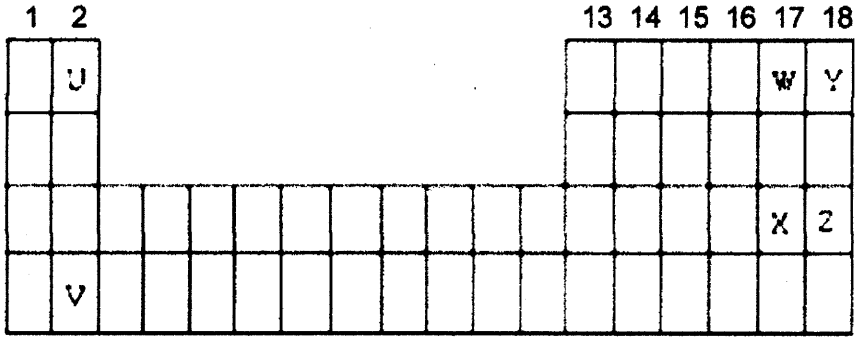
**1ATAR Chemistry Test 4: Intermolecular Forces and Gases Weighting 4%**

**Name:** ..... **Mark** /

**Section 1: Multiple Choice** **(12 marks)**

Answer all questions on the separate Multiple Choice Answer Sheet.

1. A section of the periodic table is shown below. The symbols for the elements are fictitious.




The element with the highest electronegativity is:

(a) U (b) V (c) W (d) X

2. In which of the following substances would hydrogen bonding occur?

**I** HF **II** $NH_3$ **III** $H_2$ **IV** HCℓ

(a) **I** and **III** only
(b) **II**, **III** and **IV** only
(c) **II** and **III** only
(d) **I** and **II** only

3. Which of the following best explains the difference in boiling points of HCℓ, HBr and HI, given their respective boiling points are -85, -67 and -35°C?

(a) The strength of dispersion forces increases as the number of electrons present in a molecule increases.
(b) The strength of hydrogen bonding increases as the number of electrons present in a molecule increases.
(c) The molecules become more polar as the number of electrons present increases. HCl > HBr > HI in polarity
(d) The strength of hydrogen bonds decreases as the number of electrons present in a molecule increases.

4. The correct order of increasing boiling points for the substances silica ($SiO_2$), propane ($CH_3CH_2CH_3$), ethanol ($CH_3CH_2OH$), and helium gas is:

(a) helium < propane < silica < ethanol
(b) helium < propane < ethanol < silica.
(c) helium < ethanol < propane < silica.
(d) propane < helium < ethanol < silica.

$SiO_2$ – covalent network
propane – dispersion
ethanol – H-bonding
He – dispersion

5. The shapes of many simple molecules can be predicted by the valence shell electron pair repulsion (VSEPR) theory. The VSEPR hypothesis states that:
   (a) orbitals in the outer shell of an atom stay as far away from each other as possible.
   (b) bonding pair electrons stay as far away from each other as possible.
   (c) non-bonding pair electrons stay as far away from each other as possible.
   (d) both bonding and non-bonding pair electrons stay as far away from each other as possible.

6. Consider the following substances in the molten (liquid) state:

   **I** $C_{10}H_{22}$ **II** $NH_3$ **III** $CH_3C\ell$ **IV** $N_2$

   Which of the above substances have only dispersion forces between their molecules?
   (a) None of the above
   (b) **II** and **IV** only
   (c) **II** and **III** only
   (d) **I** and **IV** only

7. Which of the following is the weakest type of molecular force or bond?
   (a) Hydrogen bond
   (b) Dipole-Dipole force
   (c) Dispersion force
   (d) Covalent bond

8. Which of the following is **not** a unit of gas pressure?
   (a) mmHg (b) N (c) atm (d) Pa

9. Which of the following is true?
   (a) The molar volume of a gas at STP is 24.5 L.
   (b) Gas volume is directly proportional to gas pressure.
   (c) Temperature and gas pressure are inversely proportional.
   (d) Gas pressure and temperature are directly proportional.

10. Kinetic energy of particles in a reaction is a measure of?
    (a) Temperature
    (b) Pressure
    (c) Volume
    (d) Heat

11. Which of the following solutions has the lowest freezing point and the highest boiling point?
    (a) 0.100 mol $L^{-1}$ sucrose (1) concentration of particles = 0.100M
    (b) 0.050 mol $L^{-1}$ $CaCl_2$ (3) ✓ ✓ ✓ = 0.150M
    (c) 0.050 mol $L^{-1}$ NaCl (2) ✓ ✓ ✓ = 0.100M
    (d) Distilled water (0) ✓ ✓ ✓ = 0

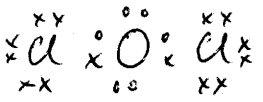
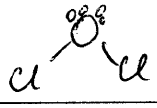
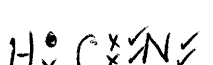
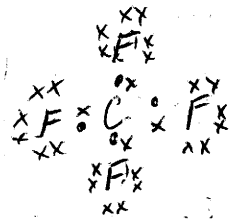
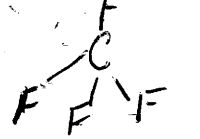
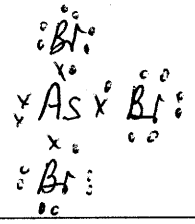
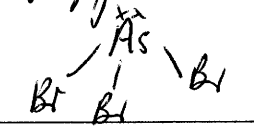
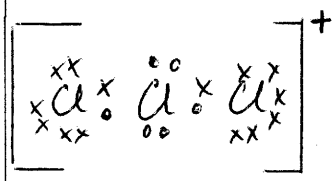
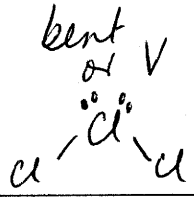
12. A test tube contains a clear, colourless salt solution. A few drops of lead nitrate solution are added to the solution and a yellow precipitate forms. Which one of the following salts was dissolved in the original solution?
    (a) NaI (b) KC$\ell$ (c) $K_2CO_3$ (d) $K_2SO_4$

    $PbI_2$ – bright canary yellow.

**Section 2: Short answer**

**Answer all questions in the spaces provided.** **(31 marks)**

1. Complete the following table for the listed molecules. Include any lone pairs of electrons that influence the shape. (7 marks)

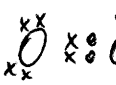
| Molecule | Electron Dot Diagram | Shape | Dominant Intermolecular Force |
|---|---|---|---|
| $Cl_2O$ |  | bent or V  | Dipole - dipole |
| Hydrogen cyanide |  | linear H − C ≡ N | Dipole - dipole [Note: Not H bonding since H not bonded to N.] |
| $CF_4$ |  | tetrahedral  | Dispersion forces [Note: each bond is polar but no net polarity] |
| $AsBr_3$ ↑ group 15 (or N) |  | (Trigonal) pyramidal  | Dipole - Dipole |
| $Cl_3^+$ |  | bent or V  | NOT REQUIRED [Note: NOT ion-dipole which requires a charged ion and a polar molecule.] |

2. Briefly explain the following, using diagrams where appropriate:

(a) Some covalent bonds are polar and some are non-polar. (3 marks)

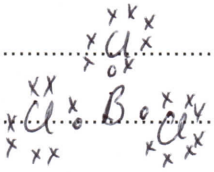
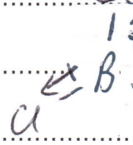
Polarity depends on the electronegativity of the atoms in the molecule.

The more electronegative the atom the more it attracts the shared pair of electrons, causing the e⁻ pairs to be unevenly shared. This results in a polar bond.

Non polar: H:H and  ; polar: 

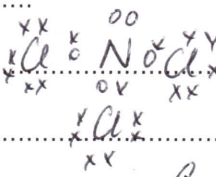
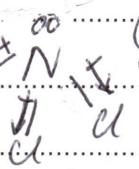
H−H O=O H→Cl

(b) The molecule boron trichloride is non-polar but nitrogen trichloride is polar. (6 marks)

$BCl_3$   ✓(½) Shape: planar triangular and symmetrical ✓

✓(½)

Each of the bonds is polar, as shown, but there is no net dipole as all polarities cancel.

$NCl_3$   ✓(½) Shape: pyramidal (trigonal) ✓

✓(½)

Each of the bonds is polar, as shown, but the polarities do not cancel, due to the lone pair, resulting in a net dipole.

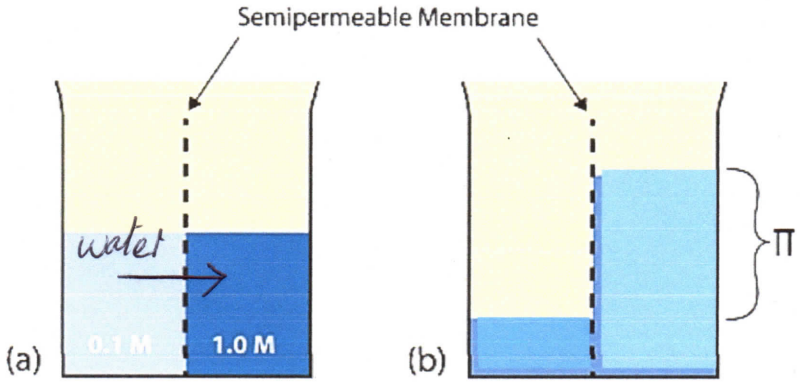
(c) Gases diffuse quickly. Refer to the Kinetic Theory of Gases in your answer. (3 marks)

1. Gas molecules are in rapid random straight line motion
2. Collisions between molecules & surfaces are elastic.

These 2 Kinetic Theory statements explain why gas molecules quickly fill the container & hence diffuse through a region quickly.

3. Consider the diagram shown. Two salt solutions of differing concentrations are placed on either side of a semipermeable membrane.

The pressure exerted by the different height of the solution on the right is called the osmotic pressure, π.




(a) What is the name of the process illustrated? (1 mark)

Osmosis

(b) On the diagram (a) show the name and the direction of movement of the liquid molecules that selectively pass through the membrane. (2 marks)

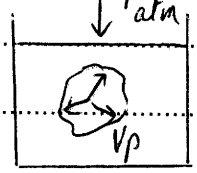
(c) When the osmotic pressure exerted by the different height of the solution on the right is stable, state the concentration of the solutions. (1 mark)

The concentrations will be equal at $\left(\frac{0.1+1.0}{2}\right) = 0.55\ mol\ L^{-1}$

(d) Give an application of a form of the process illustrated. (1 mark)

Reverse osmosis is used in desalination of salt water.

4. (a) Explain why water boils at only 71°C at the top of Mt Everest. (3 marks)




Boiling occurs when the vapour pressure of the gas in any bubble that forms in the liquid equals the external pressure acting on it, usually the Patm when in shallow water. Vapour pressure depends only on temperature. On Mt Everest, the Patm is lower ⇒ lower V.P ⇒ lower temp.

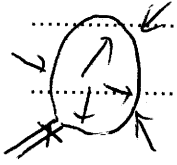
(b) When pure water is heated, the temperature rises until it begins to boil and the temperature remains constant until all the water is evaporated. When a salt solution is heated, the temperature continues to rise even after it begins to boil. Why? (3 marks)

In a salt solution the BP is higher than for pure water. The salt ions form an attraction with the water molecules making it more difficult to form water vapour bubbles that can rise to the surface. Since VP depends only on temp, the higher VP needed to form bubbles requires a higher temp. As the water boils away the salt becomes more concentrated, so even higher temps are needed

5. (a) Explain how volume of a gas affects pressure at a set temperature. (2 marks)

Boyles Law $PV = constant$ So $P \propto \frac{1}{V}$ ✓

Pressure is due to the collisions of the gas ($\frac{1}{2}$) particles with the walls of the container. The pressure inside the balloon (flexible container) will cause the container to expand ∴ increase in volume until the internal pressure equals ($\frac{1}{2}$) the external pressure.



(b) Calculate the partial pressure of the oxygen when 1 mole of oxygen and 2 moles of nitrogen are the only two gases in a container where the total pressure is 450 kPa. (2 marks)

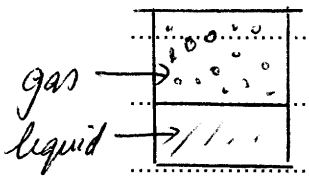
Because the gas particles are very far apart they act independently in exerting pressure.

∴ 3 mole → 450 kPa

$O_2$: 1 mol → x

∴ Partial Pressure of $O_2$ = 150 kPa.

6. The vapour pressure for water is 2.34 kPa at 20°C while the vapour pressure of acetone ($CH_3COCH_3$) is 24.6 kPa at 20°C. Explain what vapour pressure is and why water and acetone have such different values. (5 marks)




The vapour pressure of a gas is defined as the pressure exerted by the vapour when in equilibrium with its liquid phase at a given temp in a closed system.

The greater the strength of the intermolecular forces in the liquid the lower the V.P. Water has H-bonding between molecules. Acetone has dipole-dipole forces between molecules. As H-bonds are stronger than dipole-dipole forces the VP for $H_2O$ < VP for acetone. (and acetone is ∴ more volatile)

**Section 3: Calculations** **(16 marks)**

Answer all the questions in the spaces provided. All numerical answers should be given to 3 significant figures.

7. What mass of solid NaOH would be required to prepare 100 mL of a 0.15 M NaOH solution? (2 marks)

$n = cV = 0.15 \times 0.100 = 0.015$ mol

$n = \frac{m}{M}$ ; $m = nM$

$= 0.015 \times (22.99 + 16 + 1.008)$

$= 0.600$ g of NaOH

8. A beaker contains 345 mL of a 1.50 mol $L^{-1}$ NaCℓ solution. If the salt solution is boiled until the volume of the solution is 250 mL, what will the molarity of the solution be? (2 marks)

Dilution : $n_{before} = n_{after}$

$C_b V_b = C_a V_a$

$1.50 \times 345 = C_a \times 250$

$\therefore C_{after} = 2.07 \text{ mol L}^{-1}$

9. How much water would need to be added to 500 mL of a 2.40 mol $L^{-1}$ KCl solution to make a 1.0 mol $L^{-1}$ solution? (2 marks)

Dilution $n_{before} = n_{after}$

$C_b V_b = C_a V_a$

$2.40 \times 500 = 1.0 \times (500 + V_{added})$

$\therefore 1200 = 500 + V_{added}$

$\therefore V_{added} = 700 \text{ mL} = 0.700 \text{ L}$

10. What mass of carbon dioxide gas will be produced when 5.00 L of propane at STP combusts in plentiful air? (5 marks)

$C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(g)}$

m: 1 mol $\rightarrow$ 3 mol

$C_3H_8$: $n = \frac{V}{22.71} = \frac{5}{22.71} = 0.2202 \text{ mol}$

$\therefore n_{CO_2} = 0.2202 \times 3 = 0.6606 \text{ mol}$

$n = \frac{m}{M}$ ; $m = nM$

$= 0.6606 \times (12.01 + 32)$

$= 29.0687 \text{ g}$

$\therefore$ mass of $CO_2 = 29.1 \text{ g}$ at STP

11. What pressure will be exerted by 20.16 g of hydrogen gas in a 7.50 L cylinder at 20.0°C? (3 marks)

$n_{H_2} = \frac{m}{M} = \frac{20.16}{(2 \times 1.008)} = 10 \text{ mol}$

$PV = nRT$

$P \times 7.5 = 10 \times 8.314 \times (273.15 + 20)$

$P = 3249.6 \text{ kPa} = 3250 \text{ kPa}$ (3sf)

**Section 4: Extended Answer**

**Answer all questions in the spaces provided.** **(71 marks)**

12. (a) Write a balanced ionic chemical equation for the reaction when 0.5 mol $L^{-1}$ iron (III) sulfate solution and 0.5 mol $L^{-1}$ sodium hydroxide solution are mixed. State the expected observations. (2 marks)

$Fe^{3+}_{(aq)} + 3OH^-_{(aq)} \rightarrow Fe(OH)_{3(s)}$

A brown soln is added to a colourless soln & a rust brown ppt forms.

(b) When an excess of silver nitrate solution was added to 10.0 mL of sodium chloride solution, 0.780 g of silver chloride was precipitated.

(i) Write a balanced ionic chemical equation for the reaction. State the expected observations. (2 marks)

$Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$

Two colourless solns are mixed and a white ppt forms. (The ppt darkens in sunlight.)

(ii) Find the concentration of the sodium chloride solution in mol $L^{-1}$. (3 marks)

1 mol AgCl contains 1 mol $Ag^+$

AgCl: $n_{AgCl} = \frac{m}{M} = \frac{0.780}{(107.9 + 35.45)} = 0.0054 \text{ mol}$

NaCl: 1 mol NaCl soln contains 1 mol $Cl^-_{(aq)}$

$n = CV \therefore 0.0054 = C(10 \times 10^{-3})$

$C = 0.5441 \text{ mol L}^{-1} = 0.544 \text{ mol L}^{-1}$ (3sf)

13. Fluorine forms compounds with many other elements.

(a) Fluorine reacts with bromine to form liquid bromine trifluoride ($BrF_3$).
State the type of bond between Br and F in $BrF_3$ and state how this bond is formed.

Type of bond: Covalent

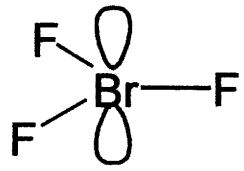
How bond is formed: Electron pairs are shared

(2 marks)

(b) Two molecules of $BrF_3$ react to form ions as shown by the following equation.

$$2BrF_3 \longrightarrow BrF_2^+ + BrF_4^-$$

The shape of $BrF_3$ is given where the lobes represent lone pairs of electrons.




(i) Suggest the shape of $BrF_3$.

Planar triangular

(ii) Predict its bond angle.

120°

(2 marks)

(c) $BrF_4^-$ ions are also formed when potassium fluoride dissolves in liquid $BrF_3$ to form $KBrF_4$. Explain, in terms of bonding, why $KBrF_4$ has a high melting point. (3 marks)

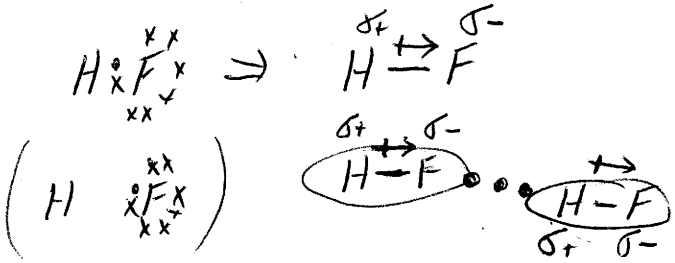
$KBrF_4$ exhibits ionic bonding. It forms an array of alternating positive + negative ions with strong electrostatic bonding between ions. This strong bonding requires a large amount of heat to disrupt the bond + so the MP is high.

(d) Fluorine reacts with hydrogen to form hydrogen fluoride (HF).

(i) State the strongest type of intermolecular force between hydrogen fluoride molecules. (1 mark)

Hydrogen bonding

(ii) Draw a diagram to show how two molecules of hydrogen fluoride are attracted to each other by the type of intermolecular force that you stated in part (d) (i).
Include all partial charges and all lone pairs of electrons in your diagram. (3 marks)



(e) The boiling points of fluorine and hydrogen fluoride are –188°C and 19.5°C respectively. Explain, in terms of bonding, why the boiling point of fluorine is very low. (2 marks)

$F_2$ has only dispersion forces between the molecules. Also the $F_2$ molecule is small, so the dispersion forces are very weak. Heat will easily disrupt the bond - so the BP will be very low. [Note: The $F_2$ molecule is larger than the HF molecule, so the dispersion forces for $F_2$ > HF but the H-bonding in HF far exceeds the dispersion forces of $F_2$ in strength.]

14. The metal lead reacts with warm dilute nitric acid to produce lead (II) nitrate, nitrogen monoxide and water according to the following equation.

$$3Pb(s) + 8HNO_3(aq) \longrightarrow 3Pb(NO_3)_2(aq) + 2NO(g) + 4H_2O(l)$$

(a) In an experiment, an 8.14 g sample of lead reacted completely with a 2.00 mol $dm^{-3}$ solution of nitric acid. Calculate the volume of nitric acid required for complete reaction. (3 marks)

Pb (less): $n_{Pb} = \frac{m}{M} = \frac{8.14}{207.2} = 0.0393$ mol ($dm^3 = L$)

$HNO_3$ (more): $n_{HNO_3} = 0.0393 \times \frac{8}{3} = 0.1048$ mol

$n = cV$; $V = \frac{n}{c} = \frac{0.1048}{2} = 0.0524\ dm^3$ $= 52.4$ mL ($52.4\ cm^3$)

(b) (i) Determine the number of moles of NO(g) expected to be produced from the reaction of 8.14 g sample of lead in (a). (1 mark)

$n_{NO} = \frac{2}{3} n_{Pb} = \frac{2}{3}(0.0393) = 0.0263$ mol of NO

(ii) The nitrogen monoxide gas produced in the reaction occupied 638 $cm^3$ at 101 kPa and 25°C. The vapour pressure of water vapour at 25°C is 7.31 kPa. Calculate the amount, in moles, of NO gas produced. Hence determine the percentage yield of the reaction. (4 marks)

$P = (101 - 7.31)$ kPa $= 93.69$ kPa

$PV = nRT$

$n = \frac{PV}{RT} = \frac{93.69 \times 0.638}{8.314 \times (273.15 + 25)}$

$= 0.0241$ mol

$\therefore$ % yield $= \frac{0.0241}{0.0263} \times 100 = 91.7\%$

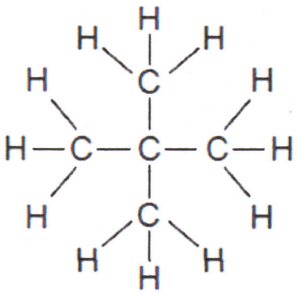
15. (a) The following table shows the boiling points of some straight-chain alkanes.

| | $CH_4$ | $C_2H_6$ | $C_3H_8$ | $C_4H_{10}$ | $C_5H_{12}$ |
|---|---|---|---|---|---|
| Boiling point / °C | −162 | −88 | −42 | −1 | 36 |

Explain the trend in the boiling points of these straight-chain alkanes. (3 marks)

With the addition of $CH_2$ homolog the C chain gets longer with increases the surface area of each progressive molecule. The larger the surface area (& number of $\bar{e}$) the greater the strength of the dispersion forces. The greater the strength of bond the higher the BP.

(b) The following compound X is an isomer of one of the alkanes in the table.



$CH_3C(CH_3)_2CH_3$

(pentane)

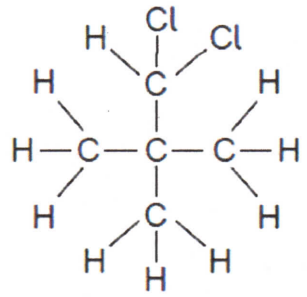
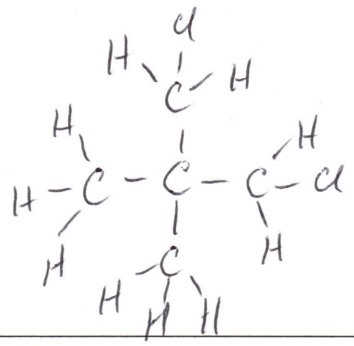
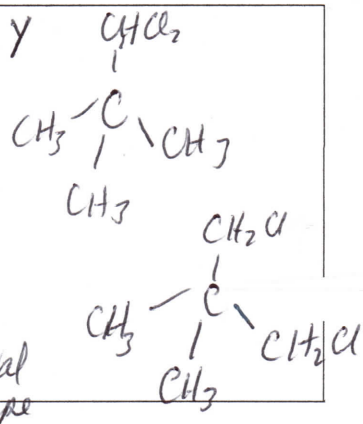
(i) Give the IUPAC name of X. (1 mark)

dimethyl propane

(ii) X has a boiling point of 9.5 °C.
Explain why the boiling point of X is lower than that of its straight-chain isomer. (2 marks)

The shape of X is more spherical than the straight chain $C_5H_{12}$. A spherical shape has a smaller surface area than a straight chain. A smaller surface area results in weaker dispersion forces, hence a lower BP.

(iii) The following compound Y is produced when X reacts with chlorine.

| Y | |
|---|---|
|  |   tetrahedral shape |

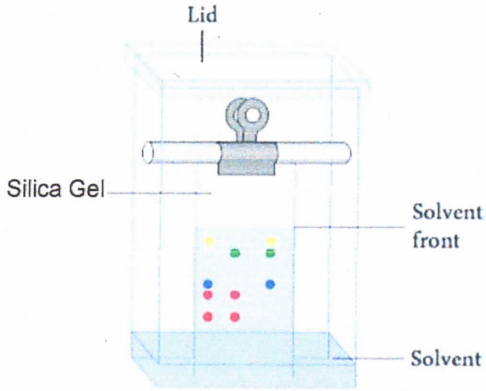
In the space provided, draw the other position isomer/s of Y that can be formed. (2 marks)

Only 1 isomer possible since can easily twist around a single bond.

Describe and explain the trend in the boiling points of these position isomers of Y. (3 marks)

Y has both Cl attached to same C atom which will result in Y being more polar than its isomer which has the Cl atoms attached to different C atoms. Hence the dipole-dipole bonds will be stronger in X than in isomer, so BP for X will be higher.

16. The following diagram shows a chromatography technique.




(a) Chromatography separates components of a mixture.

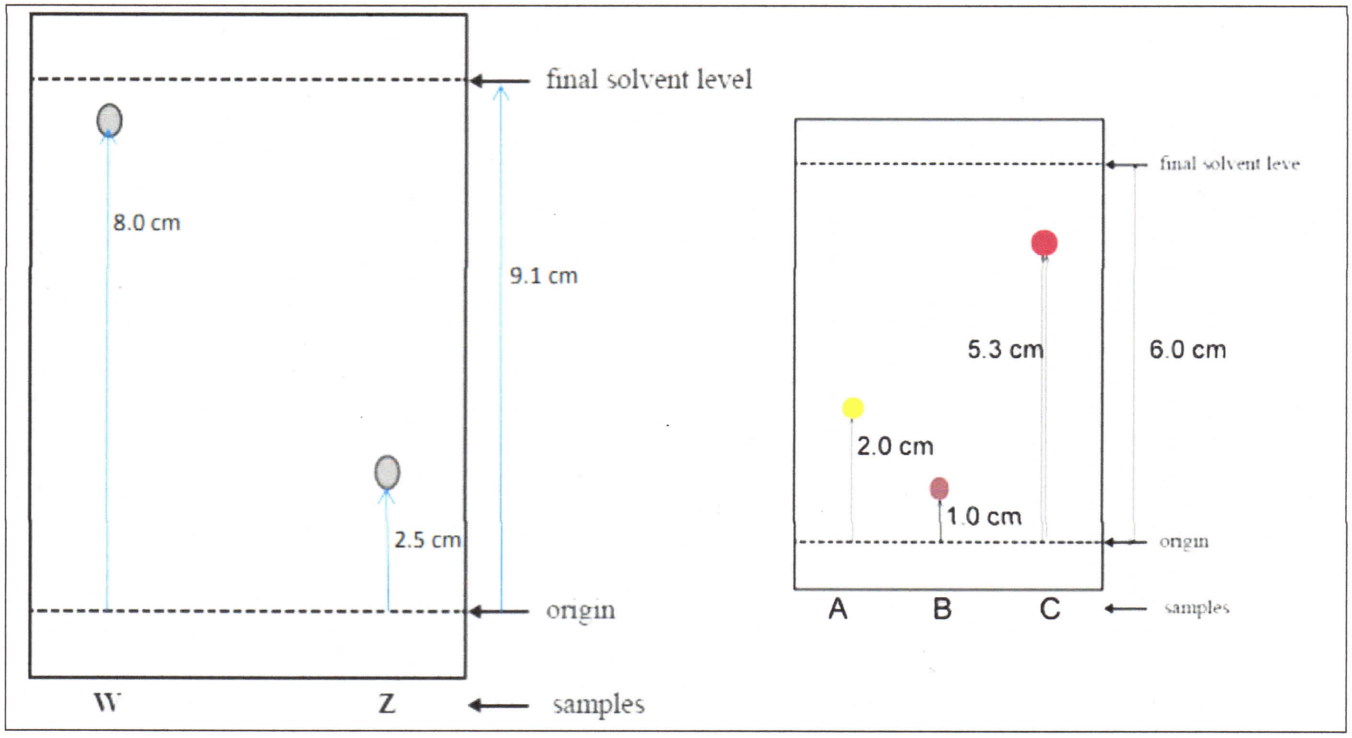
Explain the basic principals involved. (3 marks)

1. One component is the stationary phase
2. Another component is the mobile phase which moves an carries the substance along the stationary phase.
3. Different analytes travel along at different rates.
4. Due to polarity different analytes will adsorb at different distances, or times, on the stationary phase.

(b) What is the name of the chromatography technique shown in the diagram above? Give an example of the type of molecule which is suitable for this type of chromatography. (2 marks)

Thin layer chromatography or paper chromatography TLC is suitable for organic mixtures such as plant pigments + drugs.

(c) Two different food dye samples, W and Z were compared using thin layer chromatography as shown below.




(iii) Calculate the $R_f$ value of W and Z (3 marks)

$R_f$ = distance travelled by component / distance of solvent front.

W: $R_f = \frac{8}{9.1} = 0.88$ Z: $R_f = \frac{2.5}{9.1} = 0.27$

(ii) Which dye, W or Z, is more strongly adsorbed? (1 mark)

Z is more strongly adsorbed since it moves less.

(iii) Explain how dyes W and Z can be identified? (2 marks)

The Rf value is the same in the same solvent & solvent concentration. The Rf values obtained are compared to known Rf values for each substance, so W + Z can be identified.

(iv) On the right is another chromatogram of a food substance containing food dye. Is dye "W" present? Explain. (3 marks)

Sample A $R_f = \frac{2}{6} = 0.33$

Sample B $R_f = \frac{1}{6} = 0.17$

Sample C $R_f = \frac{5.3}{6} = 0.88$

YES, Sample C contains Dye W since $R_f$ is same.

(d) What is the difference in $R_f$ and $R_t$? Where would $R_t$ be used? (2 marks)

$R_f$ is a ratio of the distances moved by the fronts. $R_f$ is used in paper & TLC.

$R_t$ is the retention time & is a measure of the time taken for a solute the pass through a chromatography column, (from injection to detection).

$R_t$ is used in Gas Chromatography & HPLC.

17. Consider the following Figure 1. It shows the standard retention time for a set of various substances passed through a gas chromatography process.

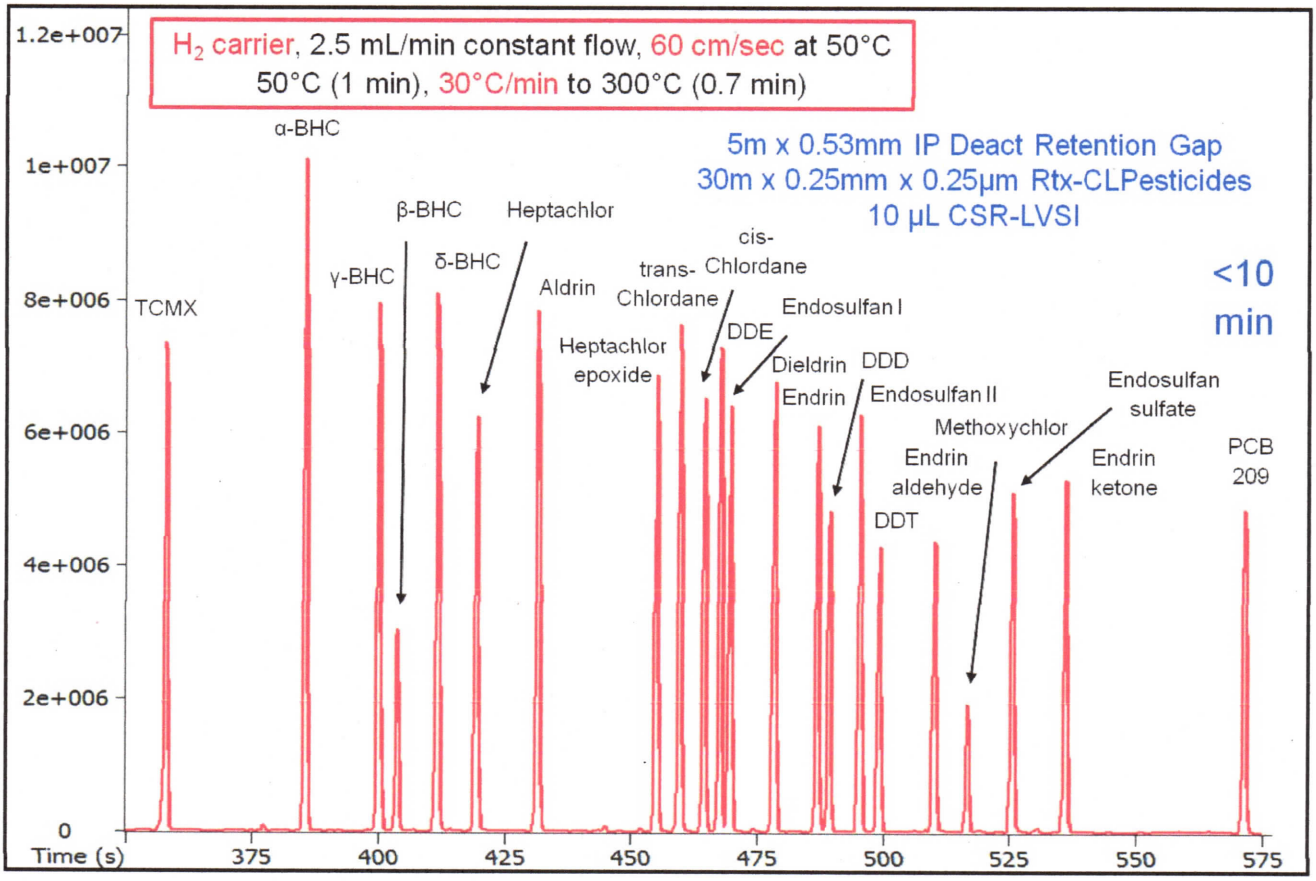



**Figure 1**

The following Figure 2 shows the gas chromatograph of a tested sample.

Convert time from min to sec

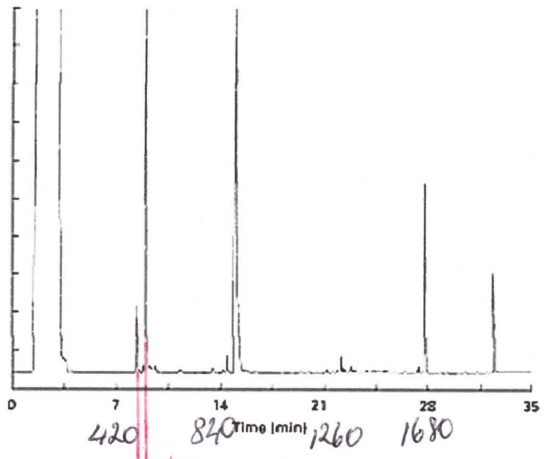



**Figure 2**

(a) Use Figures 1 and 2 to identify one substance in the sample. Show your working clearly. (3 marks)

Only the 2 peaks shown are within the given range.

Fig 2: Consider peak ① shown, $R_t \cong 8.75$ min = 525 s.

Fig 1: Peak ① is suggested to be Endosulfan sulfate

Peak ② " " " Methoxychlor

(b) The following Figure 3 shows the Calibration curve of absorbance vs concentration for the substance found in (a).

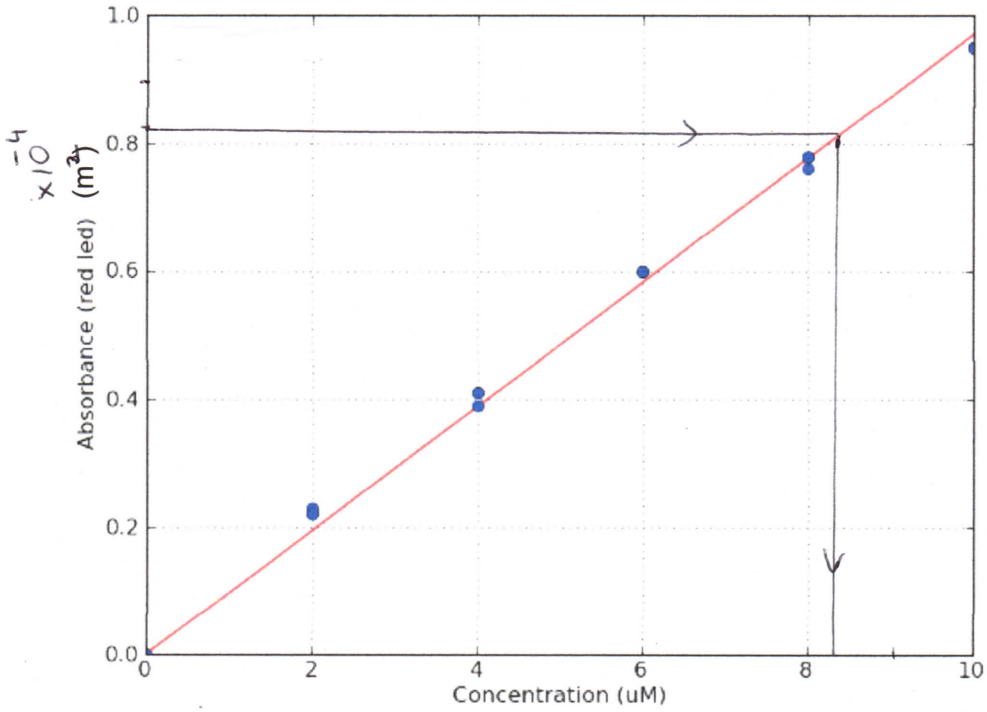



**Figure 3**

The following Figure 4 shows the enlarged and measured peak of the substance found in (a).

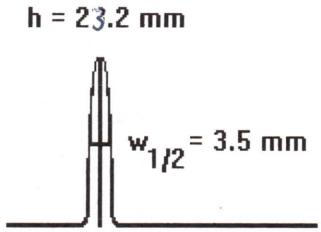



**Figure 4**

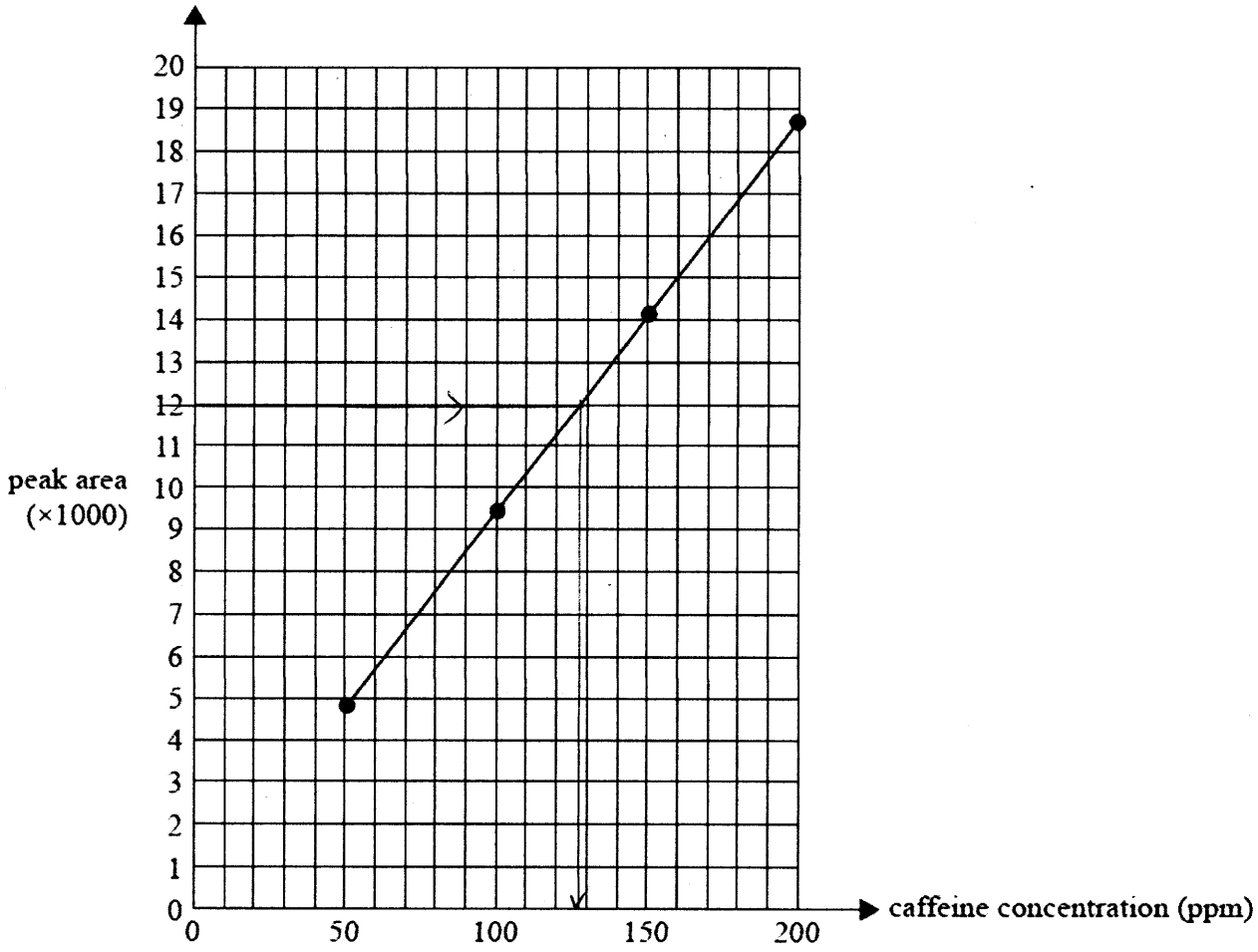
Use Figures 3 and 4 to determine the concentration of the substance in the sample. Show your working clearly. (3 marks)

Area of peak ≈ triangle = $\frac{1}{2} b \times h$ = 3.5 mm × 28.2 mm
= $3.5 \times 10^{-3} \times 23.2 \times 10^{-3}$ = $8.12 \times 10^{-5}$ $m^2$
= $0.812 \times 10^{-4}$ $m^2$

∴ From graph Concentration = 8.2 μM. (2nd from graph)

18. Caffeine is a stimulant drug that is found in coffee, tea, energy drinks and some soft drinks. The concentration of caffeine can be determined using HPLC. Four caffeine solutions containing 50 ppm, 100 ppm, 150 ppm and 200 ppm were prepared. 25 microliters of each sample was injected into the HPLC column. The peak areas were measured and used to construct the calibration graph below. The chromatograms of the standard solution each produced a single peak at a retention time of 96 seconds.

Graph: Peak area of caffeine standard solutions: retention time = 96 seconds




25 micro-litre samples of various drinks thought to contain caffeine were then separately passed through the HPLC column. The results are shown below.

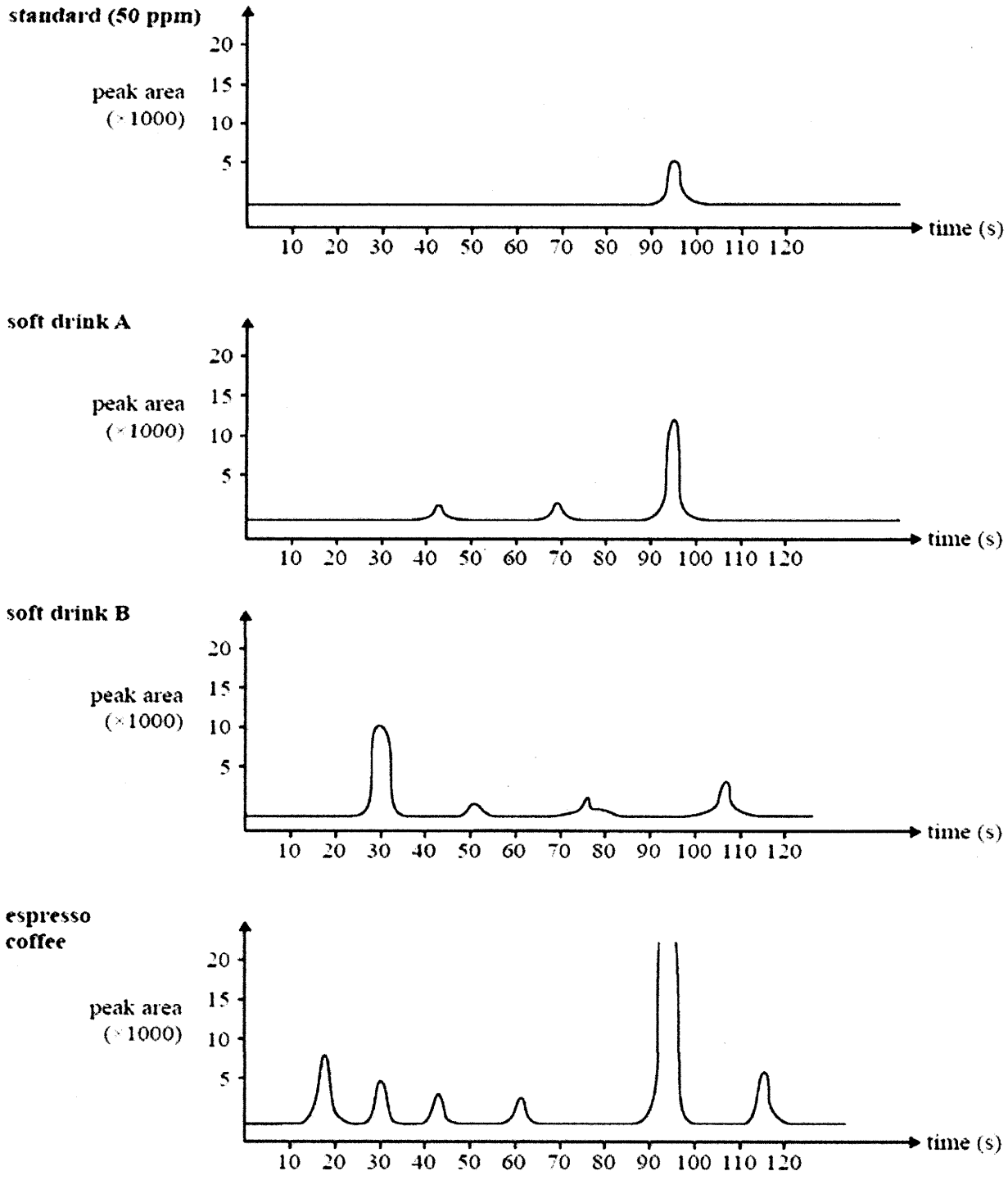
| Sample | Retention time of major peak (seconds) | Peak area of largest peak |
|---|---|---|
| Soft drink A | 96 | 12000 |
| Soft drink B | 32 | 8 500 |
| Espresso coffee | 96 | 211000 |

(a) Determine the caffeine content in ppm for drink A. (1 mark)

From graph: caffeine conc = 127 ppm

The chromatographs of the various drinks thought to contain caffeine are shown below.

**Chromatograms of 50 ppm standard caffeine solution, soft drink A, soft drink B and espresso coffee**




(b) What evidence is presented in the chromatogram that supports the conclusion that soft drink B does not contain any caffeine? (2 marks)

There is no peak at a $R_f$ of 96s. $R_f$ is characteristic of a solute so no caffeine is present.

(c) Explain why the caffeine content of the espresso coffee sample cannot be reliably determined using the information provided. (2 marks)

The caffeine peak area is beyond the range of the calibration graph. Extrapolation outside the range of the standard solns will not be accurate.

(d) Describe what can be done to the espresso coffee sample so that its caffeine content can be reliably determined using the information provided. (2 marks)

Dilute the espresso coffee sample (by factor > 12) to bring its caffeine concentration within the range of the calibration curve.