Unit 15 Molarity, pH, Strength

HKDSE Syllabus

Students should learn

e. Concentration of solutions

- concentration of solutions in mol dm^{-3} (molarity)

b. Indicators and pH

- acid-base indicators as exemplified by litmus, methyl orange and phenolphthalein
- pH scale as a measure of acidity and alkalinity $pH = -log[H^+(aq)]$
- use of universal indicator and an appropriate instrument to measure the pH of solutions

c. Strength of acids and alkalis

- meaning of strong and weak acids as well as strong and weak alkalis in terms of their extent of dissociation in aqueous solutions
- methods to compare the strength of acids/alkalis

Students should be able to

- convert the molar concentration of solutions to g dm^{-3}
- perform calculations related to the concentration of solution

- state the colours produced by litmus, methyl orange and phenolphthalein in acidic solutions and alkaline solutions
- describe how to test for acidity and alkalinity using suitable indicators
- relate the pH scale to the acidity or alkalinity of substances
- perform calculations related to the concentration of $H^+(aq)$ and the pH value of a strong acid solution
- suggest and demonstrate appropriate ways to determine pH values of substances

- describe the dissociation of acids and alkalis
- relate the strength of acids and alkalis to their extent of dissociation
- describe acids and alkalis with the appropriate terms: strong and weak, concentrated and dilute
- suggest and perform experiments to compare the strength of acids or alkalis

A. Concentration and Molarity

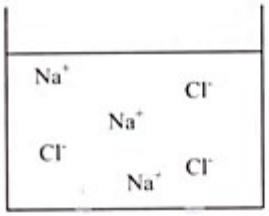
Concentration of Solutions

(a)

$$\text{Concentration of solution} = \frac{\text{of solute (\quad)}}{\text{of solution (\quad)}}$$

Unit of concentration =

In a 10 dm^3 solution, 58.5 g of sodium chloride can be found. Find the concentration in **g dm^{-3}**.



(b)

$$\textit{Molarity}\text{ of solution} = \frac{\text{of solute (\quad)}}{\text{of solution (\quad)}}$$

(concentration)

Unit of molarity =

Find the molarity (concentration) of the NaCl solution.

(R.A.M. of Na = 23, Cl = 35.5)

No of particles	Mole	Mass
	Molarity	

Remarks: _____ **X** _____ **=** _____

e.g. 25cm^3 0.75 $moldm^{-3}$ =

Examples

1. A 25 cm^3 sodium hydroxide solution contains 4 g of NaOH. (R.A.M. of H = 1, Na = 23, O = 16)

   (a) Calculate the concentration of the solution in g/dm^3.

   (b) Calculate the molarity of the solution.

   (c) Calculate the number of moles of Na^+ ions in 10 cm^3 of the solution.

Questions:

1. 500.0 cm^3 of calcium nitrate solution contains 11.5 g of calcium nitrate. What is the molarity of the solution? (Relative atomic masses: N = 14.0, O = 16.0, Ca = 40.1)

2. A solution of potassium hydroxide contains 11.2 g of potassium hydroxide in 250.0 cm^3 of the solution. What is its molarity? (Relative atomic masses: H = 1.0, O = 16.0, K = 39.1)

3. 7.69 g of ethanedioic acid crystals ($(COOH)_2 \cdot 2H_2O$) are dissolved in distilled water and made up to 250.0 cm^3. What is the molarity of the ethanedioic acid solution?(RAM: H = 1.0, C = 12.0, O = 16.0)

4. A 0.50 mol dm^{-3} zinc sulphate solution is prepared by dissolving 14.4 g of zinc sulphate-7-water crystals ($ZnSO_4 \cdot 7H_2O$) in distilled water. What is the volume of the solution formed?
(Relative atomic masses: H = 1.0, O = 16.0, S = 32.1, Zn = 65.4)

5. 102 g of lead(II) nitrate were used to prepare a 0.616 mol dm^{-3} solution. What was the volume of the solution obtained? (Relative atomic masses: N = 14.0, O = 16.0, Pb = 207.2)

6. What is the mass of solute present in 750.0 cm^3 of 0.400 mol dm^{-3} sodium hydroxide solution?
(Relative atomic masses: H = 1.0, O = 16.0, Na = 23.0)

7. What is the mass of anhydrous sodium carbonate required to prepare 2 000.0 cm^3 of 0.108 mol dm^{-3} sodium carbonate solution? (Relative atomic masses: C = 12.0, O = 16.0, Na = 23.0)

8. What is mass of ethanedioic acid crystals ($(COOH)_2 \cdot 2H_2O$) required to prepare 250.0 cm^3 of 0.180 mol dm^{-3} solution? (Relative atomic masses: H = 1.0, C = 12.0, O = 16.0)

2. What **mass** of *anhydrous sodium carbonate* would be used to prepare **250 cm^3 of 0.05 M sodium carbonate solution** ?
(R.A.M. of Na = 23, C = 12, O = 16)

3. What **volume** of *0.05 M solution of $ZnSO_4$* can be prepared from 115.0 g of zinc sulphate crystals ($ZnSO_4 \cdot 7H_2O$) ?
(R.A.M. of Zn = 65.4, S = 32, O = 16, H = 1)

4. 2.0 g of magnesium was added to 250 cm^3 of 1 M HCl which is in excess.
(R.A.M. of Mg = 24.3, Cl = 35.5, H = 1)

(a) Calculate the *concentration* of magnesium chloride formed in **mol dm^{-3}**.

(b) Calculate the *concentration* of magnesium chloride formed in **g dm^{-3}**.

(c) The **mass** of hydrogen gas produced.

5. Which statement(s) is/are true concerning 1.5 M solution of $CaCl_2$?

(1) 1.5 g of $CaCl_2$ can be found in each dm^3 of solution. ( )

(2) 1.5 mol of $CaCl_2$ molecules can be found in each dm^3 of solution. ( )

(3) Concentrations of Ca^{2+} ions and Cl^- ions are 1.5 M and 3.0 M respectively. ( )

6. Which of the following contains the largest number of ions ?

(a) 20 cm^3 of 0.6 M NaOH(s).

(b) 30 cm^3 of 1.2 M $ZnCl_2$(l).

(c) 100 cm^3 of 0.6 M HCl(g).

(d) 25 cm^3 of 0.8 M $Al_2(SO_4)_3$(s).

7. 2.0 M sulphuric acid is used to neutralize 80.0 cm^3 of 1.5 M potassium hydroxide solution in order to prepare potassium sulphate.

(a) Calculate the ***volume*** of 2.0 M sulphuric acid required for neutralization.

(b) Calculate the ***molarity*** of the potassium sulphate solution formed.

8. 2.0 g of sodium carbonate was added to 50.0 cm^3 of 2.0 M hydrochloric acid.

(a) (i) Calculate the ***molarity*** of sodium chloride formed.
(R.A.M. of Na = 23, C = 12, O = 16, H = 1, Cl = 35.5)

(ii) State an ***assumption*** in the experiment.

(b) (i) Calculate the ***mass*** of carbon dioxide gas produced.

(ii) Given that **one mole of gas occupies 24 dm^3**. Calculate the ***volume*** of CO_2 gas.

(iii) Hence find the ***density***, in g dm^{-3}, of CO_2 gas.

(iv) State TWO factors affecting the density of CO_2 gas.

9. 14.3 g of hydrated sodium carbonate are required to make one litre of 0.05 M solution. Calculate the ***number of molecule of water of crystallization*** in the hydrated salt.
(R.A.M. of Na = 23, C = 12, O = 16, H = 1, Cl 35.5)

HKCEE MC

The formula of a metal carbonate X_2CO_3. 100 cm^3 of a solution containing 0.69 g of the carbonate requires 50 cm^3 of a 0.20 M hydrochloric acid for complete reaction. What is the relative atomic mass of metal X ?
(R.A.M. of C = 12, O = 16)

A. 19.0 B. 23.0 C. 39.0 D. 78.0

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10. A sample of 1.02 g of potassium hydrogenphthalate ($C_8H_5O_4K$) is dissolved completely in distilled water, and then diluted to 250.0 cm^3. What is the concentration of the solution obtained ?

(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0, K = 39.1)

A. 0.004 M
B. 0.010 M
C. 0.020 M
D. 4.080 M

25. What is the theoretical volume of carbon dioxide that can be obtained, at room temperature and pressure, when 1.2 g of $Na_2CO_3(s)$ reacts with 50 cm^3 of 1.0 M HNO_3 ?

(Molar volume of gas at room temperature and pressure = 24 dm^3;
Relative atomic masses: H = 1.0, C = 12.0, N = 14.0, O = 16.0, Na = 23.0)

A. 272 cm^3
B. 544 cm^3
C. 600 cm^3
D. 1200 cm^3

2104 DSE

6. 50.0 cm^3 of 0.6 M $FeSO_4(aq)$ is mixed with 150.0 cm^3 of 0.2 M $Fe_2(SO_4)_3(aq)$. What is the concentration of $SO_4^{2-}(aq)$ ions in the resulting mixture ?

A. 0.3 M
B. 0.4 M
C. 0.6 M
D. 0.8 M

2015 DSE

9. In an experiment to prepare calcium sulphate, excess dilute sulphuric acid is added to 10.0 cm^3 of 1.0 mol dm^{-3} calcium nitrate solution. Which of the following is the theoretical mass of the calcium sulphate obtained ?

(Relative atomic masses: O = 16.0, S = 32.1, Ca = 40.1)

A. 0.68 g
B. 1.36 g
C. 2.72 g
D. 4.08 g

B. pH value

pH Scale

What is pH ?

It is the ***$-\log_{10}$ of the concentration of H^+ ions*** in mol dm^{-3} ( ) :

Classwork

1. *Calculate* the **pH** of the following aqueous solutions at 25°C :
   (i) 0.1 mol dm^{-3} HCl
   (ii) 0.1 mol dm^{-3} H_2SO_4
2. *Calculate* the **hydroxonium ion** *concentration* when pH = 5.2 at 25°C.

True or false

1. As temperature increases, the degree of ionization of water increases. ( )
2. The *higher* the pH, the *higher* the acidity of the solution. ( )
3. A change of 1 pH unit = 10 change in concentration of H^+ ions. ( )

Questions:

1. What is the concentration of hydrogen ions in a solution with a pH of 4.68?
   A 2.09×10^{-5} mol dm^{-3} B 2.14×10^{-5} mol dm^{-3} C 0.468 mol dm^{-3} D 0.670 mol dm^{-3}

2. What is the concentration of hydrogen ions in a sample of lemon juice with a pH of 2.44?
   A 3.63×10^{-3} mol dm^{-3} B 3.87×10^{-3} mol dm^{-3} C 0.363 mol dm^{-3} D 0.387 mol dm^{-3}

3. The pH of human blood is 7.40. What is the concentration of hydrogen ions in human blood?
   A 3.98×10^{-8} mol dm^{-3} B 3.98×10^{-6} mol dm^{-3} C 0.869 mol dm^{-3} D 1.15 mol dm^{-3}

4. The concentration of hydrogen ions in a bottle of apple juice is 3.22 x 10–4 mol dm–3. What is the pH of the juice?
   A 3.22 B 3.49 C 5.08 D 6.44

5. A 6.30×10^{-3} mol dm^{-3} sulphuric acid sample was prepared. The acid dissociated completely in water. What is the pH of the acid sample?
   A 0.501 B 1.00 C 1.90 D 2.20

6. The pH of a sample of sulphuric acid is 1.04. What is the concentration of the acid?
   A 0.00852 mol dm^{-3} B 0.0170 mol dm^{-3} C 0.0456 mol dm^{-3} D 0.0912 mol dm^{-3}

Class work

Calculate the resulting **pH** when *120 cm^3 1M HCl* is added to *100cm^3 1M NaOH* at 25°C.

True or false

1. As the concentration of H^+ ions increases, the pH decreases. ( )
2. pH value can never be negative. ( )
3. A solution of pH 3 has an H^+ concentration 100 times that of a solution of pH 5. ( )

7. A trout fishery owner added limestone to his loch to decrease the effects of acid rain. He managed to raise the pH of the water from 5 to 7.

   The concentration of $H^+(aq)$ ions

   A increased by a factor of 2.
   B increased by a factor of 100.
   C decreased by a factor of 2.
   D decreased by a factor of 100.

8. The pH of solution X is 2 while that of solution Y is 6. Which of the following statements about the concentration of hydrogen ions in the two solutions is correct?
   A It is three times as great in solution X as that in solution Y.
   B It is three times as great in solution Y as that in solution X.
   C It is 10 000 times in solution Y as than in solution X.
   D It is 10 000 times in solution X as than in solution Y.

A, A,A,B,C,C,D,D

Acid-Base Indicators (酸鹼指示劑)

- Acid-base indicators change _____ with **different concentrations of H^+ ion**.
- The following table shows the **colour** of some **common indicators** in different pH ranges :

	pH range where colour changes	pH scale 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
	3.1 - 4.4	
Litmus	5.0 – 8.0	
	8.3 – 10.0	

Measuring the pH value of a Solution

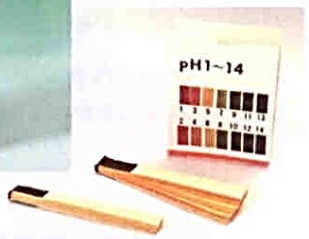
1. _____ _____ (通用指示劑)
   - a **mixture** of several indicators

   Two forms are available :

   (a) Universal indicator ( )

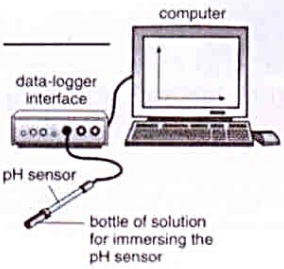
   (b) Universal indicator paper ( )

   The resulting colour is compared with the **pH** _____.



2. _____
   - gives an **accurate** measure of the pH value

3. _____ _____ (數據收集儀) with pH _____



1. Which of the following reagents can be used to measure the pH of a solution?

   A Litmus solution B Universal indicator C Phenolphthalein D Methyl orange

2. Arrange the following substances in descending order of pH values.

   (1) Milk (2) Lemon juice (3) Human blood (4) Detergent solution

   A (4) > (3) > (2) > (1) B (3) > (1) > (4) > (2)

   C (4) > (3) > (1) > (2) D (2) > (1) > (3) > (4)

C. Strength of Acids and Alkalis

Strong and Weak Acids

Although both 0.1 M HCl(aq) and 0.1 M CH_3COOH(aq) have the same concentration, their pH values are 1 and 3 respectively.

Explain why HCl(aq) is more acidic than CH_3COOH(aq).

When acids dissolve in water, they _____ to give ____ ions. Different acids ionize to _____ extents.

∴ **HCl(aq)** is a _____ acid while **CH_3COOH** is a _____ acid.

A ***strong acid*** is an acid that almost _____ ionizes / dissociates in water.

A ***weak acid*** is an acid that only _____ ionizes / dissociates in water.

Questions

Comment on the following statement :

A bottle of acid (pH 6.5) must contain a weak acid.

True or False

1. A strong acid is also a concentrated acid. ( )
2. A concentrated acid is also a strong acid. ( )
3. The strength of acids depends mainly on the degree of ionization in water to give H^+ ions. ( )
4. The concentration of acids depends on the amount of solute per unit volume. ( )
5. The terms, strength and concentration (used to describe acids), have the same meaning. ( )

Strong and weak acids

	Name of acid	Equation of ionization	Main type of particles present (besides H_2O and OH^-)
Strong acids	Hydrochloric		
	Sulphuric		
	Nitric		
Weak acids	Hydrofluoric		
	Carbonic		
	Sulphurous		
	Ethanoic		

	1 M Weak acids	1 M strong Acids
Addition of _____	Bubble are evolved at a _____ rate	Bubble are evolved at a _____ rate
Addition of _____		
Test for _____ _____		

*** The strong acid has a higher electrical conductivity because it has more _____

*** A strong/weak acid is also a strong/weak _____.

***pH paper can also be used to distinguish them.

Challenging Questions

1. Magnesium ribbons are added to same volumes of 1M HCl and 1M CH_3COOH respectively. Which of the following is/are correct ?

(a) Both reaction rates are the same. ( )

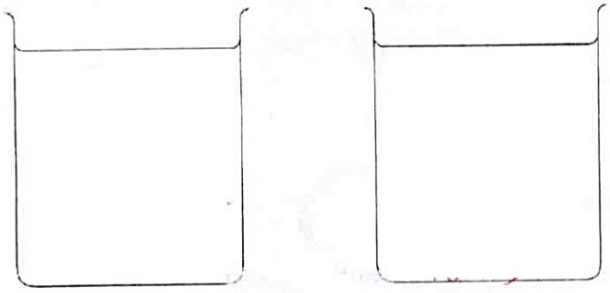
(b) Both require the same mass of magnesium for complete reaction. ( )

(c) Both take the same amount of time for complete reaction (magnesium is in excess). ( )

2. Which acid has a **lower pH**, 1M hydrochloric acid or 1M sulphuric acid ?

Strong and weak alkalis

	Name of acid	Equation of ionization	Main type of particles present (besides H_2O and OH^-)
Strong alkalis	Sodium hydroxide		
	Potassium hydroxide		
	Calcium hydroxide		
Weak alkali			



MCQ

1. Which of the following solutions has the HIGHEST pH value ?
   A. 1 M sulphuric acid
   B. 1 M magnesium hydroxide solution
   C. 1 M ammonia solution
   D. 1 M potassium hydroxide solution

2. A sample of sulphuric acid and a sample of ethanoic acid both have a pH of 3. It can be concluded that
   A. they are equally strong.
   B. they are of the same concentration.
   C. the volume of the two samples are equal.
   D. they contain the same concentration of hydrogen ions.

3. Which of the following is NOT found in a sulphurous acid solution ?
   A. $SO_2(aq)$
   B. $H^+(aq)$
   C. $SO_3^{2-}(aq)$
   D. $H_2SO_3(aq)$

1. The pH of 0.1 mol dm^{-3} hydrochloric acid is about 1 but that of 0.1 mol dm^{-3} ethanoic acid is about 3. This is because
   A ethanoic acid is a covalent compound.
   B ethanoic acid contains more hydrogen atoms per molecule.
   C ethanoic acid does not dissociate completely in water.
   D ethanoic acid is a strong acid.

2. Two flasks contain equal volumes of 0.1 mol dm^{-3} hydrochloric acid and 0.1 mol dm^{-3} ethanoic acid. Which of the following statements concerning them is correct?
   A They give the same colour change when the same quantity of universal indicator is added.
   B They contain equal concentration of hydrogen ions.
   C They react at the same rate with magnesium.
   D They neutralize the same number of moles of sodium hydroxide.

3. Comparing the same volume of 0.1 mol dm^{-3} HCl(aq) and 0.1 mol dm^{-3} CH_3COOH(aq), which of the following is INCORRECT?

	0.1 mol dm^{-3} HCl(aq)	0.1 mol dm^{-3} CH_3COOH(aq)
A	Lower pH	higher pH
B	Higher electrical conductivity	lower electrical conductivity
C	Higher initial rate of reaction with magnesium	lower initial rate of reaction with magnesium
D	Requires a greater number of moles of NaOH for neutralization	requires a smaller number of moles of NaOH for neutralization

4. Which of the following statements concerning 25 cm^3 of 1 mol dm^{-3} sulphuric acid and 50 cm^3 of 1 mol dm^{-3} ethanoic acid is INCORRECT?
   A They require the same volume of 1 mol dm^{-3} aqueous ammonia for complete neutralization.
   B They give the same colour change when the same quantity of universal indicator is added.
   C They have different electrical conductivity.
   D They react at different rates with zinc.

5. Why does magnesium react faster with 20 cm^3 of 1 mol dm^{-3} hydrochloric acid than with 20 cm^3 of 1 mol dm^{-3} ethanoic acid?
   A There are more mobile ions in 20 cm^3 of 1 mol dm^{-3} hydrochloric acid.
   B The concentration of hydrochloric acid is higher.
   C There are more hydrogen ions in 20 cm^3 of 1 mol dm^{-3} hydrochloric acid.
   D There are more mobile electrons in 20 cm^3 of 1 mol dm^{-3} hydrochloric acid.

C D D B C

2012 DSE

4. Which of the following statements concerning CH_3COOH and HCl is correct ?

A. CH_3COOH is a stronger acid than HCl.
B. The pH of 0.1 M $CH_3COOH(aq)$ is lower than that of 0.1 M HCl(aq).
C. Both $CH_3COOH(aq)$ and HCl(aq) react with $NH_3(aq)$, each giving a salt.
D. Both $CH_3COOH(aq)$ and HCl(aq) react with Ag(s), each giving a colourless gas.

2013 DSE

10. Consider the four solutions **W**, **X**, **Y** and **Z** listed below:

W: 0.01 mol dm^{-3} $HNO_3(aq)$
X: 0.01 mol dm^{-3} $H_2SO_4(aq)$
Y: 0.01 mol dm^{-3} KOH(aq)
Z: 0.10 mol dm^{-3} KOH(aq)

Which of the following represents the four solutions arranged in increasing order of pH ?

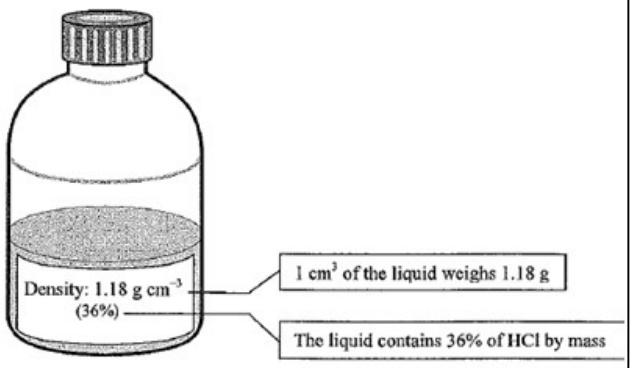
A. **W, X, Y, Z**
B. **W, X, Z, Y**
C. **X, W, Y, Z**
D. **X, W, Z, Y**

2014 DSE

13. Which of the following gases, after dissolved in 1 dm' of water, would give a solution with the highest pH ?

A. 0.002 mol of NO_2
B. 0.002 mol of SO_2
C. 0.002 mol of NH_3
D. 0.002 mol of HCl

7. A bottle of concentrated hydrochloric acid HCl(aq) is shown below:



According to the information on the label, calculate the concentration of the concentrated hydrochloric acid in **moldm^{-3}.**

2015 DSE

1. Which of the following statements is correct ?

A. All aqueous solutions contain $H^+(aq)$ ions.
B. The pH of all acid solutions is greater than zero.
C. All acidic compounds contain hydrogen as their constituent elements.
D. A 'corrosive' hazard warning label must be displayed on all reagent bottles containing acid solution.