25.1 ACIDS AND BASES

Introduction

1. In the equilibrium reaction shown below, which species are a conjugate acid-base pair?
   $CH_3CH_2CH_2COOH$ (aq) + H_2O (l) ⇌ $CH_3CH_2CH_2COO$(aq) + H_2O (aq)
   A. $CH_3CH_2CH_2COOH$ and H_2O **B**. H_2O and H_3O^+
   C. H_2O and $CH_3CH_2CH_2COO^-$ **D**. $CH_3CH_2CH_2COO^-$ and H_2O

1. Define conjugate acid–base pair.

   ………

   ……… [1]

2. Give the formula of the conjugate base of H_3PO_3. [1]

3. Hydrogen sulfide gas, H_2S(g), is slightly soluble in water. It acts as a weak acid in aqueous solution.
   Give the formula of the conjugate base of H_2S. [1]

4. Hypophosphorous acid is an inorganic acid.
   The conjugate base of hypophosphorous acid is $H_2PO_2^-$.
   Give the formula of hypophosphorous acid.

   ………
   [1]

5. A student studies the reaction of $CH_3CHClCOOH$ with aqueous NH_3 to determine the reaction mechanism. The student finds that when $CH_3CHClCOOH$ and NH_3 are added in a 1 : 1 stoichiometric ratio, the conjugate acid and base of the reactants are quickly formed.

   reaction 1 $CH_3CHClCOOH + NH_3 \rightarrow CH_3CHClCOO^- + NH_4^+$

   (i) Identify the conjugate acid–base pairs in reaction 1.

   conjugate acid–base pair I ……………………………… and ………………………………

   conjugate acid–base pair II ……………………………… and ……………………………… [1]

6. Chloric(I) acid, HCl O, is a weak Brønsted–Lowry acid.
   When chloric(I) acid is added to aqueous sodium hydroxide, an acid–base reaction takes place, as shown.

   HCl O + NaOH → NaCl O + H_2O

   (i) Identify the two conjugate acid–base pairs in this reaction.

   acid I HCl O conjugate base of acid I …………………

   acid II ……………………… conjugate base of acid II ………………… [1]

7. Water is an amphoteric compound that also acts as a good solvent of polar and ionic compounds.
(a) Equation 1 shows water acting as a Brønsted–Lowry acid.
equation 1 $H_2O + NO_2^- \rightleftharpoons HNO_2 + OH^-$
(i) Identify the **two** conjugate acid–base pairs in equation 1.

acid I ………….H_2O…..….. conjugate base of acid I ……………..……

acid II ……………………..…… conjugate base of acid II ………………..… [1]

(ii) Water also behaves as a Brønsted–Lowry acid when it dissolves CH_3NH_2.
Explain the ability of CH_3NH_2 to act as a base.

……………………….. [1]

(iii) Write an equation to show water acting as a base with CH_3COOH.

……………………….. [1]

8. When concentrated H_2SO_4 is added to water, a series of acid-base reactions occurs.
There are three conjugate acid-base pairs that can be identified during this series of reactions.
Write the formulae of these three conjugate acid-base pairs.

conjugate acid 1 .... conjugate base 1 ....

conjugate acid 2 .... conjugate base 2 ....

conjugate acid 3 .... conjugate base 3 .... [2]

9. Disodium phosphate, $(Na^+)_2(HPO_4^{2-})$, reacts with an acid to form monosodium phosphate, $Na^+(H_2PO_4^-)$.
(i) Identify the ions that are a conjugate acid–base pair in this reaction, using the formulae of the species involved.

conjugate acid

conjugate base

.... [1]

Ionic product of water

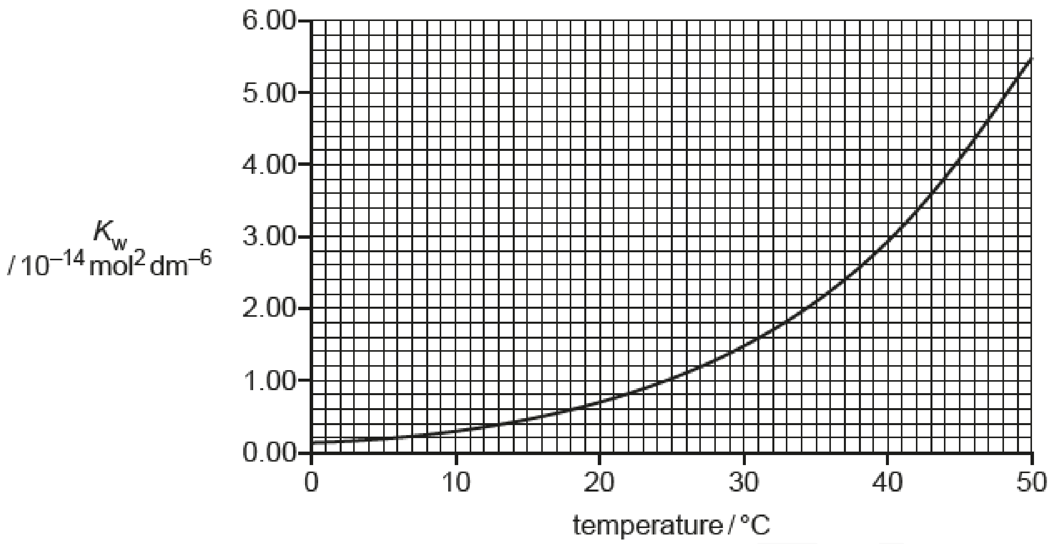
10. Define K_w mathematically by completing the expression.

K_w = ... [1]

11. Give the mathematical expression for the term Kw.

Kw = ... [1]

12. The ionic product of water, K_w, measures the extent to which water dissociates.
$H_2O (l) \rightleftharpoons H^+(aq) + OH^-(aq)$
The following figure shows how K_w varies with temperature.



(i) Use information from the above figure to deduce whether the dissociation of water is an exothermic or an endothermic process. Explain your answer.

....

....

.... [1]

(ii) An aqueous solution has pH = 7.00 at 30 °C.
Use information from Fig. 2.1 to explain why this solution can be considered to be alkaline at 30 °C.

....

....

....

.... [2]

13. When aqueous solutions of $BaCl_2$ and $Na_2Cr_2O_7$ are mixed, a yellow precipitate of $BaCrO_4(s)$ is produced and an acidic solution remains.
Write the ionic equation for this reaction.

.... [1]

Calculation of pH

14. Give the mathematical expression for the term pH.

pH = ... [1]

15. Calculate the pH of a solution whose H^+ ion concentration is 5.32×10^{-4} mol dm^{-3}.

16. Calculate the pH of the following solutions:
    a. $[H^+] = 3.00 \times 10^{-4}$ mol dm^{-3}
    b. $[H^+] = 1.00 \times 10^{-2}$ mol dm^{-3}
    b. $[H^+] = 4.00 \times 10^{-8}$ mol dm^{-3}
    d. $[H^+] = 5.40 \times 10^{-12}$ mol dm^{-3}

17. Calculate the concentration of hydrogen ions in solutions having the following pH values:
    a. pH 2.90
    b. pH 11.2
    b. pH 5.40
    e. pH 12.9

18. Find the pH of an aqueous solution containing 3.00 g HCl per dm^3.

19. Calculate the pH of a solution of sodium hydroxide of concentration 0.0500 mol dm^{-3}.
    $K_w = 1.00 \times 10^{-14}$ mol^2 dm^{-6} (at 298 K)

(ans= 12.7)

20. Calculate the pH of 0.027 mol dm^{-3} NaOH(aq).

pH = ... [1]

21. Find the pH of an aqueous solution containing 0.200 g of NaOH per dm^3 ($K_w = 1.00 \times 10^{-14}$ $mol^2\ dm^{-6}$)

22. Calculate the pH of 0.027 mol dm^{-3} NaOH(aq).

pH = ... [1]

23. Barium hydroxide, $Ba(OH)_2$, is completely dissociated in aqueous solution.
Calculate the pH of 0.120 mol dm^{-3} $Ba(OH)_2(aq)$ at 298 K.

pH = ... [2]

24. Barium hydroxide, $Ba(OH)_2$, is a strong base.
A 250.0 cm^3 solution of $Ba(OH)_2$ with a pH of 12.2 is made by dissolving $Ba(OH)_2$ in distilled water.
Calculate the mass of $Ba(OH)_2$ required to make this solution.
Show your working.
[*M*r: $Ba(OH)_2$, 171.3]

mass of $Ba(OH)_2$ = ...(0.339).......... g [4]

25. Two solutions, **V** and **W**, are described.
    - **V** is HC*l* (aq).
    - **W** is NaOH(aq).
    - The concentration of HC*l* in **V** is the same as the concentration of NaOH in **W**.
    - The pH values of **V** and **W** differ by exactly 11.00 at 298 K.

    (i) Calculate the concentration of HC*l* in **V**.

concentration of HC*l* in **V** = ... mol dm^{-3} [2]

(ii) Equal volumes of the two solutions **V** and **W** are mixed, giving solution **X**.
Name solution **X** and state its pH.

solution **X** .... pH .... [1]

(iii) A 1 cm^3 sample of 1.0 mol dm^{-3} HNO_3 is added to 100 cm^3 of solution **X**, forming mixture **Y**.
A 1 cm^3 sample of 1.0 mol dm^{-3} KOH is added to 100 cm^3 of solution **X**, forming mixture **Z**.
Estimate the pH of mixtures **Y** and **Z**. No calculations are required.

mixture **Y** .... mixture **Z** .... [1]

26. Write the mathematical expressions for pKa and pH.

pKa = ... [1]

27. The K_a value of chloric(I) acid, HC*l*O, is 3.72×10^{-8} mol dm^{-3}.
Calculate the pH of 0.010 mol dm^{-3} HC*l*O(aq).

pH = ... [1]

28. The value for the acid dissociation constant, Ka, of $HClO(aq)$ is 3.70×10^{-8}.
Calculate the concentration, in mol dm^{-3}, of $HClO(aq)$ at a pH of 4.51.

concentration of HClO = ... mol dm^{-3} [2]

29. Isocyanic acid, HNCO, is a weak acid.
$HNCO + H_2O \rightarrow H_3O^+ + NCO^-$ pKa = 3.70 at 25 ° C
(i) Calculate the pH of 0.120 mol dm^{-3} HNCO(aq).
Give your answer to three significant figures.

pH = ... [2]

(iii) Calculate the percentage of HNCO molecules that are ionised in 0.120 mol dm^{-3} HNCO.

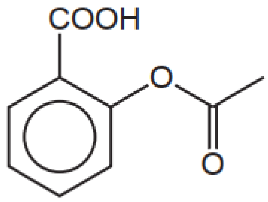
percentage ionisation of HNCO = ... [1]

30. Aqueous solutions of methanoic acid, HCOOH, and propanoic acid, CH_3CH_2COOH, are mixed together.
An equilibrium is set up between two conjugate acid–base pairs.
The p*K*a of HCOOH is 3.75 and of CH_3CH_2COOH is 4.87.
Complete the equation for the Brønsted–Lowry equilibrium between the stronger of these two acids and water.

.... + $H_2O \rightarrow$ .... + ... [1]

31. Aspirin is a weak Brønsted–Lowry acid.

aspirin



The pK_a of aspirin is 3.49.
75mg of aspirin dissolves in water to form $100 cm^3$ of an aqueous solution.
Calculate the pH of this solution.
[M_r: aspirin, 180.0]

pH = ... [3]

32. Metal–air batteries are electrochemical cells that generate electrical energy from the reaction of metal anodes with air.
The standard electrode potentials for the zinc–air battery are shown.

$[Zn(OH)_4]^{2-} + 2e^- \rightleftharpoons Zn + 4OH^-$ $E^\ominus = -1.22$ V

$O_2 + H_2O + 2e^- \rightleftharpoons 2OH^-$ $E^\ominus = +0.40$ V

(i) Calculate the standard cell potential, $E^\ominus_{cell}$, of the zinc–air battery.

$E^\ominus_{cell}$ = ...V [1]

(ii) The zinc–air battery usually operates at pH 11 and 298 K. The overall cell potential is dependent on $[OH^-]$.
The Nernst equation shows how the electrode potential at the cathode changes with $[OH^-]$.
$E = 0.40 - (0.059/z)\log([OH^-]^2)$
Calculate the electrode potential, E, at pH 11.

E = ...V [2]

33. In solution, iodic(V) acid, HIO_3, ionises as shown.

$HIO_3(aq) \rightleftharpoons IO_3^-(aq) + H^+(aq)$

The pH of a 1.0 mol dm^{-3} solution of HIO_3 is 0.47.

(i) Calculate $[H^+(aq)]$, in mol dm^{-3}, in a 1.0 mol dm^{-3} solution of HIO_3.

$[H^+(aq)]$ = ...(ans= 0.339)......... mol dm^{-3} [1]

(ii) Use your answer from (i) to calculate the equilibrium concentrations of $HIO_3(aq)$ and IO_3–(aq), in mol dm^{-3}, in a 1.0 mol dm^{-3} solution of HIO_3.

$[HIO_3(aq)]$ = ... mol dm^{-3}

$[IO_3$–(aq)] = ... mol dm^{-3}[1]

(iii) Use your answers from (i) and (ii) to calculate the Ka, in mol dm^{-3}, of HIO_3.

K_a = ... mol dm^{-3} [1]

34. Solution Y is hydrochloric acid, HCl (aq). Solution Z is aqueous 4-chlorobutanoic acid, $Cl(CH_2)_3CO_2H(aq)$. The pK_a of $Cl(CH_2)_3CO_2H(aq)$ is 4.52. The pH of both solutions is 4.00.

(a) (i) Write an expression for the K_a of $Cl(CH_2)_3CO_2H(aq)$.

K_a =

[1]

(ii) Write a mathematical expression to describe the relationship between K_a and pK_a.

.... [1]

(iii) Calculate $[H^+]$ in solutions Y and Z.

$[H^+]$ = ... mol dm^{-3} [1]

(iv) Calculate the ratio $\frac{\text{[HCl]dissolved in solution Y}}{\text{[Cl (CH2)3CO2H] dissolved in solution Z}}$

(ans= 1:3.31) [2]

35. The value of the acid dissociation constant, K_a, of butanoic acid, $CH_3CH_2CH_2COOH$, is 1.51×10^{-5} at 298 K.
(i) Calculate the pH of 0.100 mol dm^{-3} $CH_3CH_2CH_2COOH$ at 298 K.
Show your working.

pH = ... [2]

(ii) Calculate the pH of 0.100 mol dm^{-3} NaOH at 298 K.

pH = ... [1]

(iii) 5.00 cm^3 of 0.100 mol dm^{-3} NaOH is added to 10.00 cm^3 of 0.100 mol dm^{-3} $CH_3CH_2CH_2COOH$.
Calculate the pH of the resulting solution.
Show your working.

pH = ...(ans = ... [2]

36. Write an expression for the acid dissociation constant, K_a, for butanoic acid, $CH_3CH_2CH_2COOH$.

Ka = [1]

(ii) The pKa of $CH_3CH_2CH_2COOH$ is 4.82.
A solution of $CH_3CH_2CH_2COOH(aq)$ has a pH of 3.25.
Calculate the concentration, in mol dm^{-3}, of $CH_3CH_2CH_2COOH$ in this solution.

concentration of $CH_3CH_2CH_2COOH$ = ... mol dm^{-3} [2]

37. **(a)** Write an expression for the Ka of the weak acid HA in terms of the concentrations of the species involved.

Ka = [1]

(b) The hydroxylammonium ion, $HONH_3^+$, is a weak acid. A 1.00×10^{-3} mol dm^{-3} solution of hydroxylammonium ions has a pH of 4.41.
(i) Calculate the Ka of $HONH_3^+$.

Ka = ... [2]

(ii) Calculate the pKa of $HONH_3^+$.

pKa = ... [1]

38. **(i)** The numerical values of *K*a for methanoic acid, HCO_2H, and pyruvic acid, CH_3COCO_2H, are given.

Acid	*Ka*
HCO_2H	1.78×10^{-4}
CH_3COCO_2H	4.07×10^{-3}

An equilibrium mixture containing the two acid-base pairs is formed.

$HCO_2^- + CH_3COCO_2H \rightleftharpoons HCO_2H + CH_3COCO_2^-$

Use the *K*a values to calculate the equilibrium constant, *K*eq, for this equilibrium.

*K*eq = ... [1]

(ii) Use your value of *K*eq to predict the position of this equilibrium. Indicate this by placing a tick (•) in the appropriate box in the table. Explain your answer.

equilibrium lies to the left	equilibrium lies in the middle	equilibrium lies to the right

....

....[1]

(iii) Ethanedioic acid, HO_2CCO_2H, has two dissociation constants, Ka1 and Ka2, whose pKa values are 1.23 and 4.19.

Suggest equations to show the two dissociations that give rise to these pKa values.

pKa1 1.23 ....

pKa2 4.19 .... [2]

(iv) State the mathematical relationship between pKa and the acid dissociation constant Ka.

…………………….. [1]

39. A sample of 0.333 g of strontium oxide, SrO, is completely dissolved in distilled water to form a solution of strontium hydroxide, $Sr(OH)_2$.
The resulting solution is added to a volumetric flask and made up to 250.0 cm^3 with distilled water.
Calculate the pH of this solution at 298 K. Give your answer to two decimal places.

pH = ... [4]

***... ***