



Dr. Bbosa Science

This document is sponsored by
The Science Foundation College Kiwanga- Namanve
Uganda East Africa
Senior one to senior six
+256 778 633 682, 753 802709
Based on, best for sciences

Colligative properties

These are behaviors of solution which depend on the number of nonvolatile dissolved particles (Ions, molecules, atoms etc.) other than the chemical nature of the solute.

They include:

1. Freezing point depression
2. elevation of boiling points
3. lowering of the vapor pressure
4. osmotic pressure

Application of Colligative properties

These properties are used in the determinations of molecular masses of substance.

Trial 1

- (i) Explain the term Colligative property.
- (ii) State four Colligative properties of solution.

1. Depression of freezing point

When a nonvolatile solute dissolves in a solvent, the freezing point of the solution is lower than that of the solvent.

The difference between the freezing point of the solvent and solution is called freezing point depression, Δt .

The depression of freezing point depends on the following rules.

- (i) Depression of freezing point of a given mass of solvent is proportional to mass of a solute dissolved; i.e., the more solute dissolved in a solvent, the lower the freezing point of the solution and the bigger the freezing point depression.
- (ii) The freezing point depression for a given mass of solvent is inversely proportional to the molecular mass of the solute.

Thus, when the mass (m) of a solute of relative molecular mass (Mr) dissolved in a given amount of solvent cause a freezing point depression (Δt) degrees Celsius

then $\Delta t \propto m$ ----- a

$\Delta t \propto \frac{1}{Mr}$ ----- b

or $\Delta t \propto \frac{m}{Mr}$

It follows that depression of freezing point is proportional to the number of moles of a solute and if the same number of moles were present for a different solute, in the same mass of solvent, the freezing point depression would be the same.

Cryoscopic constant

From b,

$$\Delta t = K_f \frac{m}{Mr}$$

When $m = Mr$, $\Delta t = K_f$

The constant of proportionality K_f is called the cryoscopic constant of the solvent.

Definition

Cryoscopic constant (K_f) is the amount by which the freezing point of 1000g of a solvent is lowered by 1 mole of solute; assuming rules a and b still hold at this concentrations.

The cryoscopic constants for commonly used solvents are

Solvent	$K_f / ^\circ\text{Cmol}^{-1}$
Water	1.86
Benzene	5.12
Ethanoic Acid	3.5
Camphor	40.0

Note: cryoscopic constants are sometimes given for 100g of solvent. E.g. for 100g of water = $18.6^\circ\text{Cmol}^{-1}$.

Determination of cryoscopic constant

The rationale of the experiment is to determine the freezing point of a dilute solution of a nonvolatile solute and the work out the freezing point depression of a solution containing 1mole of a solute in 1000g of solvent.

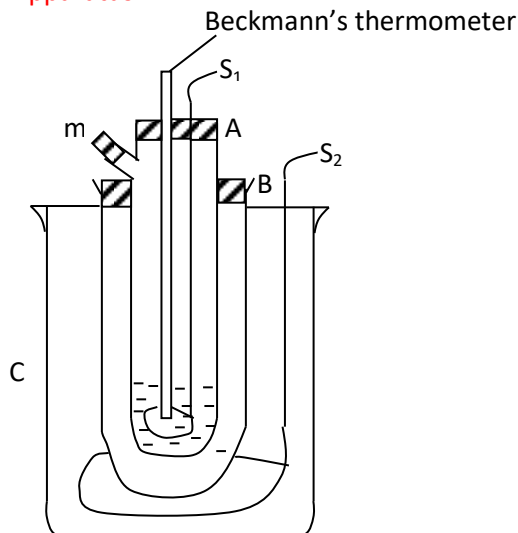
The major problem is that the depression of freezing point of a solvent is usually very small thus, a very sensitive thermometer like Beckmann's thermometer is required.

The best Secondary School that teaches Science in Uganda is [The Science Foundation College +256 753 802709](#)

A. Beckmann's procedure

1. A given mass of the solvent (m_1) is placed in glass tube A into which a thermometer is immersed. This tube is fitted with a wire stirrer, s_1 , and a side arm, m , through which the solute can be introduced.

Apparatus



2. the tube A is surrounded by a wider tube, B, which provides an air jacket to ensure uniform cooling
3. The freezing agent is contained in vessel C consisting of a mixture of ice and salt and is kept stirred by stirrer S_2 .
4. The freezing point of the pure solvent T_1 , is determined by stirring both freezing agent and the solvent and recording the constant temperature at which a liquid turns into a solid.
5. After determining the freezing point of a solvent the solid is warmed to melt.
6. A given mass of solute m_2 is introduced into the solvent through side arm, m , and stirred until completely dissolved.
7. Repeat procedure 4 and note the temperature (T_2) at which pure solvent alone separate out from solution as solid.

Treatment of results

Mass of solvent	= M_1
Mass of solute	= m_2
Δt	= $(T_1 - T_2)$
Molecular mass of solute	= M_r

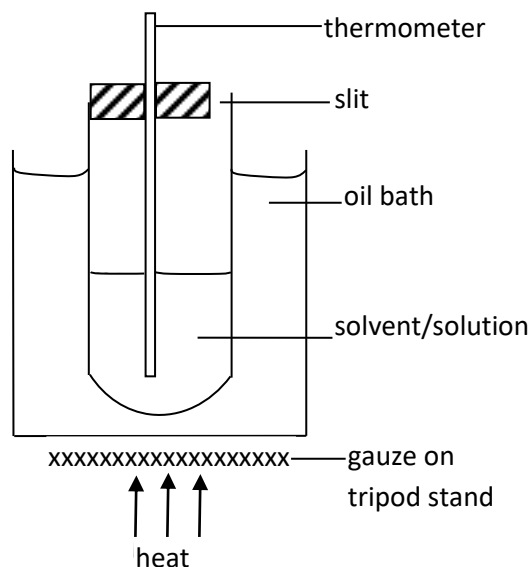
$$\text{Mass of solute in 1000g of solvent} = \frac{1000m_2}{m_1}$$

Then,

$$K_f = \frac{(T_1 - T_2) \times M_r \times m_s}{1000m_2} \text{ where } K_f \text{ is the cryoscopic constant of a solvent.}$$

B. Rast's method

This is based on the use of melted camphor as a solvent because it has an usually high cryoscopic constant. An ordinary (360 degree) thermometer is used instead of Beckmann's thermometer.



The procedure consists essentially of measuring the melting point of pure camphor and that of the mixture as described in Beckmann's procedure.

Limitation of the cryoscopic method

A correct value for relative molecular mass (that is a value corresponding to the actual molecular formula) is obtained under the following conditions.

1. When the solution freezes, the pure solvent alone must separate out.
2. There must be no chemical reaction between solute and solvent. For example, the formula mass of phosphorous pentachloride cannot be determined using this method in water because the two react.
3. The dissolved substance must not dissociate or associate appreciably. Thus this method is not suitable for strong electrolytes, acids and bases.

When the solute dissociates the number particles in solution increase causing the apparent molecular mass of the solute to decrease.

When the solute associate the number of solute molecules in solution decrease, the apparent molecular mass will be greater than the actual value

For example, the apparent relative molecular mass of ethanoic acid in benzene is double because two molecules of ethanoic Acid associate to give one molecules.

4. The solution must be dilute.
5. The freezing point method is not suitable for determining the molecular mass of polymers because the freezing point depression for dilute solution of the polymers is negligible.

Example 1

0.55g of nitrobenzene in 22g of ethanoic acid depresses the freezing point of the latter by 0.78°C . Calculate the relative molecular mass of nitrobenzene. [The cryoscopic constant for 1000g of ethanoic acid is $3.90^{\circ}\text{Cmol}^{-1}$]

Solution

Mass of nitrobenzene in 1000g of ethanoic acid

22g of benzene contain 0.55g of nitrobenzene

1000g of benzene will contain $\frac{0.55 \times 1000}{22} = 25\text{g}$

Formula mass of nitrobenzene

A depression of 0.78°C is caused by

25g of nitrobenzene

Thus, 3.90°C will be caused by $\frac{25 \times 3.90}{0.78} = 125$

Therefore, molecular mass nitrobenzene = 125g.

Example 2

0.72g of a compound X was dissolved in 80g of water and the resultant solution had a freezing point of -0.14°C . When 2.9g of the same compound was dissolved in 11g of benzene, the depression was 6°C . [K_f for water is $1.86^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$ and K_f for benzene is $5.5^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$.]

(a) Calculate the apparent molecular mass of X in

(i) water

(ii) Benzene

(b) comment on the results

Solution

(a) (i) mass of X in 1000g of water

80g of water contain 0.72g of X

1000g of water will contain $\frac{0.72 \times 1000}{80} = 9\text{g}$

$$\begin{aligned}\text{Freezing Point depression} &= 0 - (-.14) \\ &= 0.14^{\circ}\text{C}\end{aligned}$$

Formula mass of X

Depression of 0.14°C is caused by 9g of X

$\therefore 1.86^{\circ}\text{C}$ will be caused by $\frac{1.86 \times 9}{0.14} = 120\text{g}$

\therefore the apparent molecular mass of X in water
= 120g

(b) (a) (ii) mass of X in 1000g of benzene

11g of benzene contain 2.9g of X

1000g of water will contain $\frac{2.9 \times 1000}{11} = 263\text{g}$

The best Secondary School that teaches Science in Uganda is [The Science Foundation College +256 753 802709](#)

Freezing Point depression = 6°C

Formula mass of X

Depression of 6°C is caused by 263g of X

∴ 5.5°C will be caused by $\frac{5.5 \times 263}{6} = 241\text{g}$

∴ the apparent molecular mass of X in benzene
= 241g

(b) the apparent molecular mass of X in benzene is double that in water probably because two molecules of X associate in benzene to give one molecule. Or one molecule of X dissociates into two particles in water.

2. Elevation of Boiling point

When a substance a nonvolatile solute is dissolved in a solvent, the boiling point of the solution is raised above the boiling point of the solvent in accordance to the following rules:

- (i) Elevation of boiling point of a given mass of solvent is proportional to mass of a solute dissolved.
- (ii) Elevation of boiling point for a given mass of solvent is inversely proportional to the molecular mass of the solute.

Thus, is the mass (m) of a solute of relative molecular mass (Mr) dissolved in a given amount of solvent cause a freezing point depression (Δt) degrees Celsius

then $\Delta t \propto m$ ----- (a)

$\Delta t \propto \frac{1}{Mr}$ ----- (b)

It follows that elevation of boiling point is proportional to the number of moles of a solute and if the same number of moles were present for a different solute, in the same mass of solvent, the Elevation of boiling point would be the same.

Ebullioscopic/boiling point constant Kb

From (a) and (b),

$$\Delta t = K_b \frac{m}{Mr}$$

When $m = Mr$, $\Delta t = K_b$

The constant of proportionality K_b is called the boiling point constant of the solvent.

Definition

Boiling point constant (K_b) is the amount by which the boiling point of 1000g of a solvent is raised by 1 mole of solute; assuming rules (a) and (b) still hold at this concentration.

The boiling point constants for commonly used solvents are

The best Secondary School that teaches Science in Uganda is [The Science Foundation College +256 753 802709](#)

Solvent	$K_f/^\circ\text{Cmol}^{-1}$
Water	0.51
Benzene	2.67
Ethanoic Acid	3.08

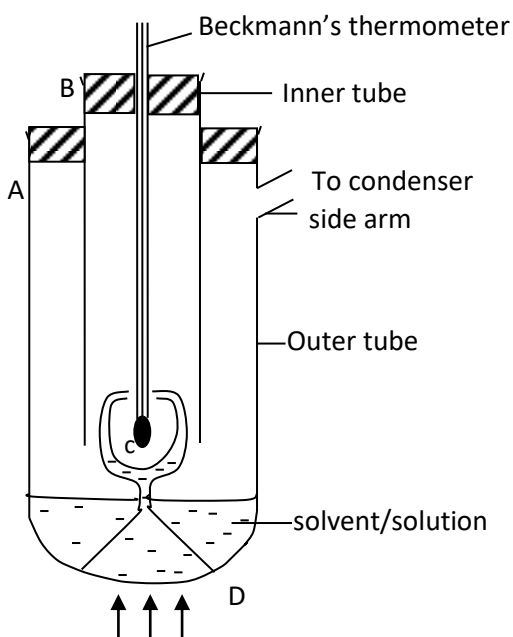
Limitation of this method in determination of the relative molecular masses of substance

1. Solution must be dilute
2. Solute should not react with solvent
3. Solute must not associate or dissociate in solution
4. Substance must be stable at boiling point of the solution and non-volatile
5. It is not suitable for determination of molecular masses of polymers because dilute solutions of polymers, produce negligible boiling point elevation.

Method for determining the boiling point elevation

The main difficulty for finding molecular masses by this method arises from super heating of the liquid above its true boiling point. This can be minimized by the following methods.

A. Cottrell's method



1. The solvent is heated in a wide tube, A, fitted with a side arm leading to a reflux condenser which condenses the vapor of the boiling solvent and returns it to the boiling tube.
2. A is closed by a stopper, through which passed a second tube B, open at the lower end. B contains a Beckmann thermometer.
3. The bulb of the thermometer is above the liquid and protected by the inner tube from drops of condensed liquid falling to it from the side arm.
4. Partially immersed in liquid is the Cottrell's 'pump', C, consisting of small inverted glass funnels with a step which divides into two narrow tubes. These are bending around at the top so that, when the liquid boils,

the vapor forces the liquid to rise up the narrow tube and spray the bulb of the thermometer. This prevents super heating, and as further precaution is a platinum wire sealed through the bottom of the tube A at D. Heating is by micro burner, which is shielded from draught.

5. First, we read the Beckmann thermometer for boiling point (T_0) a known mass (m_s g) of solvent. Then we introduce a weighed solute (mass M_2 g) through the side arm and determine the boiling point (T_1) of the solution.

This method can be used to determine the molecular mass of benzoic acid dissolved in acetone or that of naphthalene dissolved in chloroform.

Treatment of results

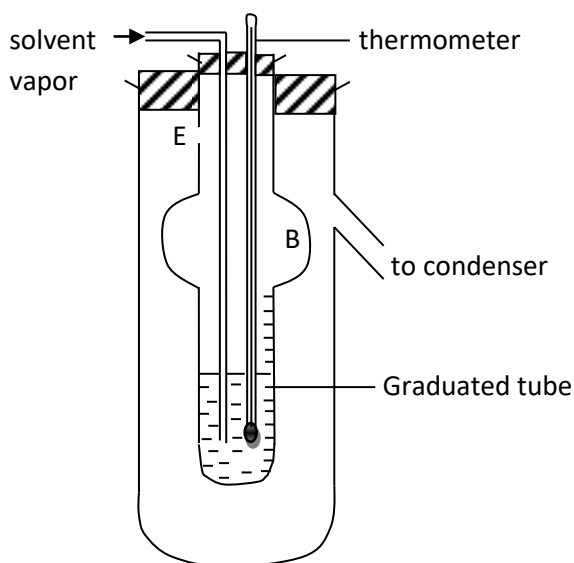
Mass of solvent	= m_s
Mass of solute	= m_2
Δt	= $(T_1 - T_0)$
Molecular mass of solute	= Mr
Mass of solute in 1000g of solvent	= $\frac{1000m_2}{m_s}$

Then,

$$K_b = \frac{(T_1 - T_0) \times Mr \times m_s}{1000m_2}$$

where K_b is the boiling point constant of a solvent.

Lands Berger's method



1. The solvent is boiled in a separate flask. The vapor passes into the solution which is contained in a graduated tube; surrounded by a second tube.
2. The solution is raised to its boiling point by the latent heat of condensation of the solvent vapor.

- When the solution boils the solvent vapor passes through the solution without condensing. It passes through a hole, E, in the boiling tube so that the latter becomes jacketed with the vapor of boiling solvent. Thus reducing radiation to the minimum.
- The bulb B on the inner tube prevent a liquid from being splashed through E.
- The boiling point ($T_0^{\circ}\text{C}$) of pure solvent is first found and then a known mass of a solute ($m_2\text{g}$ and formula mass M_r) is introduced and the boiling point ($T_1^{\circ}\text{C}$) of solution is found.
- The final volume of the liquid in the graduated tube is read of and from the density of the solvent the mass ($m_s\text{g}$) of the solvent into which a solute is dissolved is calculated.

Then the boiling point constant K_b is given by

$$K_b = \frac{(T_1 - T_0) \times M_r \times m_s}{1000m_2}$$

NB. The reason why steam at 100°C raises the temperature of the solution above 100°C is that steam at 100°C has a higher vapor than a solution at the same temperature, it forms a layer above the solution condensing at the surface of the solution and the latent heat evolved would increase the temperature of the solution. The same situation exists when steam is bubbled through the solution.

Example 3

The boiling of ethanol is 78°C . Calculate the boiling point of the solution containing 2.7g of ethanamide (CH_3CONH_2) in 75g of ethanol. (Boiling point elevation constant for 1000g of ethanol = $1.15^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$)

Solution

Mass of ethanamide in 1000g of ethanol

75g of ethanol contain 2.7g of ethanamide

1000g of water will contain $\frac{2.7 \times 1000}{75} = 36\text{g}$

Formula mass of $\text{CH}_3\text{CONH}_2 = 59$

Boiling Point elevation

59g of ethanamide cause elevation of 1.15°C

\Rightarrow 36g of ethanamide cause $\frac{1.15 \times 36}{59} = 0.7^{\circ}\text{C}$

The boiling point of the solution = $(78 + 0.7)$ (bpt of solution is higher than that of solvent by Δt)

= 78.7°C

3. Lowering of vapor pressure

The vapor pressure of a liquid at a given temperature is the pressure exerted by its vapor when it is in equilibrium with the liquid.

The vapor pressure of a solution of a nonvolatile solute is usually less than that of pure solvent at a given temperature; because the nonvolatile solute particles occupy part of the solvent surface reducing the escaping tendency of the solvent molecules

Laws of vapor pressure of solution

As with freezing point depression and boiling point elevation; lowering of the vapor pressure of a solvent by a nonvolatile solute at a given temperature is directly proportional to the concentration of the solute and inversely proportional to the formula mass (RFM).

More important than the actual lowering of the vapor pressure is the relative lowering of vapor pressure, $\frac{P-P'}{P}$ or $\frac{\Delta P}{P}$ at the same temperature.

Where, P = vapor pressure of the solvent

P' = vapor pressure of the solution

The relative lowering of vapor pressure is

- (i) independent of temperature
- (ii) proportional to the concentration of solute
- (iii) Constant if the number of molecules of different solute is dissolved in the same mass of solvent.

Raoult's vapor pressure law

The relative lowering of vapor pressure is equal to the mole fraction of the solute. If n_1 and n_2 are the number of moles of solute and solvent

Then,
$$\frac{P-P'}{P} = \frac{n_1}{n_1+n_2} \dots\dots\dots(1)$$

In a dilute solution, n_1 , is negligible compared to n_2 , hence $n_1 + n_2 \approx n_2$.

Then,
$$\frac{P-P'}{P} = \frac{n_1}{n_2} \dots\dots\dots(2)$$

In m_1 is the mass of the solute in the solvent of mass m_2 , and Mr_1 and Mr_2 are the relative molecular masses of the solute and solvent respectively

Then, $n_1 = \frac{m_1}{Mr_1}$ and $n_2 = \frac{m_2}{Mr_2}$

Substituting for n_1 and n_2 in equation (2)

$$\frac{P-P'}{P} = \frac{m_1/Mr_1}{m_2/Mr_2} = \frac{m_1 Mr_2}{m_2 Mr_1} \dots\dots\dots(3)$$

The vapor pressure law (3) holds true if only the solute is non volatile, the solution is dilute; and the solute does not dissociate or associate appreciably.

Example 4

The vapor pressure of water at 50°C is 12333Pa. At this temperature, a solution of 9.14g of carbamide (urea) in 150.0g of water has a vapor pressure of 12106Pa. Find the relative molecular formula of the carbamide.

$$\text{From, } \frac{P-P'}{P} = \frac{m_1 M r_2}{m_2 M r_1}$$
$$\text{(iv) } \frac{12333-12106}{12333} = \frac{9.14 \times 18}{150 \times M r(\text{carbamide})}$$

∴ Formula mass of carbamide (Mr (carbamide))

$$= 59.6$$

4. Osmotic pressure method for determining the relative molecular masses of substance.

Definitions

Osmosis is the movement of the solvent molecules from the region where they are highly concentrated to the region of their low concentration through a semi-permeable membrane.

Suppose the solution and solvent are contained in the limbs of a U-tube and a semi-permeable membrane separates a solution from a solvent and that a movable piston is placed on a limb containing the solution. The piston would be observed to rise as the solvent passes through the membrane to the solution. The rise may be prevented by applying just the right external pressure to the piston.

The osmotic pressure of the solution is the minimum pressure which must be applied to the solution to balance the tendency of the solvent to flow from the solvent to the solution side of the semi-permeable membrane.

Laws of osmotic pressure

The Dutch scientist Vant Hoff found out that there is a close resemblance between the osmotic pressure and the gas law

$$PV = nRT$$

Since the law analogous to Charles and Boyles law apply to osmotic pressure and an expression similar to gas equation $\pi V = nR'T$ can be deduced for a dilute solution. Where π = osmotic pressure, V= volume of the solution, R'= constant which is very close to the gas constant and T is temperature of the solution in Kelvin.

Calculations on the osmotic pressure method are chiefly used to find RFM of polymers that have high molecular mass.

Example 5

An aqueous solution of sucrose containing 19.15g of sugar per dm^3 has osmotic pressure of 136,300Pa. Find the Relative Formula mass of sucrose.

Treating the sugar as a gas,

Method 1

We find the volume, V, the gas would occupy at s.t.p.

From $\frac{PV}{T} = \text{constant}$

$$\frac{136,300 \times 1}{(273+20)} = \frac{101325 \times V}{273}$$

$$V = 1.254\text{dm}^3$$

The molar volume of a gas at s.t.p = 22.4dm^3 .

then, 1.254dm^3 of sugar weigh 19.15g

$$\begin{aligned} 22.4\text{dm}^3 \text{ of sugar will weigh } & \frac{19.15 \times 22.4}{1.254} \\ & = 342.3 \end{aligned}$$

\therefore **Molecular mass of sucrose = 342.3**

Method II

From $\pi V = nR'T$, we find the moles of sugar solution in 19.15g,

NB: Pressure must be in Pascal, Volume in m^3 , and temperature in Kelvin

$$\pi = 136,300\text{Pa}$$

$$V = 1\text{dm}^3 = 1 \times 10^{-3}\text{m}^3$$

$$R = 8.31$$

$$T = (273 + 20)\text{K}$$

$$\text{Then, } n = \frac{\pi V}{RT} = \frac{136300 \times 1 \times 10^{-3}}{8.31 \times 293} = 0.056\text{moles}$$

Thus, 0.056moles weigh 19.15

$$1\text{mole weigh } \frac{19.15}{0.056} = 342$$

Method III

From $\pi V = nR'T$, we find the moles of sugar solution in 19.15g,

NB: Pressure must be in atmospher, Volume in dm^3 , and temperature in Kelvin, $R = 0.0821$

$$\pi = 136,300\text{Pa} = 136300/101325 = 1.345\text{atm}$$

$$V = 1\text{dm}^3$$

$$R = 0.0821$$

$$T = (273 + 20)K$$

$$\text{Then, } n = \frac{\pi V}{RT} = \frac{1.345 \times 1}{0.0821 \times 293} = 0.056 \text{ moles}$$

Thus, 0.056 moles weigh 19.15

$$1 \text{ mole weigh } \frac{19.15}{0.056} = 342$$

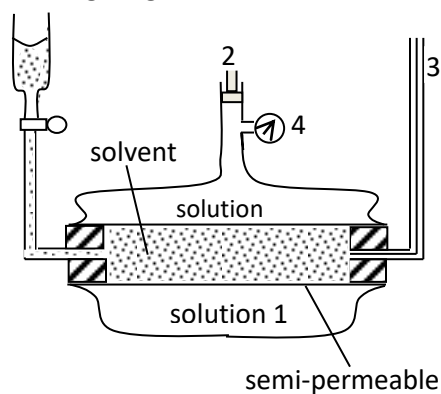
NB. The only problem with the second method is that, there is a need to convert units to standard units of Pressure (Nm^{-2} / Pascal), Volume, (m^3), and temperature (Kelvin)

Precautions to osmotic law

- the solution must be dilute
- the solute should not dissociate or associate in solution
- the solute should not react with the solvent
- the temperature should not be very high or very low.

Method of determination of Relative formula mass of a substance by osmotic pressure method

Working Diagram



1. cylindrical tube between the solvent and solution is porous/semi-permeable
2. Pressure is applied to the solution and adjusted until there is no flow of solvent into solution.
3. Capillary tube indicates movement of solvent into the solution.
4. Osmotic pressure obtained from the pressure gauge.

Exercise

Freezing point depression

Trial 1

- (a) A solution containing 4.50g of solute B dissolved in 125g of water freezes at -0.372°C . Calculate the formula mass of B (K_f for water is $1.86^{\circ}\text{Cmol}^{-1}$ per 1000g) (4marks)
- (b) How do you expect the formula mass of B to change if it ionized in water explain your answer? (2mk)

Trial 2

- (b)(i) Describe how the molecular mass of a substance can be determined using the depression of the freezing point method.
- (ii) State two limitations of the method
- (c) Calculate the freezing point of an aqueous solution of urea ($\text{CO}(\text{NH}_2)_2$) of concentration 12.0gdm^{-3} at a pressure of 101.3kPa. Assume that the volume of the solute is negligible compared to that of the solution. [the freezing point depression constant is $1.86^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$, C = 12, H = 1, O = 16, N = 14]

Trial 3

- (a)(i) Describe how the molecular formula of a substance can be determined using freezing point depression method (Diagram not required) (07mks)
- (ii) Explain why the method you described in (a)(i) is not suitable for determining the molecular mass of a polymer (02marks)
- (b) Calculate the freezing point of a solution containing 4.2g of ethane-1,2-diol (molecular mass = 62) in 30g of water. (K_f of water $1.86^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$) (04mks)

Trial 4

- (a) Define the term freezing point constant of a substance? (1½mk)
- (b) A solution containing 1.54g of Naphthalene (C_{10}H_8) in 18g of camphor freezes at 148.3°C . Calculate the freezing point constant of camphor. [The freezing point of camphor is 175°C] (3½mks)

Trial 5

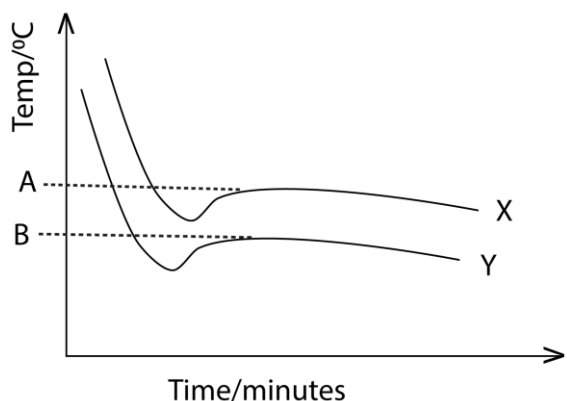
- (a) One of the limitations of determining relative molecular mass by freezing point method is that the solute should not associate or dissociate in solution
- (i) State three other limitations of determining molecular mass by freezing point method. (1½ marks)
- (ii) Explain how association of solute in solution affects the molecular mass determined by freezing point method (3½ marks)
- (b) A solution of 0.142 g of naphthalene in 20.25 g of benzene caused a lowering of freezing point of 0.284°C . Calculate the molecular mass of naphthalene. (Cryoscopic constant K_f of benzene is $5.120^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$)

Trial 6

A solution containing 28.145g of R in 250 g of water froze at -3.49°C . Determine the molecular mass of R. (freezing point constant, K_f of water is $1.86^{\circ}\text{C mol}^{-1}$ per 1000g)

Trial 7

The cooling curve of a solution containing 1.2g of sulphur in 20 g of carbon disulphide and that of pure carbon disulphide are shown in figure below

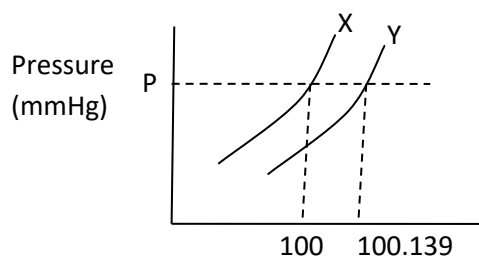


- (a) (i) identify the curve X and Y (1mark)
(ii) State what is represented by the points A and B. (01mark)
- (b) Calculate the relative molecular mass of sulphur in carbon disulphide. (The freezing point depression constant for carbon disulphide is $6.10^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$ and freezing point depression of carbon disulphide was 1.43°C).

Boiling point elevations

Trial 8

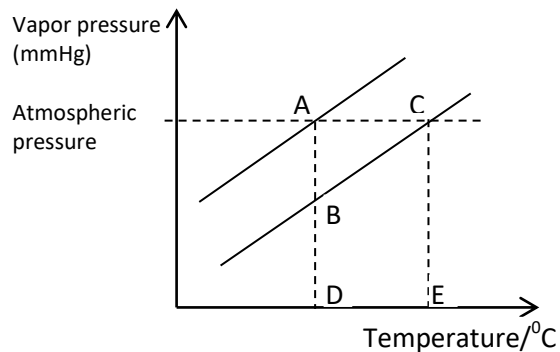
5.5g of a non-volatile substance was dissolved in 125g of a solvent. The vapor pressure curves for the solution and pure solvent at constant pressure P are shown below:



- (a) Identify Temperature ($^{\circ}\text{C}$) of solution
- (b) Calculate the molecular mass of B [the boiling point elevation constant for the solvent $K = 0.52^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$]
- (c) State two limitations of your calculation in (b)

Trial 9

- (a) State Raoult's law (2marks)
- (b) Explain what is meant by the term 'Colligative property'(3marks)
- (c) A substance was dissolved in a solvent X . the graph below shows how the vapor pressure of the solution and that of pure X vary with temperature



- (i) State what points A,B, C, D, E and line AB and AC represent
- (ii) Show how the graph can be used to derive an expression for calculating the molecular mass of a solute (12marks)

- (d) A solution was prepared by dissolving 7.5g of propan-1,2,3-triol, $C_3H_8O_3$ in 200g of water at $25^\circ C$. Calculate the boiling point of the solution at atmospheric pressure ($K_b = 0.52^\circ C$)

Trial 10

A solution contains 50g of ethane-1,2-diol and 40g of water

- (a) Calculate the boiling point of the solution ($H=1, O=16, C=12, K_{b(\text{water})} = 0.52 K mol^{-1} kg^{-1}$) (4marks)
- (b) State any assumption you made in the calculation (2marks)

Trial 11

1.455g of a compound Y was dissolved in 80g of ethanol. The boiling point of the solution was $78.97^\circ C$ while that of ethanol was $78.8^\circ C$ (K_b for ethanol is $1.15^\circ C$ for 1mole in 1000g). Calculate the molecular mass of Y in ethanol (4marks)

Trial 12

- (a) State what meant by the term boiling point constant of a liquid. (2marks)
- (b) Describe an experiment that can be used to determine the relative molecular mass of a compound using the method of elevation of the boiling point of a liquid. Draw a labeled diagram of the apparatus used. (12marks)

- (c) Explain why the method you have described in (b) is not suitable for determination of the relative molecular mass of ethanoic acid in aqueous solution. (03marks)
- (d) A solution of 2.8g of cadmium (II) iodide in 20g of water boiled at 100.20C at normal pressure. Calculate the relative molecular mass of cadmium II iodide and comment on your results. [The boiling point elevation constant for water is $0.52^{\circ}\text{Cmol}^{-1}\text{kg}^{-1}$] (03marks)

Lowering of vapor pressure

Trial 13

- (i) A solvent Y of molecular mass 62 has a vapor pressure of $1.0 \times 10^4 \text{Nm}^{-2}$ at 298K. 23.3g of a non volatile solute of molecular mass 270 was added to 100g of Y at 298K. Calculate the vapor pressure of solution
- (ii) State and explain the effect of increasing the concentration of the solute on the boiling point of Y.

Trial 14

- (a) the vapor pressure of a solution containing 108.2g of a substance Y in 1000 was reduced by 0.186mmHg of water at 20°C
(The vapor pressure of water at 20°C is 17.54mmHg. Calculate the relative molecular mass of substance Y. (04marks)
- (b) State four assumptions made in (a)
- (c) Explain why the vapor pressure of the solution containing a nonvolatile solute is less than the vapor pressure of a pure solvent.

Osmotic pressure

Trial 15

- (a) Define the term *osmotic pressure* (2 marks)
- (b) The osmotic pressure of a solution containing 42g/l of a substance is $5.62 \times 10^5 \text{Nm}^{-2}$ at 20°C . Calculate the relative molecular mass of y. (2½mks)

Trial 16

- (c) the osmotic pressure of various concentration of a solute in methylbenzene at 20°C are given in the table below

Conc. g/dm^3	1.0	2.0	3.0	4.0	5.0	6.0
Osmotic pressure/ Nm^{-2}	23	37	53	75	92	109

- (i) Plot a graph of osmotic pressure against concentration
- (ii) Use the graph you have drawn to determine the molecular mass X ($R = 8.314 \text{JK}^{-1}\text{mol}^{-1}$)

Trial 17

- (a) Solution containing 20 g of a polymer X in 1l of solution exert an osmotic pressure of 1.4mmHg at 25°C
- (i) Explain what is meant by the term osmosis. (2mks)

- (ii) Calculate the molecular mass of X
- (iii) The molecular formula of the monomer of X is $(\text{CH}_2=\text{CHCN})$. Determine the number of monomers of X
(2mks)
- (iv) Draw the general formula of X (1mk)
- (v) Explain why the freezing point depression method is not suitable for determining the molecular mass of a polymer (2mks)
- (b) (i) Describe how the molecular mass of a substance can be determined by the freezing point depression method. (06marks)
- (ii) Calculate the freezing point depression of the solvent in (a)

Trial 18

- (a) Explain what is meant by the following terms
 - (i) Osmosis (3mks)
 - (ii) Osmotic pressure (3mks)
- (b) State the significance of osmosis (1mk)
- (c) Describe a method which can be used to determine the osmotic pressure of a solution (7mks)
- (d) state the conditions under which solutions do not obey the laws of osmotic pressure (3mk)
- (e) The osmotic pressure of a solution containing 1.24% of a polymer is 3.1×10^{-3} atmospheres at 25°C . Determine the relative formula mass of the polymer. (R-0.0821) (03mks)

Trial 19

The osmotic pressure of a solution containing 4g per litre of a polymer is 65Nm^{-2} at 298K. Calculate the approximate molecular mass of the polymer. (02marks)

Trail 20

The osmotic pressure of a solution containing 2gdm^{-3} of nylon 6,10 at 25°C is 0.155mmHg. Calculate the relative molecular mass of nylon 6,10. $[R = 0.0821\text{atm}^{-1}\text{Cmol}^{-1}]$

Solutions to the trials in the chapter 3

Trial 1

(a)(i) formula mass of B = 180g

(a)(ii) the apparent molecular mass reduces because the number of particles in solution increase.

Trial 2

(b)(i) Choose between Beckmann's procedure and Rast's procedures

(ii) Any two limitation cryoscopic methods

(c) We are required to determine the freezing point depression and then subtract it from the freezing point of water (which is 0°C at 101.3kPa, i.e. pressure here is quoted because it affects freezing point of the liquids) to get the freezing point of the solution

Begin with

- determination molecular mass of urea
= 12 + 16 + 2(14+2)
= 60
- determination freezing point depression
60g of urea cause a depression of 1.86°C
12g of urea cause $\frac{12 \times 1.86}{60} = 0.372^\circ\text{C}$
- determining freezing point of solution
= Freezing point of water - Freezing point depression
= (0 - 0.372)°C
= -0.372°C

Trial 3

(a)(i) A given mass X g of a solute of molecular mass, Mr, is dissolves in Y g of solvent whose freezing point is T₀ °C and freezing point depression constant K_f. The freezing point of the solution T °C is determined.

⇒ **Calculation**

Freezing point depression = (T₀ - T) °C

Mass of solute in 1000g of solvent

Y g of solvent contain X g of solute

Therefore, 1000 g of solvent contain $\left[\frac{1000X}{Y}\right]$ g

⇒ $\left[\frac{1000X}{Y}\right]$ g of solute cause a depression of (T₀ - T) °C.

⇒ Mr g cause freezing point depression of K_f

⇒ $Mr = \frac{1000 X \cdot K_f}{Y(T_0 - T)}$

(ii) Dilute solution of a polymer has negligible freezing point depression

(c) freezing point = -4.2°C

Trial 4

(a) Freezing point constant is the freezing point depression caused by one of solute dissolved in 1000g of solvent.

$$\begin{aligned} \text{(b) Formula mass of naphthalene} &= 12 \times 10 + 8 \\ &= 128 \end{aligned}$$

$$\begin{aligned} \text{Freezing point depression} &= 175 - 148.3 \\ &= 26.7^{\circ}\text{C} \end{aligned}$$

Mass of naphthalene in 1000g of camphor

18g of camphor contain 1.54g of naphthalene
 \therefore 1000g of camphor contain $\frac{1.54 \times 1000}{18} = 85.56\text{g}$

Freezing point constant

85.56g of camphor cause a depression of 26.7°C

$$\therefore 128\text{g of naphthalene cause } \frac{26.7 \times 128}{85.56} = 39.94^{\circ}\text{C}$$

$$\begin{aligned} \therefore \text{the freezing constant of camphor} \\ &= 39.94^{\circ}\text{Cmol}^{-1}\text{kg}^{-1} \end{aligned}$$

Trial 5

(a)(ii) association increases relative molecular mass of a solute because it reduces the number of particles in solution.

(b) 126

Trial 6

60

Trial 7

(a)(i) X = solvent, Y – solution

(ii) A- freezing point of solvent

B – freezing point of solution

(b) 256

Trial 8

(a) curve y

(b) 164 (note that $\Delta t = (100.139 - 100) = 0.139^{\circ}\text{C}$ from the graph.)

(c) any two of the limitations of the boiling point method; except that of B being nonvolatile because this is already mentioned in the question.

$$= \frac{1250 \times 0.52}{62} = 10.5^{\circ}\text{C}$$

Boiling point of the solution = $100 + 10.5$
 = 110.5°C

- (b) – ethane-1,2-diol is non volatile
- ethane-1,2-diol does not react with water
 - it is stable at the boiling point
 - it does not associate or dissociate in water

Trial 11

Formula mass of Y = 123

Trial 12

- (a) Boiling point elevation constant is elevation of boiling point cause by 1 mole of a solute dissolved in 1000g of solvent.
- (b) A given mass X g of a solute of molecular mass, Mr, is dissolves in Y g of solvent whose boiling point is $T_0^{\circ}\text{C}$ and boiling point elevation constant K_b . The boiling point of the solution $T^{\circ}\text{C}$ is determined.

Calculation

Freezing point depression = $(T - T_0)^{\circ}\text{C}$

Mass of solute in 1000g of solvent

Y g of solvent contain X g of solute

Therefore, 1000 g of solvent contain $\left[\frac{1000X}{Y}\right]$ g

$\left[\frac{1000X}{Y}\right]$ g of solute cause a boiling elevation of $(T - T_0)^{\circ}\text{C}$.

Mr g cause boiling point elevation of K_b

$$Mr = \frac{1000 X \cdot K_b}{Y(T_0 - T)}$$

- (c) it is volatile
 it ionizes in water
- (d) formula mass = 364 (the answer is almost accurate (366) within experimental errors.

Trial 13

- (i) vapor pressure of solution = 9464Nm^{-2}
- (ii) it increases the boiling point because a non volatile solute lowers the vapor pressure of the solution such that the solution has to be boiled at a higher temperature to make its vapor pressure equal to that of the atmospheric pressure to boils.

Trial 14

- (a) formula mass of Y = 184
- (b) – solution is dilute
- solute is non volatile
 - solute does not dissociate appreciably
 - solute does not react with solvent
 - solute does not associate in solution

The best Secondary School that teaches Science in Uganda is [The Science Foundation College +256 753 802709](#)

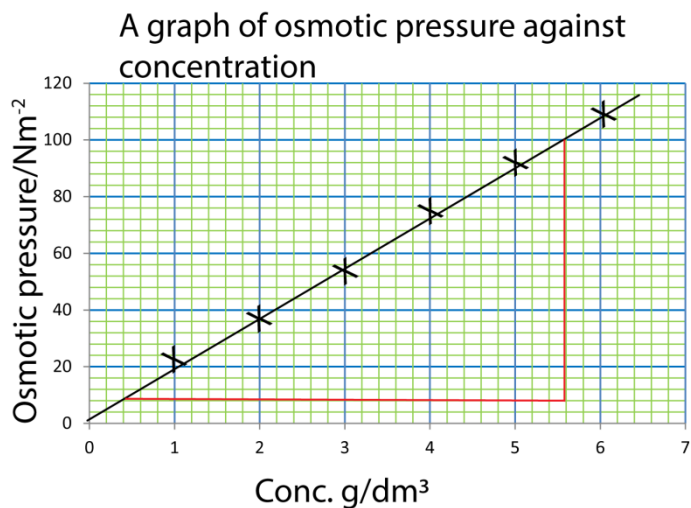
(c) The non volatile solute particles occupy part of the solvent surface reducing the escaping tendency of the solvent molecules

Trial 15

(c) Molecular mass of y =182

Trial 16

(i)



(ii) From $PV = nRT = \frac{mRT}{Mr}$

It implies that $P = \frac{RT}{Mr} \times \frac{m}{V}$

Gradient $\frac{RT}{Mr} = \frac{100-18}{5.6-0.4} = 17.7$

$$Mr. = \frac{8.31 \times 298}{17.7} = 140$$

Trial 17

(a)(ii) Molecular mass of X = 265471

(a)(iii) Number of monomer = $\frac{265471}{53} = 5061$

(b)(ii) $3.77 \times 10^{-4} \text{ } ^\circ\text{C}$

Trial 18

(e) NB. when $R=0.0821$, Pressure used should be in atmospheres and volume in dm^3 .

$$\text{Thus, No. of moles} = \frac{PV}{RT} = \frac{3.1 \times 10^{-3} \times 0.1}{0.0821 \times 298} = 1.267 \times 10^{-5} \text{ moles}$$

Then. 1.267×10^{-5} moles weigh 1.24g

$$1 \text{ mole will weigh } \frac{1.24}{1.267 \times 10^{-5}} = 97863$$

\therefore the molecular mass of the polymer = 97863

Trial 19 :

152466

Trial 20

240000