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Church of England Academy
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YEAR 10

GCSE CHEMISTRY

STATES OF MATTER AND MIXTURES

Objectives

By the end of this unit you should be able to:

- Describe the arrangement, movement and the relative energy of particles in each of the three states of matter: solid, liquid and gas.
- Recall the names used for the interconversions between the three states of matter
- Explain the changes in arrangement, movement and energy of particles during these interconversions.
- Recognise that these interconversions are physical changes: contrasted with chemical reactions that result in chemical changes.
- Predict the physical state of a substance under specified conditions, given suitable data.
- Explain the difference between the use of 'pure' in chemistry compared with its everyday use and the differences in chemistry between a pure substance and a mixture.
- Interpret melting point data to distinguish between pure substances which have a sharp melting point and mixtures which melt over a range of temperatures.
- Explain the types of mixtures that can be separated by using the following experimental techniques: simple distillation, fractional distillation, filtration, crystallisation, paper chromatography.
- Describe an appropriate experimental technique to separate a mixture, knowing the properties of the components of the mixture.
- Describe paper chromatography as the separation of mixtures of soluble substances by running a solvent (mobile phase) through the mixture on the paper (the paper contains the stationary phase), which causes the substances to move at different rates over the paper.
- Interpret a paper chromatogram: a to distinguish between pure and impure substances b to identify substances by comparison with known substances c to identify substances by calculation and use of Rf values.
- Describe how: a waste and ground water can be made potable, including the need for sedimentation, filtration and chlorination b sea water can be made potable by using distillation c water used in analysis must not contain any dissolved salts.

There is also a core practical as part of this topic.

- *Core Practical: Investigate the composition of inks using simple distillation and paper chromatography*

LESSON 1

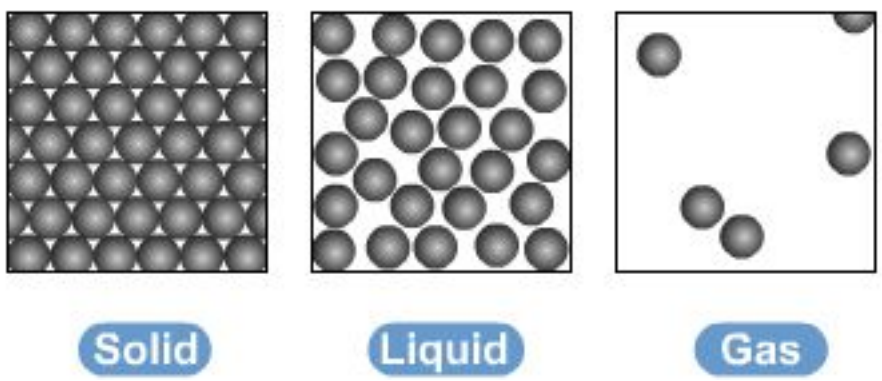
PRIOR KNOWLEDGE QUIZ:

1. Name 1 solid, 1 liquid and 1 gas.
2. What is the melting point of water?
3. What is the name for a gas turning into a liquid?
4. Which state of matter has the least energy?
5. Which state of matter is the most dense?
6. In which state of matter do the particles have the strongest attraction to each other?

If you struggled with any of these questions visit BBC Bitesize/KS3/Chemistry/States of matter to revisit what was covered at KS3.

NOTES:

The three states of matter are solid, liquid and gas.
Melting and freezing take place at the melting point
• solid —> liquid: melting
• liquid —> solid: freezing
Boiling (evaporation) and condensing take place at the boiling point
liquid —> gas: boiling (evaporating)
gas —>liquid: condensing



The three states of matter can be represented by the simple model above, particles are represented by small solid spheres. Gas particles have the most energy, the particles are the most spread apart and they move quickly in random directions. Liquid particles have more energy than those in a solid, but less than those in a gas, the particles are mostly touching,

in a random arrangement and flow past each other. Solid particles have the least energy, they have a regular arrangement and vibrate in a fixed position.

State changes (melting, boiling, freezing and condensing) are physical changes – they involve the forces between the particles of the substances but the particles themselves don't change. Chemical changes are where a new product has been formed.

Particle theory can help to explain melting, boiling, freezing and condensing. The amount of energy needed to change state from solid to liquid and from liquid to gas depends on the strength of the forces between the particles of the substance. The stronger the forces between the particles the higher the melting point and boiling point of the substance.

It is possible to predict the state that a substance will be in if you are given the melting point and boiling point of a substance:

- at temperatures below the melting point, the substance will be solid.
- at temperatures above the melting point but below the boiling point, the substance will be liquid.
- at temperatures above the boiling point, the substance will be a gas.

WHAT CAN YOU REMEMBER?

1. Name the three states of matter.
2. In which state(s) do substances have a:
   A. definite volume?
   B. definite shape?
3. Use the particle model to explain how the particles in a gas behave in a container.
4. Compare the energy of the particles in a substance in the solid state, liquid state and gas state.
5. What is it called when a substance changes from a solid to a liquid?
6. Use the particle model to describe the process of:
   A. melting,
   B. condensing

WORKED EXAMPLES

1. Explain why a solid expands when it is heated.

As the temperature increases, the particles in a solid gain more kinetic energy. This means that they vibrate more in their fixed positions and push the other particles away slightly, causing the solid to expand.

2. Which of the substances in the table is a liquid at room temperature (25 °C)?

	Melting point	Boiling point
Oxygen	-219 °C	-183 °C
Nitrogen	-210 °C	-196 °C
Bromine	-7 °C	59 °C

Oxygen and nitrogen both have boiling points below 25 ºC so they will both be gases at room temperature.

Bromine melts at -7 ºC and boils at 59 ºC. So, it's a liquid at room temperature.

PRACTICE QUESTIONS

1. A scientist has a sample of solid menthol in a beaker. He gently heats the menthol, and it turns into a liquid. He notices that the liquid menthol has flowed to fill the bottom of the beaker, whereas when the menthol was solid it kept its shape. Explain this difference using ideas about the forces of attraction between particles.
2. Ethanol melts at -114 ºC and boils at 78 ºC. Predict the state of ethanol at:
   A. -150 ºC,
   B. 25 ºC,
   C. 0 ºC,
   D. 100 ºC

EXAM QUESTION

1 **Figure 1** shows a vessel in a distillery. The walls of the vessel are solid copper.

(a) Describe the arrangement of particles in the solid copper walls of the vessel.

[1 mark]

(b) Inside the vessel, liquid ethanol is turned into ethanol gas. Explain the changes in arrangement, movement and energy of the ethanol particles when the liquid ethanol is heated to become a gas.

[3 marks]

Figure 1

2 **Table 1** shows the melting and boiling points of three molecular substances.

Substance	Melting point (°C)	Boiling point (°C)
oxygen	–219	–183
chlorine	–101	–34
bromine	–7	59

Table 1

(a) Predict the state of bromine at room temperature (25 °C).

[1 mark]

(b) Predict the state of chlorine at –29 °C.

[1 mark]

3 This question is on states of matter.

(a) Use your knowledge of how particles move to explain why gases fill their containers.

[2 marks]

(b) Use your knowledge of how particles move to explain why a liquid is able to flow but a solid is not.

[2 marks]

LESSON 2

PRIOR KNOWLEDGE QUIZ:

1. How are the electrons in magnesium arranged?
2. How many mL are in $1dm^3$?
3. What is the formula of the oxide ion?
4. Describe the arrangement of particles in a solid.
5. Describe how the particles change in arrangement when a liquid turns into a gas.
6. What is the change from a gas to a liquid called?

If you struggled with questions 1-3 review your learning from the key concepts booklet. If you struggled with questions 4-6 look back at the notes from lesson 1 in this booklet.

NOTES:

A mixture:

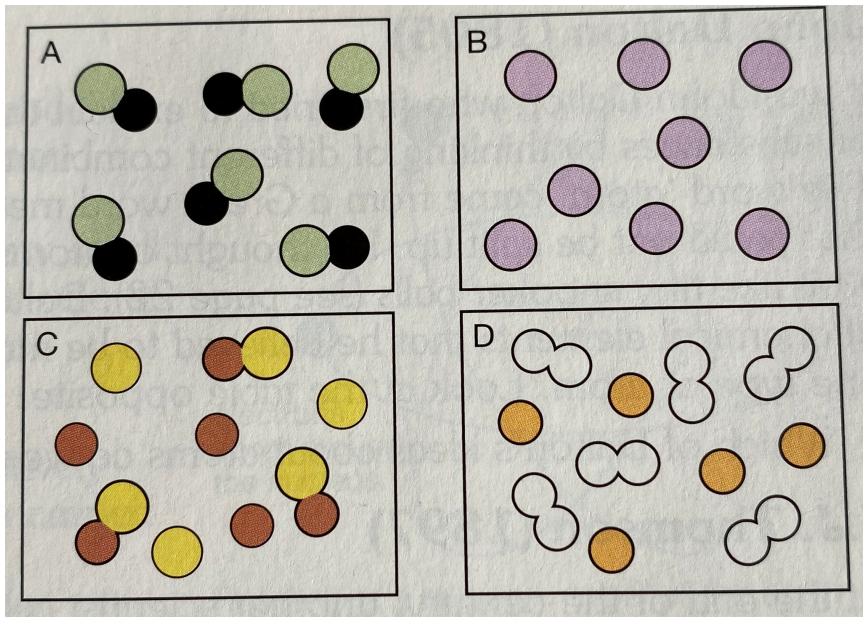
- Consists of 2 or more elements or compounds not chemically combined together
- Chemical properties of each substance in the mixture are unchanged

A pure substance is a single element or compound, not mixed with any other substance. In everyday language, a pure substance is a substance that has had nothing added to it, so it is unadulterated and in its natural state, e.g. pure water.

Pure substances melt and boil at specific/exact temperatures, mixtures do not. This means melting and boiling points data can be used to distinguish pure substances from mixtures (which melt over a range of temperatures due to them consisting of 2 or more elements or compounds).

WHAT CAN YOU REMEMBER?

1. Give two differences between a pure substance and a mixture.
2. Look at the boxes below:



Which box contains:

A. one element,
B. a mixture of elements,
C. a pure compound,
D. a mixture of elements and a compound.

WORKED EXAMPLE

Adil's teacher gives him samples of four powdered solids, labelled A, B, C and D. He uses melting point apparatus to determine the melting point of each of the solids. Adil's results are shown in the table below. Which of the four solids was a mixture?

Solid	A	B	C	D
Melting point (°C)	82	72-79	101	63

Adil's results show that solid B must be the mixture, because it melted over a range of temperatures. The other solids melted at a specific temperature, so must be pure substances.

PRACTICE QUESTIONS

1. A scientist has samples of three solids, labelled X, Y and Z. She grinds them to a powder, and uses the melting point apparatus to measure their melting points. The results of her experiment are shown in the table below.

Solid	Melting point (°C)
X	115
Y	127-129
Z	65-73

   A. Which of the solids, X, Y or Z was pure? Explain your answer.
   B. Suggest which of the solids was the most impure. Give a reason for your answer.

2. You have been given two test tubes that haven't been labelled. Your teacher tells you that one test tube contains ice made using pure water and the other contains ice made using impure water (a mixture).

   Write a method for how you would deduce which test tube contained which type of ice. Include in your answer:

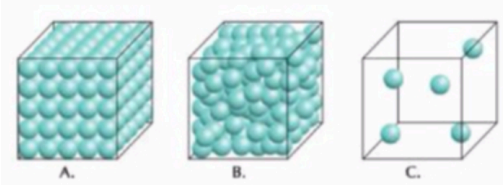
   - what equipment you will need,
   - how you will carry out the investigation,
   - what measurements you will take,
   - how you will know if the ice was pure or a mixture.

DIAGNOSTIC QUIZ

Circle the correct answers for each question.

1.

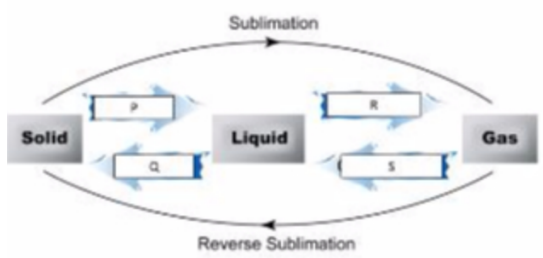
Look at the picture. What state is C?



A) Solid
B) Liquid
C) Gas
D) Foam

2.

Methane can be a gas, a liquid or a solid. In the diagram arrows P, Q, R and S represent changes of state. What does arrow R represent?



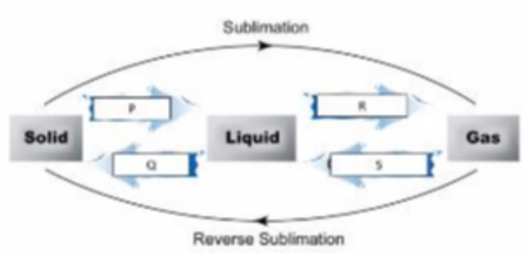
A) Freezing
B) Melting
C) Boiling
D) Condensing

3. Why does squash diffuse faster in hot water than cold water?

A) Increasing temperature makes particles move more slowly.
B) Increasing temperature makes particles move faster.
C) Decreasing the temperature makes particles move more slowly

4.

Methane can be a gas, a liquid or a solid. In the diagram arrows P, Q, R and S represent changes of state. Which arrows show an increase in kinetic energy in the particles?



A) R and S
B) P and R
C) S and P
D) Q and R

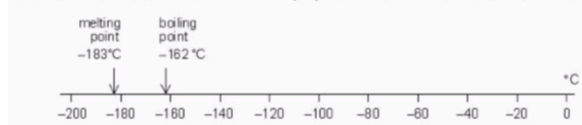
5. Using the data in the table, at which temperature are both substances a solid?

Substance	Melting point	Boiling point
Water	0°C	100°C
Mercury	-39°C	357°C

A) Between -45 °C and -40 °C
B) Between -25 °C and 0 °C
C) Between 5 °C and 25 °C

6.

This scale shows the melting point and the boiling point of the chemical methane. What is the physical state of methane at -170C?



A) Solid
B) Liquid
C) Gas
D) Plasma

7. Which of the following statements is true?

A) New substances are always formed from physical changes.
B) New substances are always formed from chemical reactions.
C) New substances can sometimes be formed from chemical reactions.
D) New substances are never formed from chemical reactions.

8. Which of these is a mixture?

A) Air
B) Carbon dioxide
C) Oxygen
D) Seawater

LESSON 3

PRIOR KNOWLEDGE QUIZ:

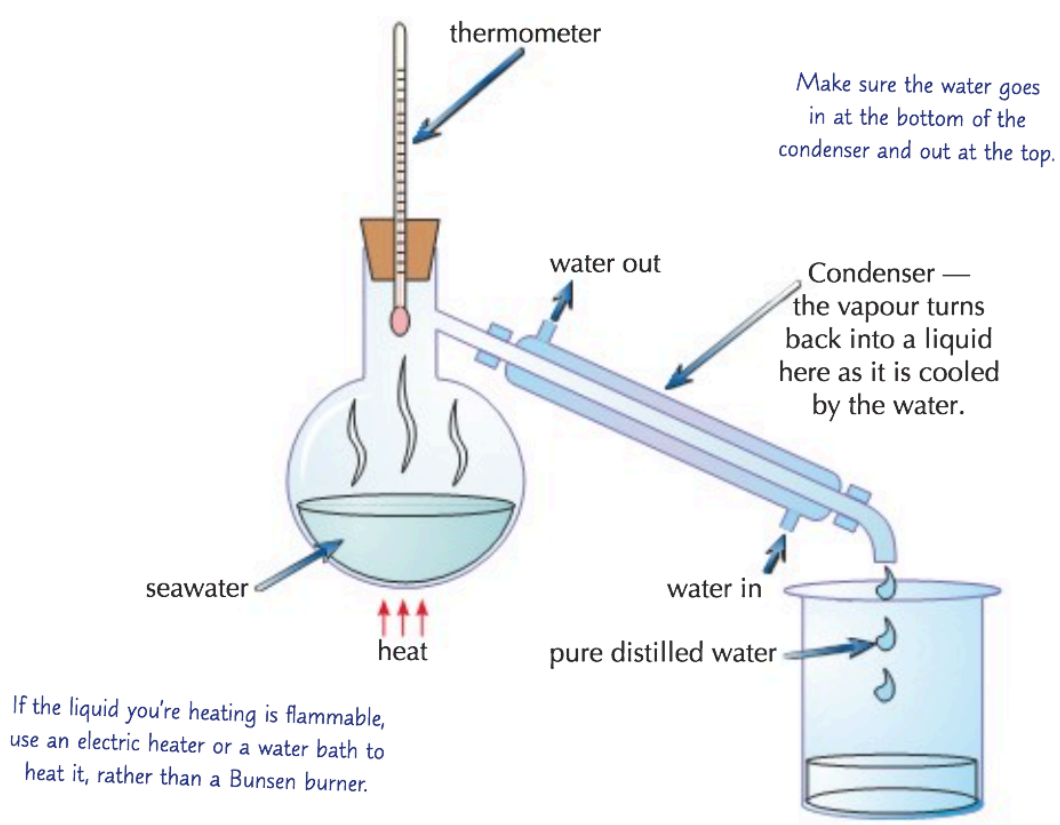
1. How do you work out the mass number of an element?
2. How many electrons are in the outer shell of sodium?
3. How many electrons can go in the first shell? How many in the second shell?
4. What are the 3 states of matter?
5. In chemistry what is a pure substance?
6. Define the term mixture.

If you struggled with questions 1-3 review your learning from the key concepts booklet. If you struggled with questions 4-6 look back at the notes from lesson 1 and 2 in this booklet.

NOTES:

<u>**Simple distillation**</u> is used to separate a pure liquid from a mixture of liquids

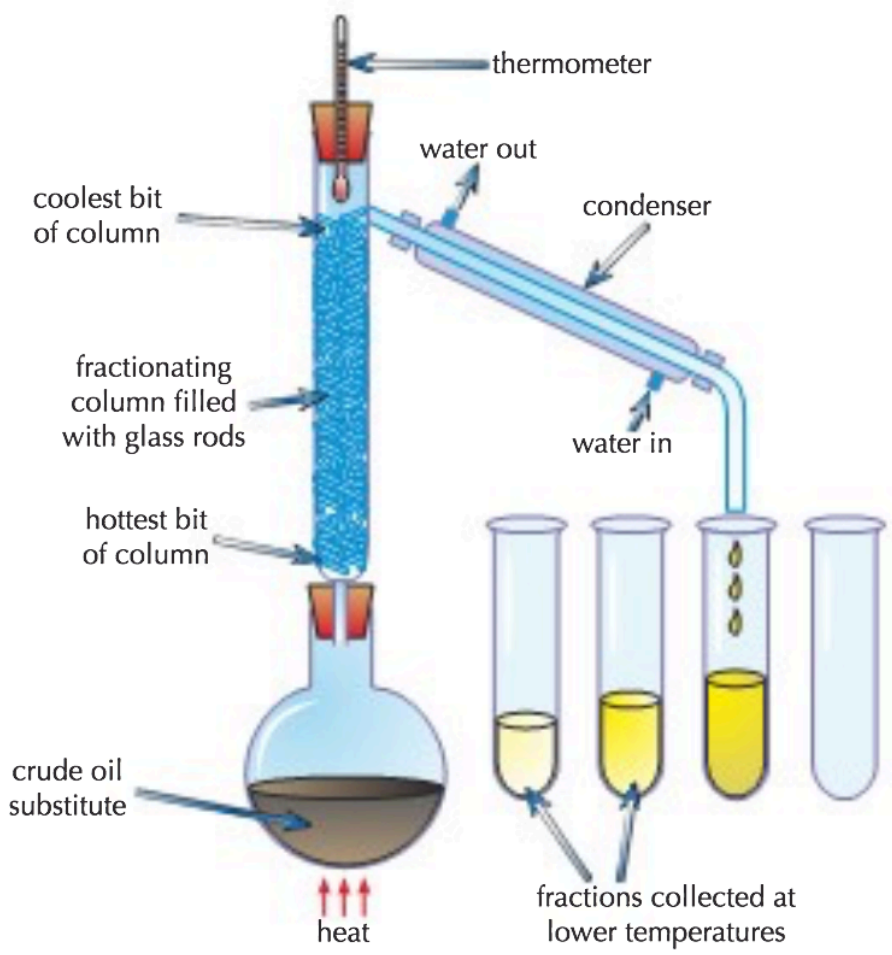
- Works when the liquids have different boiling points.
- Commonly used to separate ethanol from water.
- Taking the example of ethanol: ethanol has a lower boiling point than water so it evaporates first. The ethanol vapour is then cooled and condensed inside the condenser to form a pure liquid.
- Sequence of events in distillation is as follows: heating -> evaporating -> cooling -> condensing.



Fractional distillation is used to separate mixtures of liquids when the boiling points are similar.

- The oil is heated in the fractionating column and the oil evaporates and condenses at a number of different temperatures.
- There is a temperature gradient within the fractionating column which is hot at the bottom and cooler at the top.
- The many hydrocarbons in crude oil can be separated into fractions each of which contains molecules with a similar number of carbon atoms.

The fractionating column works continuously, heated crude oil is piped in at the bottom. The vaporised oil rises up the column and the various fractions are constantly tapped off at the different levels where they condense. The fractions can be processed to produce fuels and feedstock for the petrochemical industry.



Filtration is used to separate an insoluble solid from a liquid or solution.

- If you have produced a precipitate (which is an insoluble salt), you would want to separate the salt/precipitate from the salt solution by filtering the solution.
- The insoluble solid is left behind on the filter paper, this is called the residue.
- The solution that passes through the filter paper is called the filtrate.

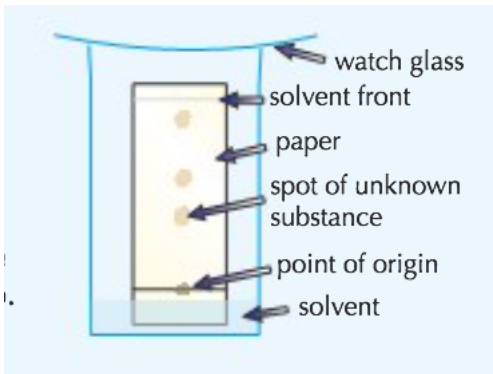
Crystallisation is used if you have produced a soluble salt and you wanted to separate this salt from the solution that it was dissolved in.

- You would first warm the solution in an open container, allowing the solvent to evaporate, leaving a saturated solution.
- Allow this solution to cool.
- The solid will come out of the solution and crystals will start to grow, these can then be collected and allowed to dry.
- The more slowly the solute is evaporated, the bigger the crystals that will form.

Paper chromatography is used to separate mixtures (usually of coloured substances) and give information to help identify which substances make up the mixture. Coloured substances are sometimes called pigments.

- Involves a stationary phase (doesn't move/the chromatography paper)and a mobile phase (does move/the solvent).
- Separation depends on the distribution of substances between the phases and how soluble they are.
- A more soluble substance will move further along the chromatography paper than a less soluble one.
- Insoluble substances do not move along the paper at all.

You need to be able to select the correct technique for separating given mixtures. To do this identify which types of substance you have in the mixture and so which technique is most appropriate.



WHAT CAN YOU REMEMBER?

1. Name the four stages involved in distillation.
2. What additional piece of equipment is needed for fractional distillation compared to simple distillation?
3. Give one technique that can be used to separate an insoluble solid from a liquid.
4. What is the final stage in crystallisation?
5. In chromatography, what is the name of the phase which can't move?
6. How can you tell is a substance is insoluble in paper chromatography?

WORKED EXAMPLE

A mixture is composed of two substances, X and Y. The table below shows some information about the properties of substances X and Y.

Substance	Melting point (°C)	Boiling point (°C)	State at room temperature
X	5	60	liquid
Y	745	1218	solid

Substance Y dissolves completely in substance X. Suggest a purification method you could use to obtain:

A. a pure sample of substance X
B. a pure sample of substance Y

A. To get X on its own, you need to distill it from the solution. You can use <u>simple distillation</u> here as there is only one liquid in the solution. Sample Y will be left behind in the round bottomed flask and pure sample X will be collected from the end of the condenser.
B. In theory if you distilled the mixture until all of substance X had evaporated off, you'd end up with just substance Y left in the flask. But there may still be traces of substance X present - <u>crystallisation</u> is a better way of obtaining a pure sample of a solid from a solution.

PRACTICE QUESTIONS

1. Describe how you would separate and collect the first substance in each mixture: salt and sand, iron filings and sugar, water and salt, sand and sugar, blue dye and red dye, ethanol and water.
2. During paper chromatography, why must you make sure the ink spot doesn't touch the solvent when you place the filter paper into the solvent?
3. A mixture contains methanol, ethanol and propanol. The boiling points of the components are 65 C, 78 C, and 97 C respectively. Describe a process that could be used to separate the mixture.
4. Silver bromide is insoluble in water. A student needs to separate a mixture containing water and silver bromide. Describe a method to remove the silver bromide from the water.
5. A student has a sample of magnesium carbonate and sodium chloride in water. Magnesium carbonate is insoluble in water, whilst sodium chloride is soluble. Suggest how the student could obtain a pure sample of sodium chloride from this mixture.

EXAM QUESTION

1 Propan-1-ol, methanol and ethanol have boiling points of 97 °C, 65 °C and 78 °C respectively.
A student uses fractional distillation to separate a mixture of these compounds.
State which liquid will be collected in the first fraction and explain why.

[2 marks]

2 Lawn sand is a mixture of insoluble sharp sand and soluble ammonium sulfate fertiliser.

(a) Describe how you would obtain pure, dry samples of the two components of lawn sand in the lab.

[3 marks]

(b) A student separated 51.4 g of lawn sand into sharp sand and ammonium sulfate.
After separation, the total mass of the two products was 52.6 g.
Suggest a reason for the difference in mass.

[1 mark]

3 **Table 1** gives the boiling points of three liquids.

Liquid	Boiling point (°C)
Methanoic acid	101
Propanone	56
Water	100

Table 1

(a) State why simple distillation cannot be used to separate water from a solution of water and methanoic acid.

[1 mark]

(b) The apparatus in **Figure 1** was used to separate a mixture of propanone and water.
Complete the table using the options below.

no liquid **water** **propanone** **both liquids**

Temperature on thermometer	Contents of the flask	Contents of the beaker
30 °C	.....	.....
65 °C	.....	.....
110 °C	.....	.....

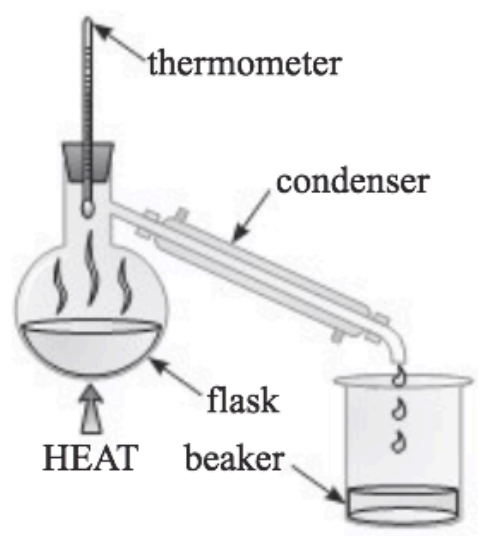


Figure 1

[3 marks]

LESSON 4

PRIOR KNOWLEDGE QUIZ:

1. Define the term atom.
2. What types of elements form ionic bonds?
3. Explain why chlorine and fluorine form covalent bonds.
4. What equipment is needed for filtration?
5. What is the change from a gas to a liquid called?
6. Describe how the arrangement of particles changes when a liquid changes to a solid.

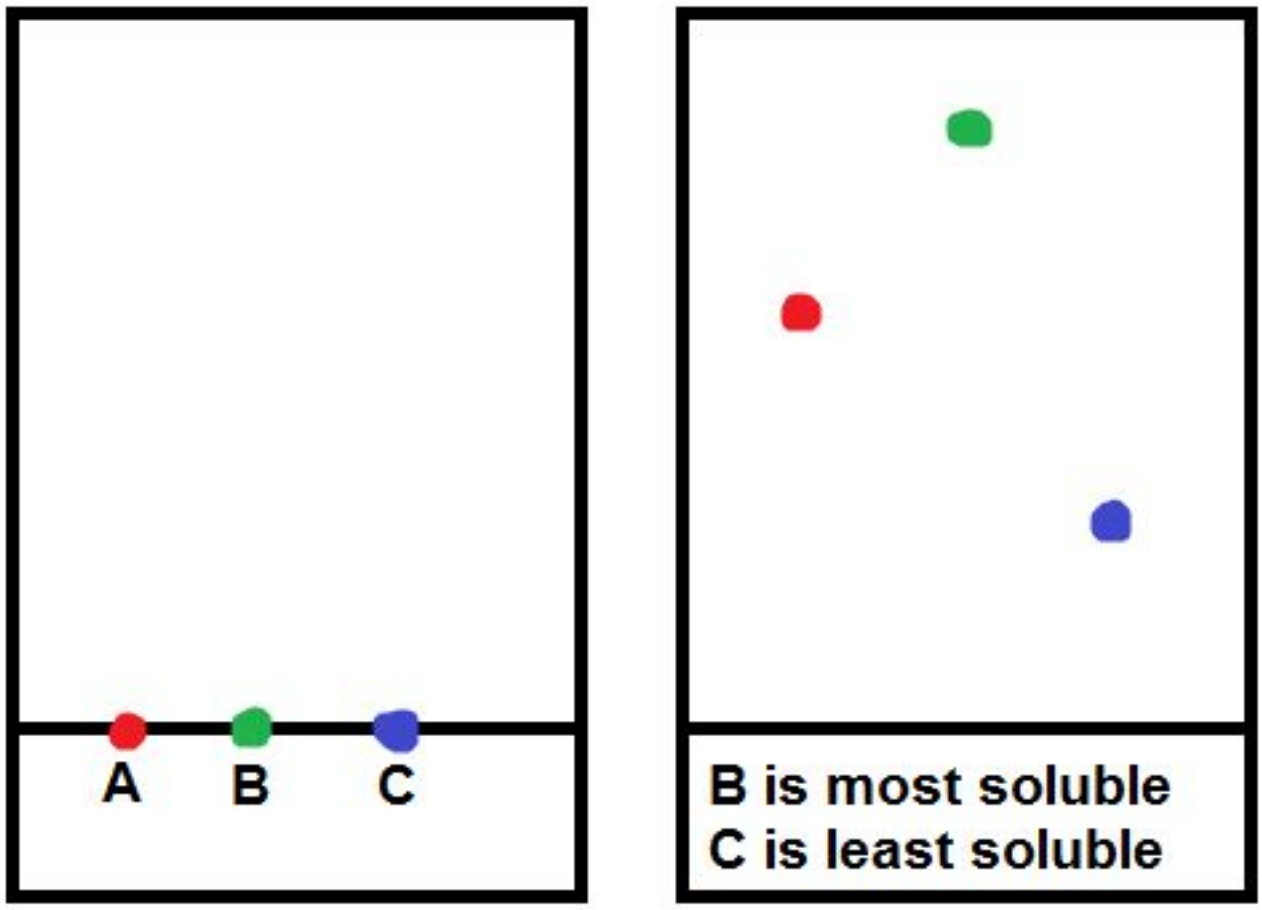
If you struggled with questions 1-3 review your learning from the key concepts booklet. If you struggled with questions 4-6 look back at the notes from lesson 1-3 in this booklet.

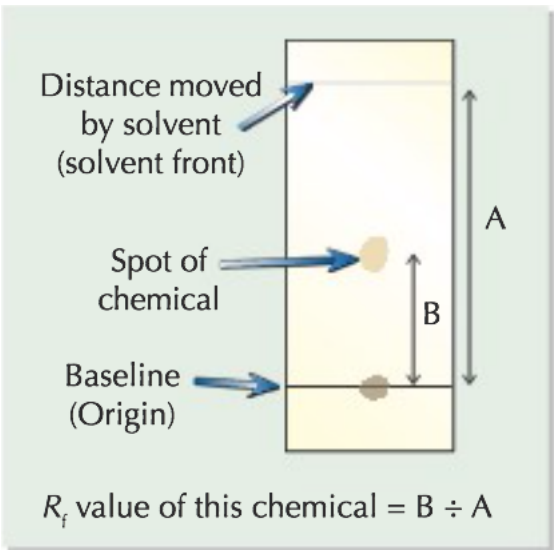
NOTES:

The results of separation by chromatography are called chromatograms. There are several pieces of information that can be gained from a chromatogram, including:

- pure substances only have one spot on a chromatogram.
- impure substances/mixtures will show up with more than one spot on a chromatogram.
- the number of spots on the chromatogram will tell you how many substances are in the mixture.
- if a substance is insoluble in a solvent the spot will stay on the baseline, to calculate an R_f value for this substance you will need to use a different solvent.
- to identify what a substance is by comparing with known substances: carry out paper chromatography with both the known substance and substance you're testing on the same paper. If both spots are at the same height up the paper at the end then you know the substance you're testing is the same as the known substance.
- to identify what a substance is by calculation of R_f values: you can calculate R_f values and then compare them to known values for different substances.
- R_f value = distance moved by substance / distance moved by solvent (you need to remember this equation)
- Different compounds have different Rf values in different solvents, which can be used to help identify the compounds.
- Compounds in a mixture may separate into different spots depending on the solvent but a pure compound will produce a single spot in all solvents

Example chromatogram





WHAT CAN YOU REMEMBER?

1. What is the pattern of spots produced by paper chromatography known as?
2. Why do you place the lid on top of the container whilst carrying out paper chromatography?
3. Give the equation used to calculate R_f values.
4. Using chromatography, how would you tell if a substance was pure?

WORKED EXAMPLES

Chromatography was carried out on a reference dye and an ink at the same time. The solvent moved 10.0 cm, the pot from the reference dye moved 4.0 cm. There were two spots in the ink, one moved 7.0 cm and the other 4.0 cm. Calculate the R_f values for the three spots and explain whether the reference dye is present in the ink.

Reference dye R_f value = distance moved by substance / distance moved by solvent
= 4.0/10.0 = 0.4

Ink spot 1 R_f value = distance moved by substance / distance moved by solvent
= 7.0/10.0 = 0.7

Ink spot 2 R_f value = distance moved by substance / distance moved by solvent
= 4.0/10.0 = 0.4

As the Rf values of the reference dye and ink spot 2 are the same, this suggests that the reference sample is in the ink.

PRACTICE QUESTIONS

1. On a chromatogram, a solvent travelled 12.3 cm and a substance travelled 6.9 cm. Calculate the R_f value of the substance.
2. A red spot and a blue spot are on a chromatogram. The R_f value of the red substance is 0.77, the blue substance has an R_f value of 0.52.
   A. Which substance has travelled the furthest up the chromatogram?
   B. Which substance spent the most time in the mobile phase?
3. A student analysed a chromatogram of a mixture containing three substances. A red spot was 3.5 cm from the baseline, a purple spot was 4.7 cm from the baseline and a yellow spot had travelled 5.3 cm. The solvent had travelled 8.3 cm.
   A. Calculate the R_f values of the red, purple and yellow substances.
   B. The student thinks that the purple substance is methyl violet. Suggest how she could investigate whether she is correct.

EXAM QUESTION

1 A student is making a solution to use in an experiment by dissolving pure, solid sodium iodide in water. Suggest why the student should not use tap water. State what he should use instead.

[2 marks]

PRACTICAL

2 A scientist used chromatography to analyse the composition of five inks. Four of the inks were unknown (**A** – **D**). The other was sunrise yellow. The results are shown in **Figure 1**.

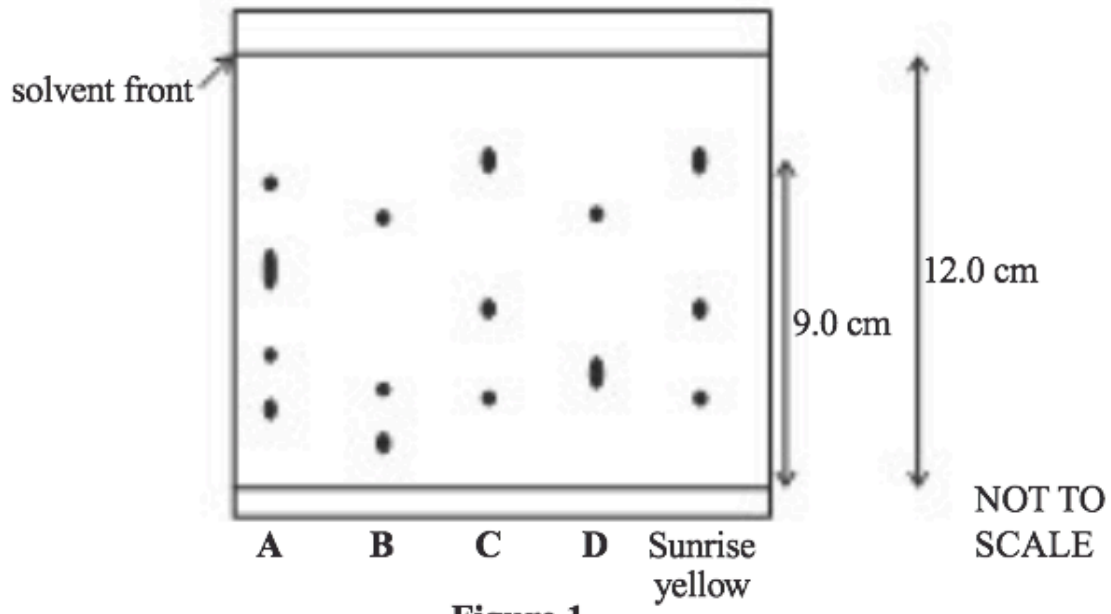


Figure 1

(a) Explain how **Figure 1** shows that none of the inks are pure substances.

[1 mark]

(b) Which ink definitely contains at least four different compounds?

[1 mark]

(c) Which of the inks, **A**-**D**, could be the same as sunrise yellow? Explain your answer.

[2 marks]

(d) Calculate the R_f value for the spot of chemical in sunrise yellow which is furthest up the chromatogram.

[2 marks]

(e) State **one** technique you could use to identify the solvent in each of the inks.

[1 mark]

LESSON 5

PRIOR KNOWLEDGE QUIZ:

1. Why are some numbers for relative atomic mass not whole numbers?
2. What is the name for a substance made of billions of oppositely charged ions joined together?
3. What does (aq) stand for?
4. What is crystallisation?
5. Describe the melting and boiling points of impure substances.
6. In chromatography, why must the substances be placed on a pencil line?

If you struggled with questions 1-3 review your learning from the key concepts booklet. If you struggled with questions 4-6 look back at the notes from lesson 1-4 in this booklet.

NOTES:

Potable water is suitable for drinking so it must have:
- low levels of microbes
- low levels of contaminating substances

Potable water is not the same as pure water but is still safe to drink.

Making waste (contaminated by industrial processes) and ground water (from rocks that trap water underground) potable:
- sedimentation: large insoluble particles will sink to the bottom of the water
- filtration: water is filtered through beds of sand which removes small insoluble particles
- chlorination: chlorine gas is put through water to kill microbes, this is also called sterilisation.

Making sea water potable using distillation:
- filter the seawater to remove any insoluble particles
- boil it to evaporate the water, leaving the salt behind
- water vapour is cooled and condensed to collect the potable water

The water that is used in analysis, such as chromatography, must be pure because any dissolved salts could react with the substances you are analysing, leaving you with a false result.

WHAT CAN YOU REMEMBER?

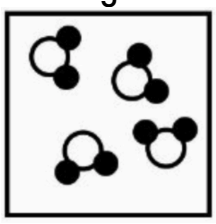
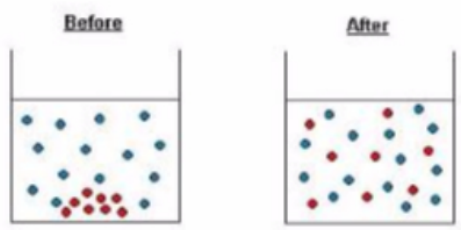
1. What is potable water?
2. Describe the source of ground water in the U.K.
3. What is waste water?
4. Describe the sedimentation step in water purification.
5. What is meant by the term ‘deionised water’?
6. Name the process used to convert sea water to potable water.

PRACTICE QUESTIONS

1. Fresh water is sourced from ground water or is in lakes and rivers. Describe the steps required to produce potable water from fresh water.
2. In certain countries such as Singapore where fresh water is scarce, treated waste water can be recycled as potable water. Suggest one other possible method of producing water in countries without enough fresh water.

DIAGNOSTIC QUIZ

Circle the correct answers for each question.

1. Which statement best describes this diagram? 	2. Which of these are mixtures - air, carbon dioxide, oxygen, seawater?	3. A student investigates a substance and makes the following notes • It is a brown colour • It changes shape if I put it into different bottles • It flows if I move the bottle around What state of matter has the student investigated?
A) It shows an element because it's made from only one type of atom. B) It shows a compound because it shows two different types of atom chemically joined together. C) It shows an element because it's made from two different types of atom chemically combined together. D) It shows a mixture because it shows two different types of atom chemically combined together.	A) Air and carbon dioxide B) Carbon dioxide and oxygen C) Oxygen and seawater D) Air and seawater	A) Liquid B) Gas C) Solid D) Not enough information
4. Filtration cannot be used to separate a mixture of salt, sugar and water. What is the best explanation for this?	5. What has happened to the particles in this picture? 	6. Which statement about dissolving is true?
A) Salt and sugar have different boiling points. B) Sugar and salt particles are different sizes, so only salt can pass trough the filter paper. C) When salt and sugar are dissolved in solution they can pass through the small holes in a filter. D) The holes in a filter are too small to let the solution pass through.	A) They have diffused. B) They have melted. C) They have turned into a gas. D) They have evaporated.	A) Dissolving is an irreversible process. B) During dissolving a new substance is formed. C) Dissolving is an example of a chemical reaction. D) During dissolving solvents surround particles of a solute.
7. Which separation technique can be used to separate salt from water?	8. Salt dissolves in water. What word describes This property of salt?	
A) Chromatography and filtration only. B) Distillation and evaporation only. C) Distillation, filtration and evaporation only. D) Filtration and evaporation only.	A) Solvent B) Insoluble C) Solute D) Soluble	

CHECK YOUR UNDERSTANDING OF THE WHOLE TOPIC

Triple or Higher tier: Seneca Learning/Chemistry/2.2.6 End of Topic Test - Separating & Purifying

Foundation: Seneca Learning/Chemistry/2.2.4 End of Topic Test - Separating & Purifying

Write your score here: _____%