Acid/Base terminology

1. Which species is the **conjugate base** of H_2CO_3?

A. CO_3^{2-}
B. HCO_3^-
C. H_3O^+
D. OH^-
E. H_3CO_4

*The conjugate base is formed when **one proton is removed**.*
$H_2CO_3 \rightarrow HCO_3^- + H^+$

2. In the reaction

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

Which is a conjugate acid–base pair?

A. NH_3 / NH_4^+
B. NH_3 / OH^-
C. H_2O / OH^-
D. NH_4^+ / OH^-
E. H_2O / NH_4^+

*Conjugate pairs differ by **one proton only**.*
NH_3 gains $H^+ \rightarrow NH_4^+$

3. Which base is **strongest** in water?

A. NO_3^-
B. Cl^-
C. CH_3COO^-
D. SO_4^{2-}

*CH_3COO^- is the conjugate base of a **weak acid (acetic acid)**.*
*The conjugate bases of **strong acids** (NO_3^-, Cl^-, SO_4^{2-}) are **very weak bases**.*

4. Which acid is **diprotic**?

A. HNO_3
B. HCl
C. CH_3COOH
D. H_3PO_4
E. H_2SO_4

*A diprotic acid can donate **two protons**.*
$H_2SO_4(aq)+H_2O(l)\rightarrow H_3O^+(aq)+HSO_4^-(aq)$
and
$HSO_4^-(aq)+H_2O(l)\rightarrow H_3O^+(aq)+SO_4^{2-}(aq)$

5. Which species can donate **three protons** in aqueous solution?

A. CH_3COOH
B. H_3PO_4
C. CH_3CH_2COOH
D. NH_4^+
E. NH_3

H_3PO_4 is triprotic
$H_3PO_4(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + H_2PO_4^-(aq)$
$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HPO_4^{2-}(aq)$
$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + PO_4^{3-}(aq)$

6. Which reaction represents the **second ionisation** of sulfuric acid?

A. $H_2SO_4 \rightarrow H^+ + SO_4^{2-}$
B. $H_2SO_4 \rightarrow H^+ + HSO_4^-$
C. $H_2O \rightarrow H^+ + OH^-$
D. $SO_4^{2-} \rightarrow H^+ + SO_4^{3-}$
E. $HSO_4^- \rightarrow H^+ + SO_4^{2-}$
Diprotic acids ionise stepwise.
Second step removes H^+ from HSO_4^-.

7. Which species is **amphiprotic**?

A. CO_3^{2-}
B. H_3O^+
C. NO_3^-
D. Na^+
E. HCO_3^-
Amphiprotic substances can donate or accept a proton.
HCO_3^- can become H_2CO_3 or CO_3^{2-}.

8. Which statement is **correct**?

A. All amphoteric substances are amphiprotic
B. Amphoteric substances react only with acids
C. Amphiprotic substances donate and accept protons
D. Amphoteric means only proton transfer
E. Amphiprotic substances react only with bases

Amphiprotic specifically refers to proton transfer.
Amphoteric is broader (can react as acid or base, not always via protons).

9. Which statement is correct?

A. Strong acids have weak conjugate bases
B. Weak acids have weak conjugate bases
C. Strong acids have strong conjugate bases
D. Acid strength does not affect conjugate strength
E. Conjugate acids and bases have equal strength

There is an inverse relationship between acid and conjugate base strength.

10. In the reaction

$$H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+$$

$H_2PO_4^-$ is acting as a:

A. Base only
B. Acid only
C. Spectator ion
D. Salt
E. Both an acid and a base

$H_2PO_4^-$ donates a proton → acts as an acid.

Short-answer questions

1. Define the term **conjugate acid–base pair**.
   A conjugate acid/base pair consists of two species that differ by one proton, formed when an acid donates a proton or a base accepts a proton.
2. Identify the conjugate acid and conjugate base in the reaction:

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

   - *Conjugate acid: H_3O^+*
   - *Conjugate base: Cl^-*
3. Explain why CH_3COO^- is a stronger base than NO_3^-.
   CH_3COO^- is the conjugate base of a weak acid, whereas NO_3^- is the conjugate base of a strong acid.
   Therefore, acetate has a greater tendency to accept a proton.
4. A student described the species HCO_3^- as amphoteric. Is the student correct? Explain your answer.
   Yes, the student is correct.
   The hydrogen carbonate ion, HCO_3^-, is amphoteric because it can act as both an acid and a base.
   - *As an acid, HCO_3^- donates a proton:*

$$HCO_3^- + H_2O \rightleftharpoons CO_3^{2-} + H_3O^+$$

   - *As a base, HCO_3^- accepts a proton:*

$$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$$

   Because HCO_3^- can both donate and accept a proton, it is amphoteric (and more specifically, amphiprotic).

5. Al_2O_3 undergoes two reactions as shown below.

   $Al_2O_3(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2O(l)$
   and
   $Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow 2NaAl(OH)_4(aq)$
   i. Compare and contrast an amphoteric substance and an amphiprotic substance.

   An amphoteric substance is one that can react as either an acid or a base, depending on the substance it reacts with. This does not require proton transfer and may involve oxide or hydroxide ions.

   An amphiprotic substance is a species that can both donate and accept a proton (H^+) in acid–base reactions.

   Similarity -Both amphoteric and amphiprotic substances can behave as either an acid or a base.
   Difference- Amphiprotic behaviour specifically involves proton transfer, whereas amphoteric behaviour is broader and does not necessarily involve protons.

ii. Using aluminium oxide as an example classify this substance as an amphiprotic or amphoteric substance. Explain why.

Using aluminium oxide as an example, classify this substance as amphiprotic or amphoteric. Explain why.

Answer:
Aluminium oxide is classified as amphoteric, not amphiprotic.

Explanation:
Al_2O_3 reacts with acids, such as HCl, where it behaves as a base:

$$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$$

It also reacts with bases, such as NaOH, where it behaves as an acid:

$$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$$

However, aluminium oxide does not donate or accept protons directly, so it is not amphiprotic

6. Consider the following species, SO_4^{2-}, NO_3^- and CH_3COO^- .
    a. Write the balanced equation for the reaction of each base with water.
        i. $SO_4^{2-}(aq) + H_2O(l)$ → *$HSO_4^-(aq) + OH^-(aq)$*

        ii. $NO_3^-(aq) + H_2O(l)$ → *$HNO_3(aq) + OH^-(aq)$*

        iii. $CH_3COO^-(aq) + H_2O(l)$ → *$CH_3COOH(aq) + OH^-(aq)$*

    b. Which reaction produces the most amount of OH^-? Explain why.

        The reaction of CH_3COO^- with water produces the most OH^-.

        - *The conjugate base of a weak acid (CH_3COOH) is stronger and more likely to accept a proton from water.*
        - *SO_4^{2-} and NO_3^- are conjugate bases of strong acids (H_2SO_4 and HNO_3), so they react very little with water.*