** – each molecule dissociates to produce **two OH^- ions** in solution

Add $Al(OH)_3$ to water



$Al(OH)_3 \longrightarrow Al^{3+} + 3OH^-$

Notice:
$Al(OH)_3$ is a **tribasic base** – each molecule dissociates to produce **three OH^- ions** in solution

Bronsted - Lowry

Bronsted (1879-1947) Lowry (1874-1936)

Q: Define an acid according to the Bronsted-Lowry theory?

- An acid is a **proton (H^+) donor** (loses a proton)

Example: $HCl + H_2O \longrightarrow Cl^- + H_3O^+$

Gives away a proton (H^+) to H_2O….. HCl is an acid

Q: Define a base according to the Bronsted Lowry theory?

- A base is a **proton (H^+) acceptor** (takes in a proton)

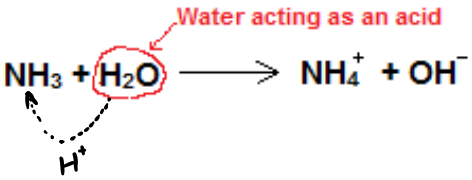
Example: $NH_3 + H_2O \longrightarrow NH_4^+ + OH^-$

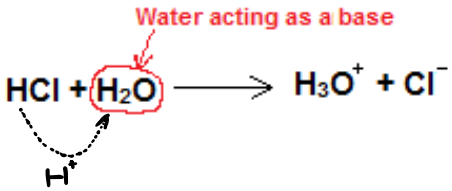
Takes in a proton (H^+) from H_2O……NH_3 is a base

Q: What is an amphoteric substance?

- An amphoteric substance is a substance that **can act as either an acid or a base**

Example: Water is an amphoteric substance





Q: Compare the Arrhenius theory with the Bronsted-Lowry theory of acids and bases

1) **Arrhenius** theory is **limited to aqueous solutions** i.e. reactions in water
Bronsted-Lowry theory **also applies** to reactions in **other solvents and gaseous reactions**

2) Substances such as **NH_3** would **not** be classified as **a base under** the **Arrhenius** theory but are classified as **a base under** the **Bronsted-Lowry** theory

3) The **Arrhenius** theory **cannot explain how a substance can be amphoteric,** but the **Bronsted-Lowry theory can**

Strong acids Vs weak acids

	Arrhenius	Bronsted – Lowry	Examples
Strong acid	- **Dissociates fully** in water to produce H^+ ions	- **Good** proton donor	**-Hydrochloric acid (HCl)** **- Sulfuric acid (H_2SO_4)** **- Nitric acid (HNO_3)**
Weak acid	- **Dissociates only slightly** in water to produce H^+ ions	- **Poor** proton donor	**- All carboxylic acids** **Example: Ethanoic acid (CH_3COOH)**

Strong bases Vs weak bases

	Arrhenius	Bronsted – Lowry	Examples
Strong base	- **Dissociates fully** in water to produce OH^- ions	-**Good** proton acceptor	**- Sodium hydroxide (NaOH)** **- Potassium hydroxide (KOH)** **- Calcium hydroxide ($Ca(OH)_2$)** (Limewater)
Weak base	- **Dissociates only slightly** in water to produce OH^- ions	-**Poor** proton acceptor	**- Sodium carbonate (Na_2CO_3)** **- Ammonium hydroxide (NH_4OH)** (solution of NH_3 in water)

Conjugate acids and bases

Q: What is a conjugate acid?

- A conjugate acid is the substance formed when **a proton (H^+) is added to a base**

Note: If asked to give the conjugate acid in a question, you are being shown a base

Example: Identify the conjugate acid in the following:

a) **NH_3** $NH_3 \xrightarrow{+H^+} NH_4^+$

b) **HSO_4^-** $HSO_4^- \xrightarrow{+H^+} H_2SO_4$

c) **SO_4^{2-}** $SO_4^{2-} \xrightarrow{+H^+} HSO_4^-$

d) **H_2O** $H_2O \xrightarrow{+H^+} H_3O^+$

e) **$HC_2O_4^-$** $HC_2O_4^- \xrightarrow{+H^+} H_2C_2O_4$

Q: What is a conjugate base?

- A conjugate base is the substance formed when **a proton (H^+) is taken from an acid**

Note: If asked to give the conjugate base in a question, you are being shown an acid

Example: Identify the conjugate base in the following:

a) **HCl** $HCl \xrightarrow{-H^+} Cl^-$

b) **H_2O** $H_2O \xrightarrow{-H^+} OH^-$

c) **CH_3COOH** $CH_3COOH \xrightarrow{-H^+} CH_3COO^-$

d) **HSO_4^-** $HSO_4^- \xrightarrow{-H^+} SO_4^{2-}$

e) **H_2SO_4** $H_2SO_4 \xrightarrow{-H^+} HSO_4^-$

Q: Give the (i) conjugate acid (ii) conjugate base of HPO_4^{2-}?

i) $HPO_4^{2-} \xrightarrow{+H^+} H_2PO_4^-$

ii) $HPO_4^{2-} \xrightarrow{-H^+} PO_4^{3-}$

Q: Give the (i) conjugate acid (ii) conjugate base of OH^-?

i) $OH^- \xrightarrow{+H^+} H_2O$

ii) $OH^- \xrightarrow{-H^+} O^{2-}$

Q: Give the (i) conjugate acid (ii) conjugate base of $HC_2O_4^-$?

i) $HC_2O_4^- \xrightarrow{+H^+} H_2C_2O_4$

ii) $HC_2O_4^- \xrightarrow{-H^+} C_2O_4^{2-}$

Note: The stronger the acid – the weaker its conjugate base

The weaker the acid – the stronger its conjugate base

Example: Sulfuric acid is a strong dibasic acid. The formula HA represents a weak monobasic acid.

a) What is the conjugate base of (i) sulfuric acid (ii) HA?
b) Which of these conjugate bases is the stronger? Explain

a) (i) $H_2SO_4 \xrightarrow{-H^+} HSO_4^-$ (conjugate base)

(ii) $HA \xrightarrow{-H^+} A^-$ (conjugate base)

b) A^- is the stronger conjugate base – it is the conjugate base of a weak acid; it has a high tendency to accept a proton and form the HA acid again

HSO_4^- is the weaker conjugate base – it is the conjugate base of a strong acid; it has little tendency to accept a proton and from the H_2SO_4 acid again

Q: What is a conjugate acid-base pair?

- A conjugate acid-base pair is **an acid and a base that differ by one proton (H^+)**

Examples of conjugate acid-base pairs: **HCl and Cl^-** **HNO_3 and NO_3^-** **NH_3 and NH_4^+**

Example: In the following reaction identify which species are acting as acids and which are acting as bases

$$HNO_3 + H_2F_2 \rightleftharpoons H_2NO_3^+ + HF_2^-$$

Also indicate the conjugate acid-base pairs

Acids: H_2F_2 ; $H_2NO_3^+$

Bases: HF_2^- ; HNO_3

Conjugate acid-base pairs: 1) HNO_3 and $H_2NO_3^+$

2) H_2F_2 and HF_2^-

ROUGH WORK

Forward Reaction:

$HNO_3 \xrightarrow{+H} H_2NO_3^+$ (Base)

$H_2F_2 \xrightarrow{-H^+} HF_2^-$ (Acid)

Reverse Reaction:

$H_2NO_3^+ \xrightarrow{-H^+} HNO_3$ (Acid)

$HF_2^- \xrightarrow{+H^+} H_2F_2$ (Base)

Example: Identify two species acting as acids and also their conjugate bases in the following system

$$H_2S + O^{2-} \rightleftharpoons OH^- + SH^-$$

Acids: H_2S ; OH^-

Conjugate bases: SH^- ; O^{2-}

ROUGH WORK

Forward Reaction:

$H_2S \xrightarrow{-H^+} SH^-$

H_2S: Acid — SH^-: Conjugate Base

Reverse Reaction:

$OH^- \xrightarrow{-H^+} O^{2-}$

OH^-: Acid — O^{2-}: Conjugate Base

Example: Show by writing a balanced equation for its dissociation in water, that the conjugate base of sulfuric acid is itself an acid

- Conjugate base of sulfuric acid: $H_2SO_4 \xrightarrow{-H^+} HSO_4^-$ (HSO_4^-: conjugate base)

Equation for dissociation of HSO_4^- in water:

$$HSO_4^- + H_2O \longrightarrow SO_4^{2-} + H_3O^+$$

- When dissociated in water, **HSO_4^- donates a proton (H^+) to H_2O** and becomes SO_4^{2-}.....it is behaving as an acid

Reactions of acids

1. **With bases:** Acid + Base → Salt + H_2O

2. **With carbonates:** Acid + Carbonate → Salt + H_2O + CO_2

3. **With metals:** Acid + Metal → Salt + H_2

Notice: A salt is always formed in these reactions of acids

Q: What is a salt?

- A salt is formed when the **H^+ ion of** an **acid** is **replaced by** a **metal ion or ammonium ion (NH_4^+)**

Q: Write balanced chemical equations for the following reactions.

i) Hydrochloric acid and sodium hydroxide

$HCl + NaOH \rightarrow NaCl + H_2O$

ii) Ethanoic acid and sodium hydroxide

$CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

iii) Hydrochloric acid and sodium carbonate

$2HCL + Na_2CO_3 \rightarrow 2NaCl + H_2O + CO_2$

iv) Ethanoic acid and sodium carbonate

$CH_3COOH + Na_2CO_3 \rightarrow CH_3COONa + H_2O + CO_2$

v) Hydrochloric acid and magnesium

$2HCl + Mg \rightarrow MgCl_2 + H_2$

vi) Ethanoic acid and magnesium

$2CH_3COOH + Mg \rightarrow (CH_3COO)_2Mg + H_2$

Q: What is neutralisation?

- Neutralisation is the **reaction between an acid and a base to form a salt and water**

Q: Give three examples of neutralisation in everyday life

1) **Indigestion tablets are alkalis** are taken to **neutralise excess stomach acid** and give relief from heartburn

2) **Lime (CaO) is an alkali** spread on soil to **neutralise the acidity of the soil** allowing plants to grow

3) **Vinegar is an acid** that will **neutralise alkaline sting of wasps**

Household examples of acids and bases

Acids	Bases
Ethanoic acid in vinegar as a flavouring agent	Sodium hydroxide in caustic soda in oven cleaners
Citric acid in lemons and oranges	Magnesium hydroxide in milk of magnesia for indigestion and constipation

Acids and Bases – Questions

Q1:

a) What is an acid, according to the Arrhenius theory?
b) What is a monobasic acid?
c) Give an example of an acid that is monobasic
d) What is a dibasic acid?
e) Give an example of an acid that is dibasic
f) What is a tribasic acid?
g) Give an example of an acid that is tribasic
h) Write an equation to show the dissociation of hydrogen chloride in water
i) Write an equation to show the dissociation of nitric acid in water
j) Write an equation to show the dissociation of ethanoic acid in water
k) Write an equation to show the dissociation of sulfuric acid in water
l) Write an equation to show the dissociation of phosphoric acid in water
m) If an acid is represented by 'HA' write a chemical equation to represent the dissociation of this acid in water

Q2:

a) What is a base, according to the Arrhenius theory?
b) What is meant by an alkali?
c) What is a monobasic base?
d) Give an example of a base that is monobasic
e) What is a dibasic base?
f) Give an example of a base that is dibasic
g) What is a tribasic base?
h) Give an example of a base that is tribasic

Q3:

a) What is an acid, according to the Bronsted-Lowry theory?
b) Write a chemical equation to show why hydrochloric acid classifies as an acid according to Bronsted and Lowry
c) What is a base, according to the Bronsted-Lowry theory?
d) Write a chemical equation to show why ammonia classifies as a base according the Bronsted and Lowry
e) What is meant by an amphoteric substance?
f) Give an example of an amphoteric substance
g) Write a chemical equation to show an amphoteric substance acting as an acid
h) Write a chemical equation to show an amphoteric substance acting as base

Q4: Give three limitations of the Arrhenius definitions of acids and bases/differences between the Arrhenius and Bronsted-Lowry definitions of acids and bases

Q5:

a) What is a strong acid, according to Arrhenius?
b) What is a strong acid, according to Bronsted-Lowry?
c) Give three examples of strong acids and write their chemical formulae
d) What is a weak acid, according to Arrhenius?
e) What is a weak acid, according to Bronsted-Lowry?
f) Give an example of a weak acid and write its chemical formula
g) What is a strong base, according to Arrhenius?
h) What is a strong base, according to Bronsted-Lowry?
i) Give two examples of strong bases and write their chemical formulae
j) What is a weak base, according to Arrhenius?
k) What is a weak base, according to Bronsted-Lowry?
l) Give two examples of a weak bases and write their chemical formulae

Q6:

a) What is a conjugate acid?
b) What is a conjugate base?
c) What is a conjugate acid – base pair?
d) *Which of the following acid/base pairs is not a conjugate pair?

H_3O^+/H_2O HSO_4^-/H_2SO_4 H_3PO_4/HPO_4^{2-}

***Q7:**

a) Identify the conjugate acid of:

i. $H_2PO_4^-$
ii. HPO_4^{2-}
iii. HSO_3^-
iv. SO_3^{2-}
v. CH_3COO^-
vi. CH_3NH^-
vii. H_2O

b) Identify the conjugate base of:

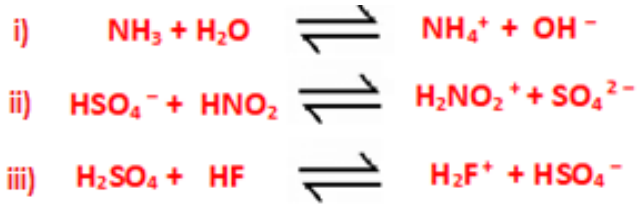
i. HSO_3^-
ii. $H_2PO_4^-$
iii. HNO_2^-
iv. $HClO_2$
v. $HClO^-$
vi. H_2CO_3
vii. H_2O

Q8: Explain why:

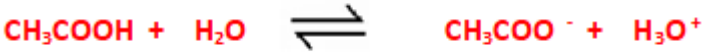
i. HCl has a weak conjugate base
ii. NH_3 has a strong conjugate acid

Q9:

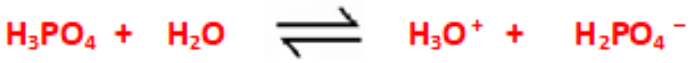
a) What is a conjugate acid-base pair?
b) * In the following reactions, identify which species are acting as acids and which species are acting as bases and identify the conjugate acid-base pairs



***Q10: Identify two species acting as acids and also their conjugate bases in the following equilibrium:**



***Q11: Identify two species acting as bases and also their conjugate acids in the following equilibrium:**



Q12:

a) What is a salt?

*b) Write a balanced chemical equation for the reaction of

i. Hydrochloric acid and sodium hydroxide
ii. Hydrochloric acid and magnesium
iii. Ethanoic acid and sodium hydroxide
iv. Ethanoic acid and sodium carbonate
v. Hydrochloric acid and sodium carbonate
vi. Ethanoic acid and magnesium
vii. Sulfuric acid and calcium
viii. Nitric acid and calcium carbonate
ix. Sulfuric acid and potassium hydroxide

Q13:

a) What is neutralisation?
b) Give three everyday examples of neutralisation
c) Give two household examples and acids and two household examples of bases

Calculation/Working out answers

Q6:

d) H_3PO_4/HPO_4^{2-}

Q7:

a)

i. H_3PO_4
ii. $H_2PO_4^-$
iii. H_2SO_3
iv. HSO_3^-
v. CH_3COOH
vi. CH_3NH_2
vii. H_3O^+

b)

i. SO_3^{2-}
ii. HPO_4^{2-}
iii. NO_2^{2-}
iv. ClO_2^-
v. ClO^{2-}
vi. HCO_3^-
vii. OH^-

Q9:

b)

i) **Acids:** H_2O ; NH_4^+

Bases: OH^- ; NH_3

Conjugate acid-base pairs: H_2O and OH^-
NH_3 and NH_4^+

ii) **Acids:** HSO_4^- ; $H_2NO_2^+$

Bases: SO_4^{2-} ; NNO_2

Conjugate acid-base pairs: HSO_4^- and SO_4^{2-}
$H_2NO_2^+$ and NNO_2

iii) **Acids:** H_2SO_4 ; H_2F^+

Bases: HSO_4^- ; HF

Conjugate acid-base pairs: H_2SO_4 and HSO_4^-
H_2F^+ and HF

Q10:

Acids	Conjugate bases
CH_3COOH	CH_3COO^-
H_3O^+	H_2O

Q11:

Bases	Conjugate acids
H_2O	H_3O^+
$H_2PO_4^-$	H_3PO_4

Q12:

b)

i. $HCl + NaOH \rightarrow NaCl + H_2O$

ii. $2HCl + Mg \rightarrow MgCl_2 + H_2$

iii. $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

iv. $2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + H_2O + CO_2$

v. $2HCl + Na_2CO_3 \rightarrow 2NaCl + H_2O + CO_2$

vi. $2CH_3COOH + Mg \rightarrow (CH_3COO)_2Mg + H_2$

vii. $H_2SO_4 + Ca \rightarrow CaSO_4 + H_2$

viii. $2HNO_3 + CaCO_3 \rightarrow Ca(NO_3)_2 + H_2O + CO_2$

ix. $H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$