Chapter 2 – Purification of Substances

(A) Pure Substances

1. What is a pure substance?

- A pure substance is a single substance not mixed with anything else.

2. Give two examples of pure substances.

- White sugar
- Crystals

3. What is a mixture?

- A mixture contains two or more substances.

Comment:

√ *A mixture is not pure, as it comprises more than one substance.*

4. Fill in the blank:

_____ is the process of separating mixtures into pure substances.

- Purification

(A1) Effects of Impurities on Pure Substances

(A1.1) Solids

5. State one characteristic of a pure solid.

- Fixed melting point

6. How do impurities affect a solid's melting point?

- Impurities lower the melting point.
- Impurities cause the solid to melt over a range of temperature.

Comment:

√ *For instance, pure ice melts at 0°C. However, the presence of impurities will cause ice to melt:*
  - *below 0°C (e.g. - 2°C)*
  - *over a range of temperature (e.g. it starts melting at -2°C and then continues to melt till 0°C)*

(A1.2) Liquids

7. State one characteristic of a pure liquid.

- ❖ Fixed boiling point

8. How do impurities affect a liquid's boiling point?

- ❖ Impurities raise the boiling point.
- ❖ Impurities cause the liquid to boil over a range of temperature.

Comment:

√ *For instance, petrol fuel is a mixture (i.e. not a pure substance) and has a boiling point range of 35°C to 75°C. This means it starts boiling at 35°C, with the temperature continuously rising to 75°C as it keeps boiling.*

9. What is the relationship between the amount of impurities in a substance and the substance's melting / boiling point?

- ❖ The greater the amount of impurities, the lower the melting point.
- ❖ The greater the amount of impurities, the higher the boiling point.

Comment:

√ *For example, the melting point of pure ice is 0°C. If a piece of ice is contaminated with a little impurity, its melting point could drop to -1°C. If the same piece of ice is further mixed with even more impurities, its melting point will become increasingly lower, such as -2°C, -3°C, etc.*

(A2) Tests of a Substance's Purity

10. State three methods that can be used to determine whether a substance is pure.

- ❖ Melting point comparison
- ❖ Boiling point comparison
- ❖ Chromatography

Comment:

√ *Chromatography will be covered later in this chapter.*

11. You are given a substance labelled X. Describe an experiment how you can determine the purity of substance X, given that the melting point of this element is 80°C.

- ❖ The substance is heated.
- ❖ The temperature of the substance is recorded at regular time intervals.
- ❖ During the heating, the thermometer will show a constant temperature for a few minutes. This is the melting point of the solid.
- ❖ If the melting point obtained is 80°C, then the substance is pure.

(A3) Identifying Substances

12. In addition to testing the purity of a substance, what can the methods of melting / boiling point comparison and chromatography be used for?

- ❖ Used for determining the identity of a substance.

13. A substance is found to melt at 0°C and boil at 100°C. What might be the identity of the substance?

- ❖ Water.

Comment:

√ *Pure water always melts at 0°C and boils at 100°C. Since the substance has the same melting and boiling points, it must be water.*

(B) Purification Methods

14. State seven methods of separating mixtures.

- Filtration
- Crystallisation
- Evaporation
- Distillation
- Sublimation
- Use of a separating funnel
- Chromatography

(B1) Filtration

15. When is filtration used?

- To separate an insoluble solid from a solution.
- To separate two solutes in which one can dissolve in a solvent.

16. Give an example of:

(a) An insoluble solid in a solution;

- Sand in water.

Comment:

√ *Another example is chalk particles in water.*

(b) Two solutes in which one can dissolve in a solvent.

- Sand and sodium chloride in water.

Comments:

√ *Sodium chloride is typically referred to as "common salt". It is used in cooking and is found in sea water.*

√ *Sodium chloride dissolves in water, whereas sand remains insoluble. Thus by adding water and then using filtration, both solutes can be separated.*

17. Fill in the blanks:

(a) The solid which remains on the filter paper when a suspension is filtered is called the _____.

- ❖ residue

(b) The liquid or solution that passes through the filter paper is called the _____.

- ❖ filtrate

18. State whether the following salts are soluble or insoluble:
(Present your answer in the form of a table.)

- **Sodium salts**
- **Potassium salts**
- **Ammonium salts**
- **Nitrates**
- **Chlorides**
- **Sulphates**
- **Carbonates**

❖ Answer:

Soluble salts	Insoluble salts
All sodium salts	
All potassium salts	
All ammonium salts	
All nitrates	
All chlorides	Except → Silver chloride, Lead(II) chloride
All sulphates	Except → Barium sulphate, Lead(II) sulphate, Calcium sulphate (sparingly soluble)
Sodium carbonate, Potassium carbonate, Ammonium carbonate	Except → All carbonates

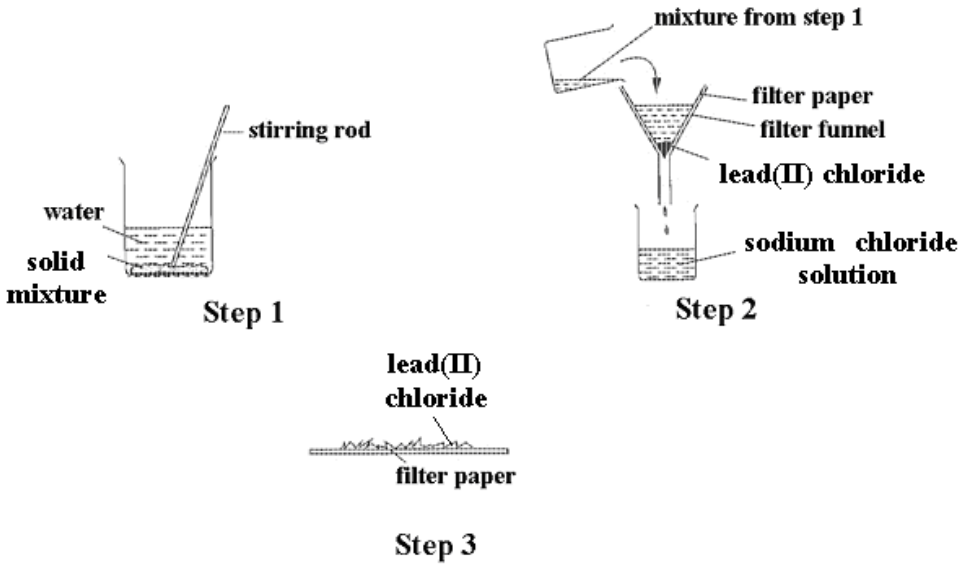
Comments:

√ *The above list enables us to determine which compounds are soluble and which insoluble, and thus in whether filtration can be used to separate a mixture.*

√ *The above list will be discussed again in Chapter 12 – Salts. If you cannot remember the entire list now, it is not a major concern.*

19. With the aid of diagram(s), describe how you can obtain lead(II) chloride from a solid mixture of lead(II) chloride and sodium chloride. [You are not required to obtain sodium chloride.]

❖



- ❖ Distilled water is added to the mixture. Sodium chloride dissolves but lead(II) chloride does not.
- ❖ The mixture is filtered. Sodium chloride solution is the filtrate, and lead(II) chloride is the residue.
- ❖ The residue of lead(II) chloride is washed with distilled water and dried by pressing it on sheets of filter paper.

Comment:

√ *In this case, we have two solutes in which one can dissolve in a solvent (water), while the other remains insoluble.*

(B2) Crystallisation

20. When is crystallisation used?

- ❖ To separate a dissolved solid from a solution.

21. Give an example of a dissolved solid in a solution.

- ❖ Copper(II) sulphate powder dissolved in water to form copper(II) sulphate solution.

22. Fill in the blanks:

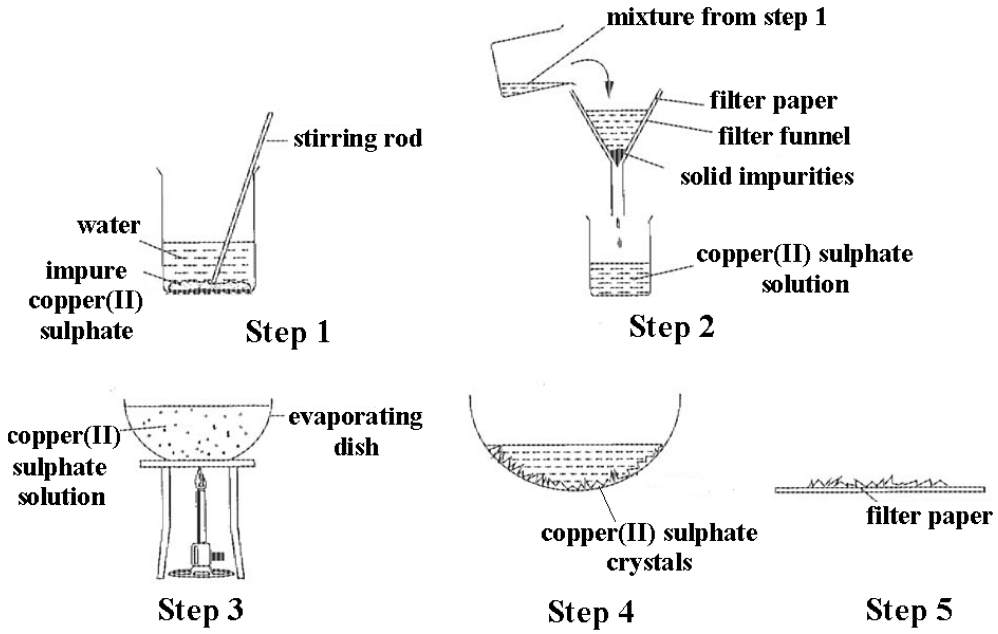
Crystallisation will result in the formation of pure _____ from a _____ solution.

- crystals
- saturated

23. What is a saturated solution?

- A saturated solution is one that contains the maximum amount of dissolved solute at a given temperature.

24. With the aid of diagram(s), describe how you can obtain pure copper(II) sulphate crystals from an impure sample of solid copper(II) sulphate.



- Distilled water is added to the sample of copper(II) sulphate. The copper(II) sulphate dissolves to form a solution.
- The solution is filtered to remove any impurities.
- The filtrate of aqueous copper(II) sulphate is then transferred into an evaporating dish and heated over a Bunsen flame until the solution is saturated. To test for saturation, a glass rod is dipped into the mixture; if the solution is saturated, crystals will form on the glass rod.
- The solution is left to cool for crystallisation to take place.
- The solution is then filtered, and the copper(II) sulphate crystals rinsed with distilled water and dried between sheets of filter paper.

(B3) Evaporation

25. When is evaporation used?

- ❖ To separate a dissolved solid from a solution.

Comment:

√ *Evaporation is similar to crystallisation, the only difference being that evaporation involves the complete vaporisation of the solvent from the solution.*

26. Give an example of a dissolved solid in a solution.

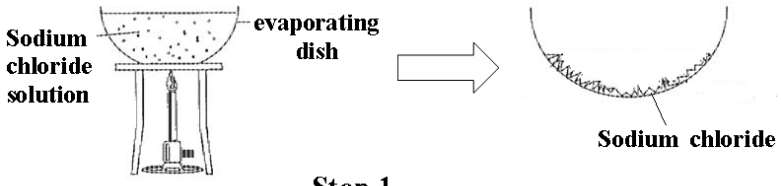
- ❖ Sodium chloride dissolved in water.

27. Some salts are obtained through crystallisation from a saturated solution while others are heated and evaporated to dryness. Describe one factor that determines the choice of method.

- ❖ Decomposition of the solute when heated to dryness.
  - o If the solute decomposes when heated to dryness, crystallisation will be used as this method prevents the solute from being excessively heated and becoming decomposed.
  - o If the solute does not decompose when heated to dryness, evaporation will be used.

28. With the aid of diagram(s), describe how you can obtain solid sodium chloride from sea water.

- ❖



Step 1

Step 2

- ❖ The sea water is placed in an evaporating dish and heated over a Bunsen flame to dryness. Solid sodium chloride will be left behind in the evaporating dish.
- ❖ The residue of sodium chloride is dried by pressing it on sheets of filter paper.

Comment:

√ *Unlike copper(II) sulphate, sodium chloride does not decompose on heating.*

(B4) Distillation

29. Fill in the blanks:

Distillation is essentially the process of _____ a liquid and _____ the vapour.

- ❖ boiling
- ❖ condensing

30. The apparatus used for distillation includes a distillation flask and a condenser (see question 38 for diagram).

Describe what happens in the distillation flask and condenser during distillation.

- ❖ In the distillation flask, the solution boils. The liquid vaporises and changes into a vapour, which rises and enters the condenser.
- ❖ In the condenser, the vapour condenses and changes back into a liquid (pure).

31. Explain why a distillation flask should not be filled by more than two thirds of its volume with the mixture.

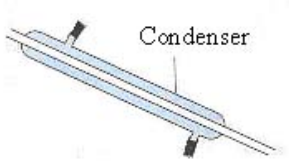
- ❖ This ensures sufficient space above the surface of the mixture.
  - ⇨ Thus, no mixture is spilled / propelled into the condenser to compromise the purity of the distillate.

32. Fill in the blank:

The _____ is the pure liquid that is obtained after its vapour condenses in the condenser.

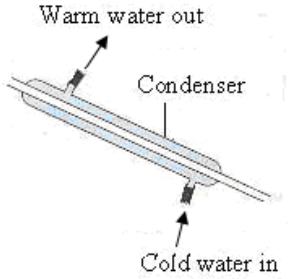
- ❖ distillate

33. The diagram below shows a condenser used in distillation experiments.



(a) Indicate, on the diagram, the flow of water in and out of the condenser.

- Answer:



(b) Give two reasons for your answer in (a).

- The flow of water is such that the coldest part of the condenser is at the end just before the vapour escapes from the condenser. This ensures the most effective cooling of the vapour.
- Having water entering from the bottom and leaving from the top of the condenser ensures that the entire interior of the condenser will be filled with water.

34. Give two reasons why it is preferable to add boiling chips / boiling stones into the mixture in the distillation flask during distillation.

- To prevent overheating of the liquid being distilled.
- To ensure a smooth boiling process.

Comment:

√ *Without boiling chips, a liquid heated in a container can become superheated and "bump" in a sudden, sometimes violent release of vapour. This sudden burp of gas can cause the solution and reagents to be thrown out of the container, possibly causing severe burns, ruining an experiment, or simply making a mess.*

35. When is a water bath used during distillation?

- When the liquid to be heated is flammable.

Comment:

√ *Flammable liquids are those that easily ignite / catch fire. Examples include turpentine and acetic acid.*

(B4.1) Simple Distillation

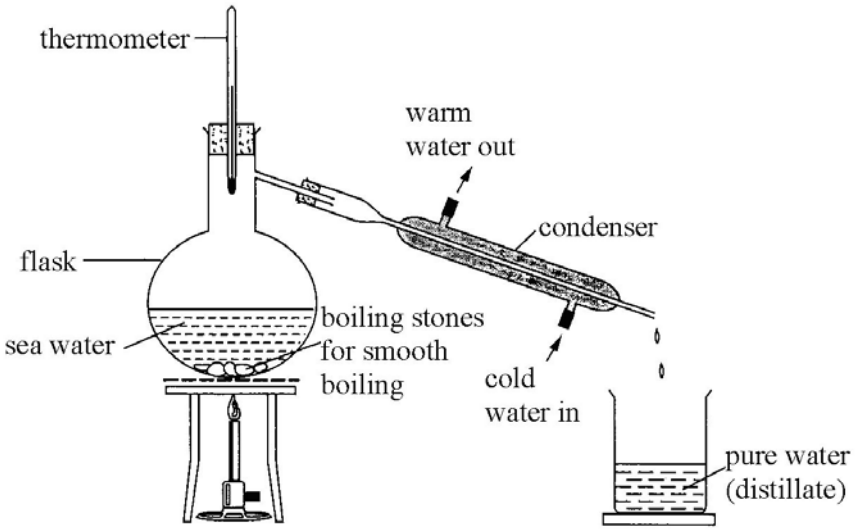
36. When is simple distillation used?

- To separate a solvent from a solution.

37. Give an example of a solvent in a solution.

- Fresh water in sea water.

38. With the aid of diagram(s), describe how you can obtain pure water from sea water by distillation.

- 

- The sea water is poured into a round-bottom flask.
- The flask of sea water is boiled.
- The steam produced is cooled by the condenser.
  - Pure water is obtained as the distillate.
  - The salt remains behind in the flask.

(B4.2) Fractional Distillation

39. When is fractional distillation used?

- To separate a mixture of miscible liquids with different boiling points.

40. Give an example of a mixture of miscible liquids with different boiling points.

- A mixture of ethanol and water.

Comment:

√ *In short, we will use fractional distillation if we need to obtain pure liquids from a mixture of liquids.*

41. What are miscible liquids?

- ❖ Miscible liquids are those that mix completely to form one liquid.

42(a) How can we conclude that oil and water are immiscible?

- ❖ They do not mix well, and will form two separate layers when mixed.

(b) How can we conclude that ethanol and water are miscible?

- ❖ They mix together completely to form a single solution.

43. State the difference in the apparatus used between simple and fractional distillation.

- ❖ In fractional distillation, an additional apparatus – the fractionating column – is attached to the distillation flask and condenser.

44. Fill in the blank:

The fractionating column contains many _____ which provide a large surface area for the condensation of vapour.

- ❖ glass beads

45. State the purpose of the glass beads in a fractionating column.

- ❖ The glass beads provide greater surface area for repeated condensation of vapour and re-boiling of liquids. This ensures a more complete separation of the mixture.

46. State the factor that determines which liquid distills over first during fractional distillation.

- ❖ The liquids' boiling point.

47. Which liquid in a mixture will distill over first during fractional distillation?

- ❖ The liquid with the lowest boiling point.

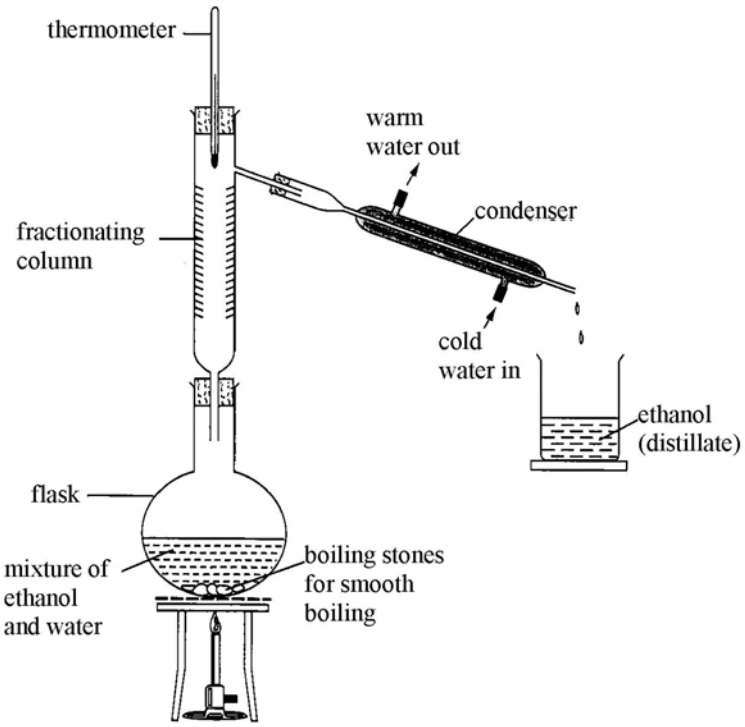
Comment:

√ *This will be followed by the liquid with the next lowest boiling point, and so on.*

48. State five substances that are obtained industrially via fractional distillation.

- Nitrogen
- Argon
- Oxygen
- Petroleum fractions from crude oil
- Alcoholic beverages

49. With the aid of diagram(s), describe how you can separate a mixture of ethanol and water.

- 

- The mixture is poured into a round-bottom flask.
- The mixture is boiled.
- The vapour produced is cooled by the condenser.
    - Ethanol, which has a lower boiling point, distills out at 78ºC and is collected as the first distillate
    - Water, which has a higher boiling point, distills out at 100ºC and is collected as the next distillate.

(B5) Separating Funnel

50. What type of mixture is a separating funnel used to separate?

- A mixture of two immiscible liquids of different densities.

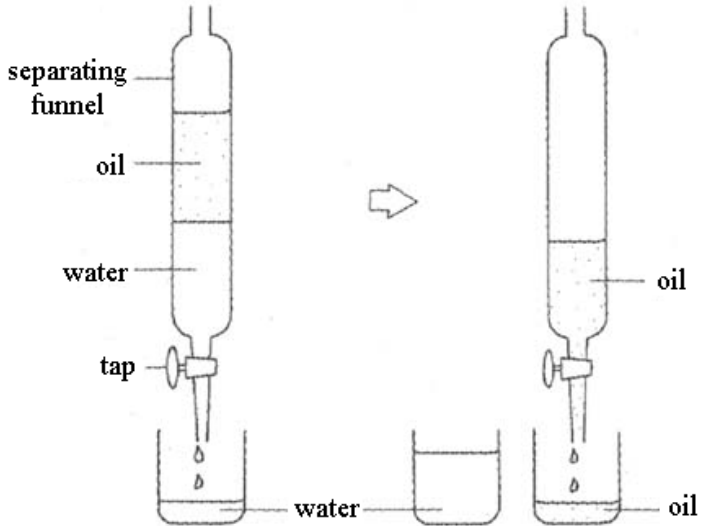
51. Give an example of a mixture of two immiscible liquids of different densities.

- Crude oil and water

52. How can a separating funnel be used to separate a mixture of two immiscible liquids?

- The less dense liquid floats on the denser liquid and the two liquids are collected separately by running them into separate containers.

53. Describe how you can separate a mixture of oil from water.



- The mixture is poured into a separating funnel.
- Oil being less dense, will float on top of water.
- Water is released into a beaker by opening the tap of the separating funnel.
- Oil remains in the separating funnel.

(B6) Sublimation

54. What type of mixture is sublimation used to separate?

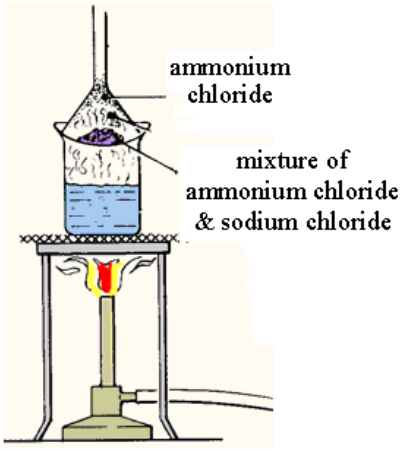
- A mixture of solids where only one of the solids sublimes.

55. Give two examples of mixtures of solids where only one of the solids sublimes.

- Mixture of ammonium chloride and sodium chloride; only ammonium chloride sublimes.
- Mixture of iodine and sodium chloride; only iodine sublimes.

56. Describe how you can separate ammonium chloride from a mixture of ammonium chloride and sodium chloride.

- The mixture of ammonium chloride and sodium chloride is placed on an evaporating dish.
- The evaporating dish is heated gently.
- Strips of filter paper soaked in water are placed on the filter funnel when it becomes hot in order to cool it.
- Ammonium chloride sublimes after some time and is found on the filter funnel.
- The ammonium chloride is scrapped off from the filter funnel. Sodium chloride remains on the evaporating dish.



(B7) Chromatography

57. State three uses of chromatography.

- To determine if a substance is pure.
- To separate coloured components in mixtures.
- To identify complicated substances such as dyes and drugs.

58. State two advantages of chromatography.

- Only tiny amounts are required.
- Results can be quickly obtained.

59. Give three examples of mixtures that can be separated by chromatography.

- Pigments from plants
- Dyes from ink
- Amino acids from proteins

60. Give two examples of mixtures that can be identified by chromatography.

- Poison / drugs
- Traces of unlawful dyes or other additives in foodstuff.

61. Why should the dyes in food be identified?

- Some artificial dyes are poisonous and harmful to human beings if consumed.

62. State three forms of chromatography.

- ❖ Paper chromatography
- ❖ Liquid chromatography
- ❖ Gas chromatography

Comments:

√ *Basically, liquid chromatography involves the use of liquids that may incorporate hydrophilic, insoluble molecules, while gas chromatography involves the use of a gas instead of a liquid to separate the substances being analysed.*

√ *Only paper chromatography is important for the O-Levels syllabus.*

63. Fill in the blank:

A _____ shows the results of the separated components in a chromatography experiment.

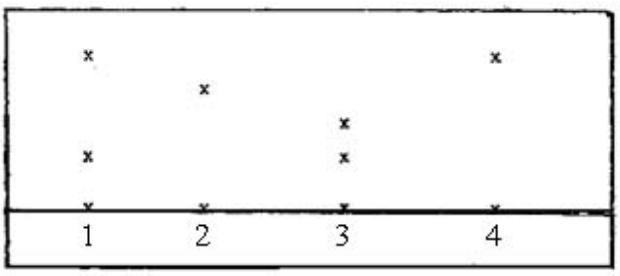
- ❖ chromatogram

(B7.1) Paper Chromatography – Determining Purity

64. How can we determine if a substance is pure by using chromatography?

- ❖ A pure substance will leave only one spot on its chromatogram.

Eg **65. Which of the components as shown in the chromatogram below are pure?**



- ❖ Components 2 and 4

(B7.2) Paper Chromatography – Separating Mixtures

66. What type of substances is paper chromatography used to separate?

- ❖ The coloured components in dyes or inks.

67. What is necessary to separate the components of a coloured mixture via paper chromatography?

- A solvent.

Comment:

√ *Examples of solvents: Alcohol, methylated spirit.*

68. State one factor that will determine how far a dye travels on a chromatogram.

- The solubility of the dye in the solvent – the more soluble the dye is in the solvent, the farther it will travel.

69. Fill in the blanks:

Because of their difference in _____ in a solvent, each coloured component will travel to different _____ on a chromatogram.

- solubility
- locations

70. What are the two methods of paper chromatography?

- Ascending method
  - The solvent travels up the chromatogram.
- Descending method
  - The solvent travels down the chromatogram.

71. State one advantage and one disadvantage of the descending method of paper chromatography.

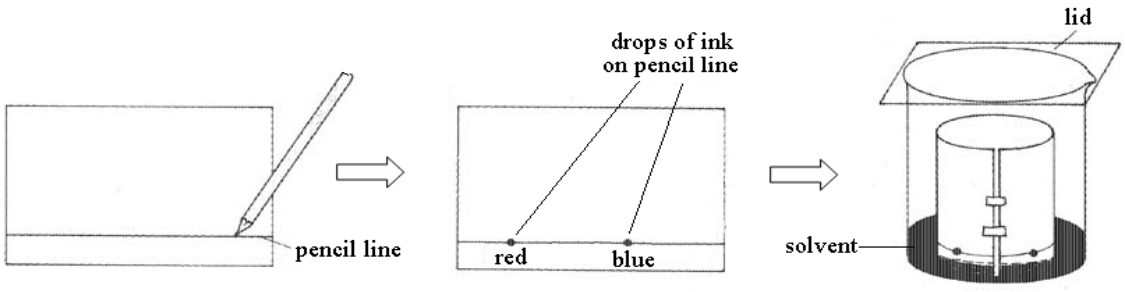
- Advantage: The separation between the spots on the chromatogram will be greater.
- Disadvantage: Separation may not be complete as the solvent will travel a longer distance due to the gravitational pull.

Comment:

√ *In the descending method, the solvent does not have to move against gravity. Thus, the solvent will move faster and further, resulting in greater separation between spots and longer chromatograms to be used.*

72. With the aid of diagram(s), describe how you would separate red dye from a mixture of red and blue dyes using the ascending method of paper chromatography.

❖



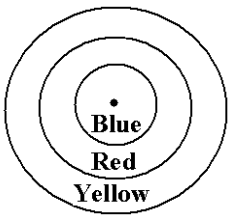
- ❖ A pencil line is drawn on a piece of chromatography paper. This paper is similar to a filter paper.
- ❖ A drop of the red and blue dye is placed on the chromatography paper.
- ❖ The paper is rolled into a cylinder and secured.
- ❖ This paper is placed in a beaker with a suitable solvent. The starting line must be above the solvent so that the dyes will not dissolve in the solvent.
- ❖ A lid is placed on top of the beaker to prevent the loss of solvent by evaporation.
- ❖ The solvent will travel up the paper.
- ❖ When the solvent almost reaches the top of the paper, the paper is taken out of the beaker and allowed to dry.
- ❖ As the blue and red dyes have different solubilities in the solvent, they will travel up the chromatogram to different extent. Thus, the red dye is separated from the mixture of red and blue dyes.

73. Describe how coloured spots will be left on different parts of a chromatogram in a paper chromatography experiment.

- ❖ As the solvent travels across the chromatogram, it dissolves the dyes.
- ❖ A dye that is strongly absorbed onto the paper and not very soluble in the solvent will be left behind.
- ❖ A dye that is weakly absorbed by the paper and is very soluble in the solvent will be carried furthest away from the starting line.

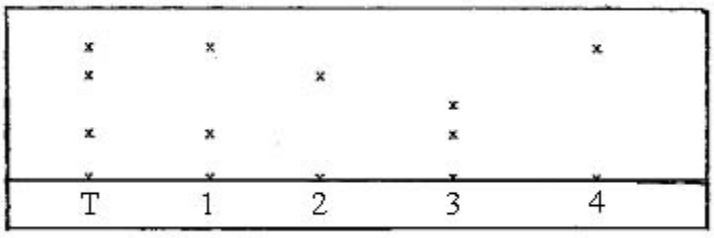
Eg

74. A small drop of ink is placed on a filter paper and chromatography carried out. The chromatogram is as shown in the diagram. What can you infer from the experiment? Which is the most soluble dye?



- ❖ The ink contains three dyes - blue, red and yellow.
- ❖ The yellow dye is the most soluble in the solvent and thus is carried furthest away from the center.

75. Study the chromatogram below and state the components that make up the mixture, T.

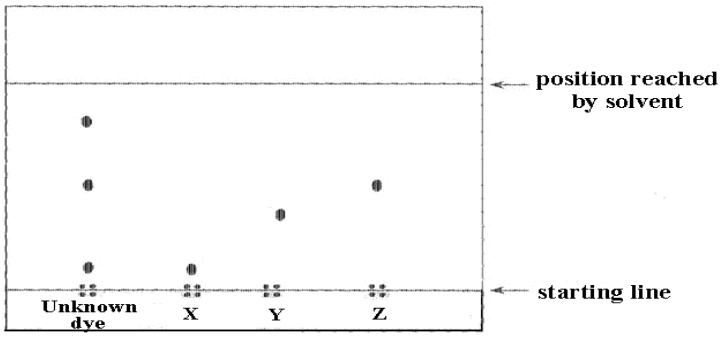


- Components 1 and 2

Comment:

√ *The spots left behind by components 1 and 2 are in line with the spots from T.*

76. Which substances (X, Y and/or Z) are present in the unknown dye as shown in the chromatogram below?



- Dyes X and Z are present in the unknown ink.

77. How can colourless substances on a chromatogram be identified?

- The chromatogram is sprayed with a locating agent to show where the substances are on the paper.

78. What is a locating agent?

- A locating agent is a substance that reacts with colourless substances on a chromatogram to produce coloured products.

(B7.3) Paper Chromatography – Identifying Substances

79. Explain how the dyes left on a chromatogram can be identified.

- By comparing the dye's position in the chromatogram with that of a known dye.

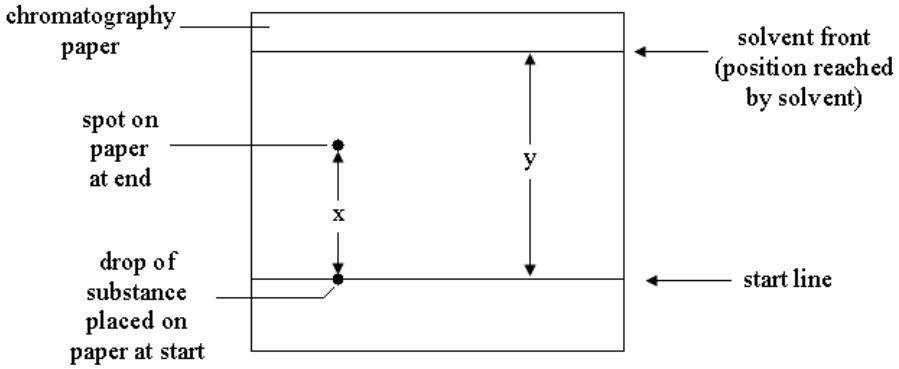
80. State the purpose of the R_f value.

- Used for the identification of substances on a chromatogram.

81. Write down the formula for determining R_f value.

- R_f value = Distance moved by substance / Distance moved by solvent

Eg **82. Based on the diagram below, what is the R_f value equal to?**

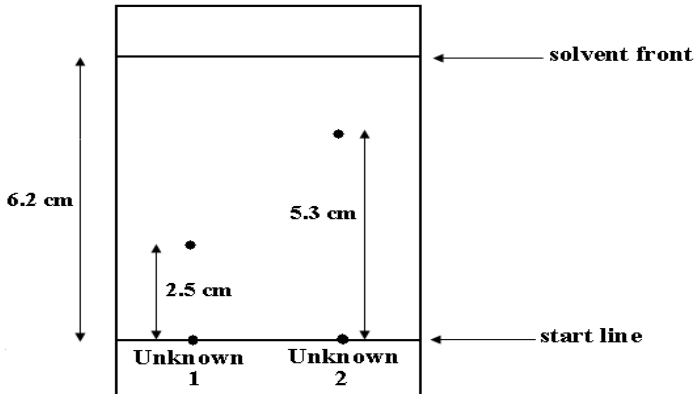


- R_f value = x ÷ y

83. Explain how the R_f value can be used to identify a dye.

- The R_f value is first calculated using the formula:
  - R_f value = Distance moved by substance / Distance moved by solvent
- The calculated R_f value is then compared to known values of R_f values.

Eg **84. The components of a sugar solution are separated through chromatography, with the results as shown below. With the help of the R_f table provided, identify the substances present in the sugar solution.**



Sugar	R_f value
Sucrose	0.20
Maltose	0.40
Glucose	0.57
Galactose	0.69
Fructose	0.86

- R_f value of first unknown substance = 2.5 / 6.2
  = 0.40
- R_f value of second unknown substance = 5.3 / 6.2
  = 0.85

⇨ From the R_f table, substances present are maltose and fructose.