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Eton College 13+ Science 2022

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CONTENTS

01 **Question Paper**

Eton College 13+ Science. Work through this paper first.

Includes Paper Notes: overview, topics, revision tips, common mistakes.

02 **Question Paper**

Eton College 13+ Science. Work through this paper first.

Includes Paper Notes: overview, topics, revision tips, common mistakes.

Eton College King's Scholarship Examination 2022

SCIENCE 1 (Theory)

(60 minutes)

***Candidate Number:*___________________________**

<u>Remember to write your candidate number on every sheet in the space provided.</u>

*You should attempt **ALL** the questions. Write your answers in the spaces provided.*

The maximum mark for each question or part of a question is shown in square brackets.

Calculators are allowed. In questions involving calculations, all your working must be shown.

Total Marks Available: 70

For examiners' use only.

1	2	3	4	5	TOTAL [70]

Do not turn over until told to do so.

1. This question is about solutions.

A solution can be prepared by dissolving a solute in a solvent, with the rate of dissolving being affected by a range of different factors, such as the temperature of the solvent.

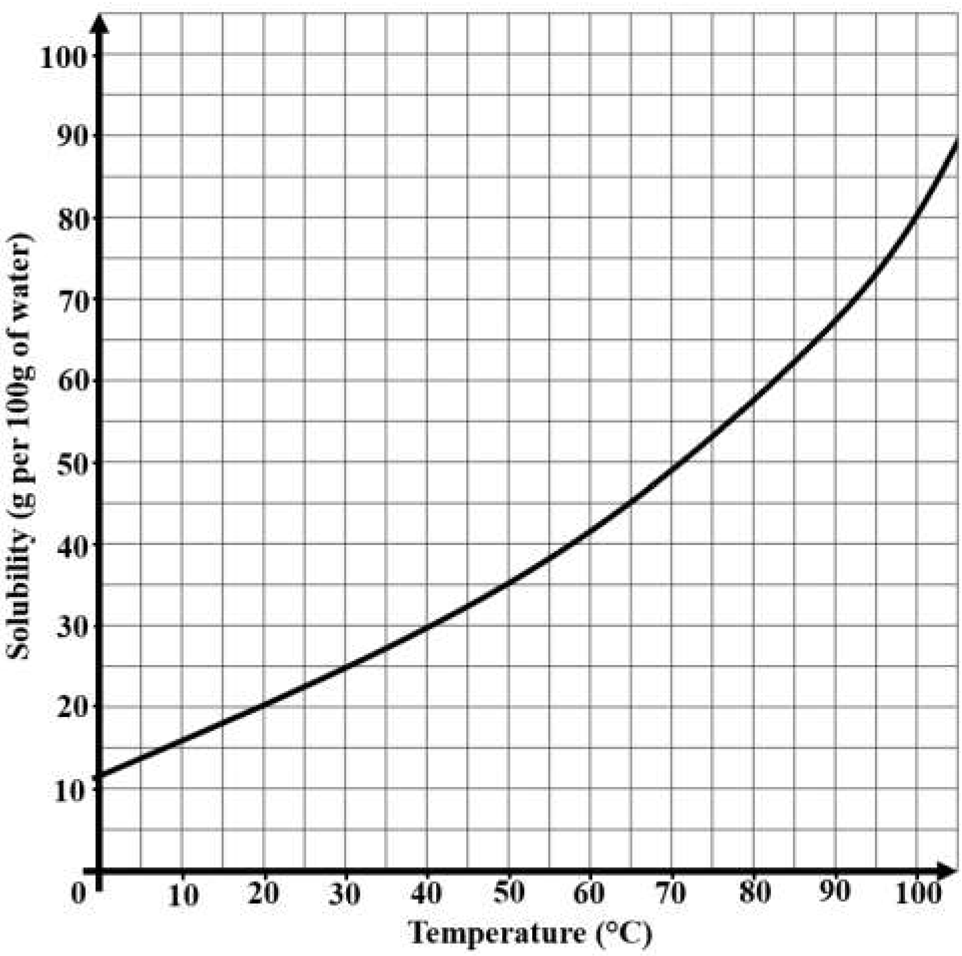
(a) State one other factor that can affect the rate at which solutes dissolve in a given volume of solvent.

____ **[1]**

The solubility of a substance is measured by the maximum mass of solute which can dissolve in 100 g of a solvent at a particular temperature to form a saturated solution.

$$\text{Solubility (g per 100g of solvent)} = \frac{\text{mass of solute (g)}}{\text{mass of solvent (g)}} \times 100$$

Solubility curves can be plotted to show how the solubility of a solid changes with temperature. The solubility curve below is for copper sulfate in water.



(b) Name the solute being used.

____ [1]

(c) Explain, in detail, why the solubility of this solute increases at higher temperatures.

____

____

____ [3]

The solubility curve tells us that the solubility of copper sulfate in water at 65 °C is 45 g per 100g of water.

(d) Use the solubility curve to find the solubility of copper sulfate in water at 50 °C.

____

____ [1]

(e) If 200 g of water was used to prepare a saturated copper sulfate solution at a temperature of 100 °C, what mass of copper sulfate crystals form if the solution was then cooled to 40 °C? Show your working.

____

____

____ [3]

When we have more than one type of solute dissolved in the same solution, we then refer to the solution as a **mixture**.

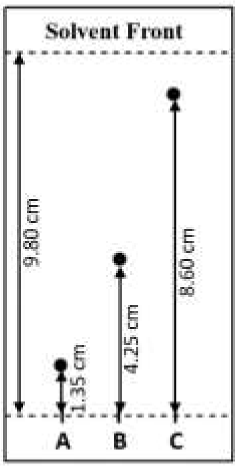
Paper chromatography can be used to separate a mixture of soluble solids and relies on the principle that different compounds have different solubilities in a given solvent. The more soluble a substance is, the further it will travel up the piece of chromatography paper.

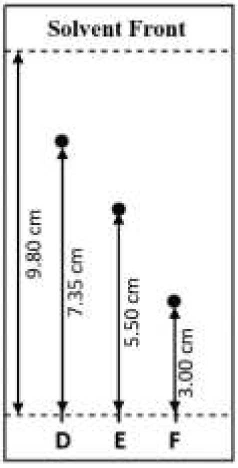
Chromatograms show the results of separating the components of a mixture using paper chromatography and can be analysed to measure R_f values of particular compounds in a specific solvent. They show how far the compound has travelled and how far the solvent has travelled (solvent front) in a given amount of time.

Calculating the R_f value of a compound allows chemists to identify unknown substances because it can be compared with R_f values of known substances under the same conditions. To do so, the following equation is used:

$$R_f = \frac{\text{distance moved by the spot}}{\text{distance moved by the solvent front}}$$

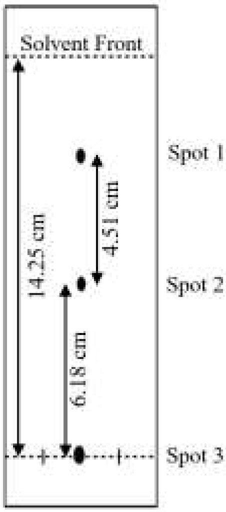
Here chromatograms of known dyes A-F are shown below with a table of their R_f values to 3 decimal places (diagrams not to scale).





Dye	R_f Value (3 d.p.)
A	0.138
B	0.434
C	0.878
D	0.750
E	0.561
F	0.306

You can now use these R_f values to identify which dyes are present in the mixture being analysed on the following chromatogram.



(f) Calculate R_f values for spots 1 and 2 to three decimal places and state which known dyes are present in the unknown mixture. Show your working.

____

____**[1]**

(g) Suggest a reason why the dye(s) at spot 3 didn't move up the chromatogram.

____**[1]**

(h) In a separate experiment, an unknown substance, X, was identified as part of a mixture. When a chromatogram was produced, the R_f value of X was found to be 0.90 and the solvent front was $7.2\ cm$. Calculate the distance moved by substance X on this chromatogram to two decimal places. Show your working.

____

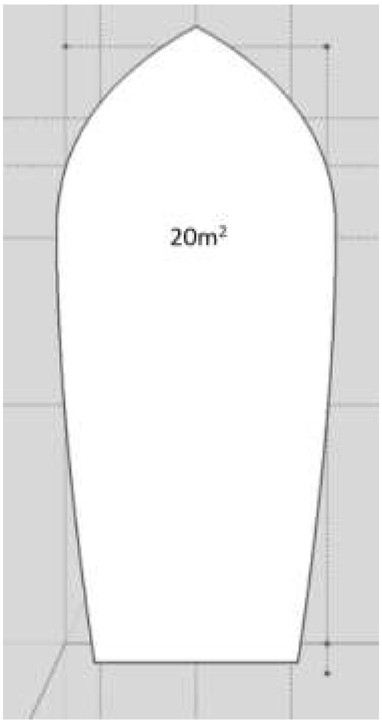
____**[2]**

(i) State a factor that could be changed which would affect the R_f value of substance X.

____**[1]**

2. This question is about pressure and forces.

Archimedes' principle states that the upward buoyant force that is exerted on a body immersed in a fluid, whether fully or partially, is equal to the weight of the fluid that the body displaces. A flat-bottomed scuba diving boat with a three-person crew of divers has a cross-sectional area of $20\ m^2$ and a total laden mass of $3000\ kg$. You can assume the density of water is $1000\ kg/m^3$.



(a) How much of the boat is below the waterline? State your answer in metres.

____

____

____**[3]**

(b) The boat sails down a freshwater stream and into the sea (salt-water is more dense than fresh water). Explain whether the boat sits higher or lower as it enters the sea.

____

____

____**[2]**

One of the divers gets off the boat to go under water where they experience a greater pressure on them than at the surface.

(c) Describe the vertical motion of the boat immediately after the diver enters the water.

____

____[1]

(d) Explain why, as the diver goes under water, there is an increase in pressure on the diver.

____

____[1]

(e) At the water's surface the pressure is $100\,000\ N/m^2$ due to the atmosphere. At $10\ m$ underwater the pressure is double what it is at the surface due to the mass of water. What would the pressure on the diver be at $25\ m$?

____

____

____[3]

The pressure change due to the depth in a fluid applies in the atmosphere, but the rate of change is less due to the difference in the density between air and water. The density of air is $1.3\ kg/m^3$ while the density of water is $1000\ kg/m^3$. For this question we will assume the density of the atmosphere is constant throughout.

(f) Show that at an altitude of approximately $3800\ m$ the pressure is half of that at sea level.

____

____

____[2]

(g) The summit of Ben Nevis is $1345\ m$ above sea level. What is the pressure at the summit of Ben Nevis?

____

____

____[2]

3. This question is about energy and momentum.

Conservation of momentum and conservation of energy are important laws in physics. These two laws can be used to calculate the speed of a bullet using a ballistic pendulum.

The momentum of an object is given by the following equation

$$\text{momentum} = \text{mass} \times \text{speed}$$

(a) Consider a bullet of mass $0.0035\ kg$ travelling at a speed of $105\ m/s$. Calculate the momentum of the bullet and give the unit of momentum.

[Note: the units on the left-hand side of the equation must be the same as the units on the right-hand side]

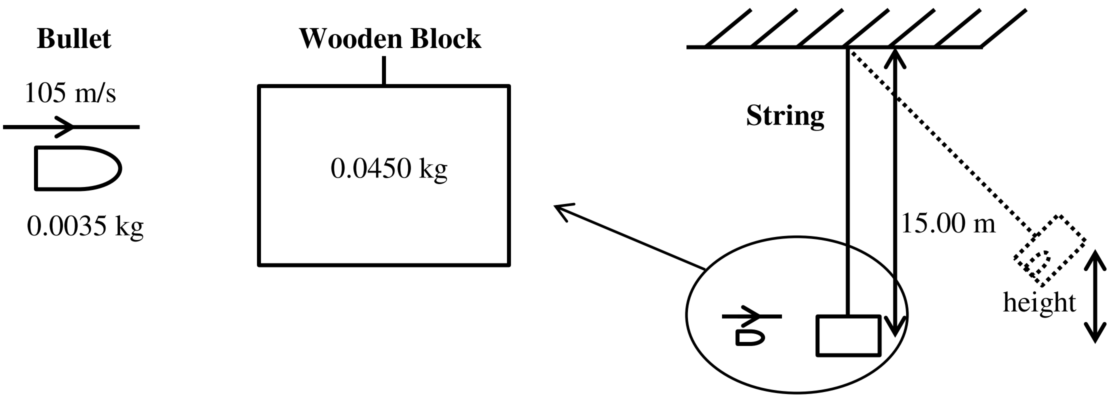
____

____

____ **[2]**

When two objects collide, the conservation of momentum law states that the sum of the momentum of the two objects before the collision equals the sum of the momentum of the two objects after the collision.

The bullet collides with a stationary block of wood with a mass of $0.0450\ kg$ that is hanging from a $15.00\ m$ long string.



(b) Explain why the initial momentum of the wooden block is zero even though it has a much greater mass than the bullet.

____

____ **[1]**

(c) State the combined momentum of the bullet and the wooden block after the collision.

____

____ **[1]**

(d) The bullet embeds itself into the block of wood. Use the conservation of momentum to show that the speed of the block with the bullet embedded is about 8 m/s.

____

____

____ **[2]**

The kinetic energy, KE, of an object is given by the following equation

$$\text{KE}=\frac{1}{2}\times \text{mass}\times \text{speed}^2$$

(e) Calculate the KE of the **combined wooden block and bullet** just after they have collided.

____

____

____ **[2]**

The combined wooden block and bullet swing upwards on the string to a maximum height.

The gravitational potential energy, GPE, of an object is given by the following equation

$$\text{GPE} = \text{mass} \times 10 \times \text{height}$$

Here we will only deal with KE and GPE. In this case, the conservation of energy means

$$\text{change in KE} = \text{change in GPE}$$

(f) Taking the initial GPE to be zero and the final KE to be zero, use the conservation of energy to show that the maximum height above the ground the wooden block and bullet will swing to is about 3 m.

____

____

____

____ **[3]**

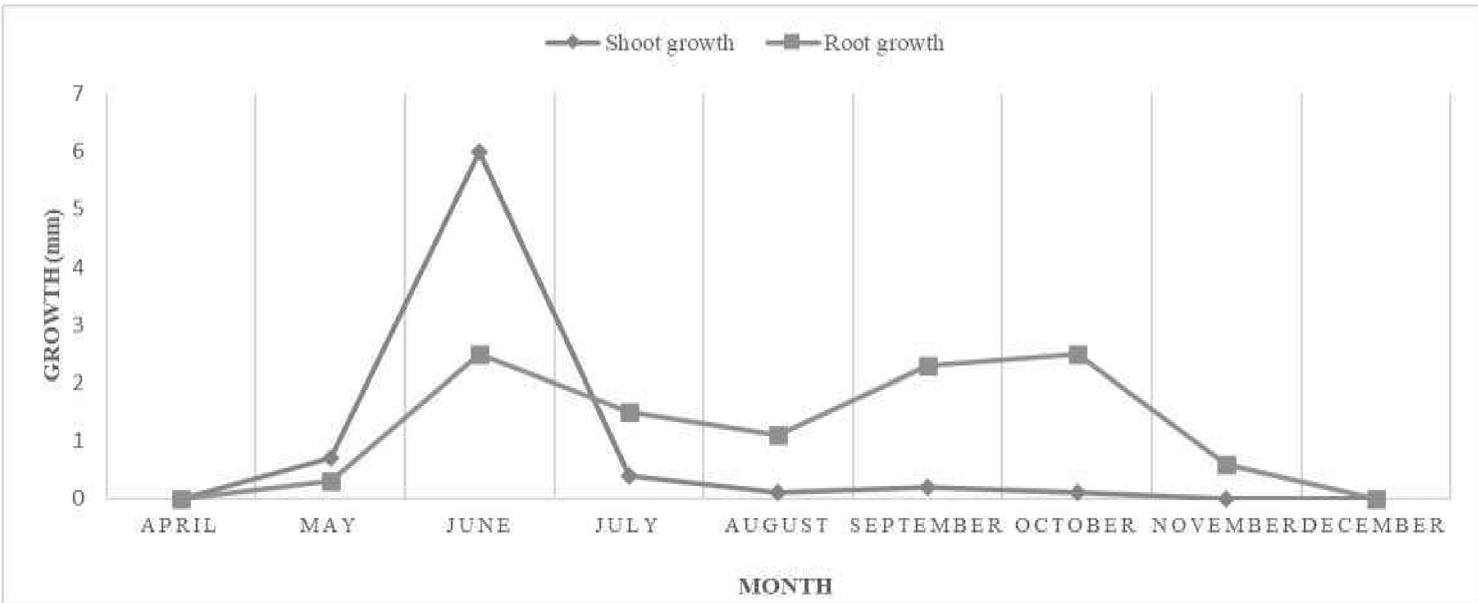
The ballistic pendulum is set up again with a new piece of wood with the same mass and on a piece of string with the same length. This time the bullet has the same mass but travels faster. The combined wooden block and bullet rise to a height of $11.50\ m$.

(g) Determine the approximate speed of the bullet and clearly explain your reasoning.

____ [3]

4. This question is about plant growth.

The chart below shows the average daily growth (in mm) of shoots and roots in a species of North American pine tree.



Shoots and roots are examples of biomass.

(a) What process does a plant rely upon to produce the glucose required for biomass production?

____ **[1]**

(b) Suggest two reasons why shoot and root growth (measured in mm per day) may not be an accurate measure of biomass production.

____

____

____ **[2]**

(c) Explain why root growth ceases in winter.

____

____

____

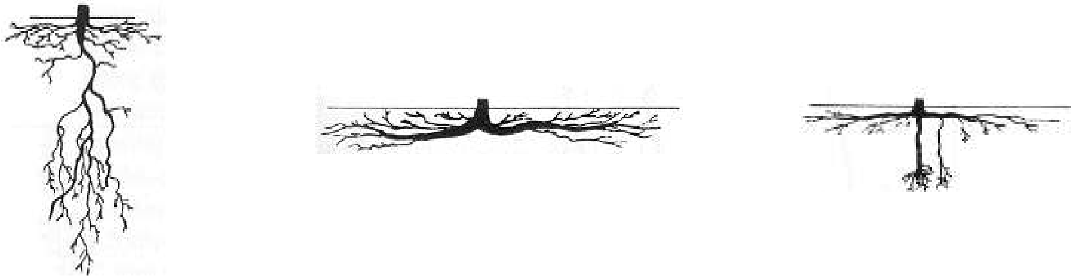
____ **[3]**

(d) Suggest a reason why most shoot growth precedes the period of most root growth.

____

____ **[1]**

Study the diagrams of these root systems.



(e) Roots are able to grow sideways and/or downwards. Given that the amount of energy available for growth is limited, explain the possible advantages to a tree of having root growth that is:

i. mostly sideways

____

____ **[2]**

ii. mostly downwards

____

____ **[2]**

(f) What microscopic structures, vital for obtaining mineral ions from the soil, can you not see on the diagrams above?

____ **[1]**

(g) How are these structures specifically adapted to adsorb water and mineral ions?

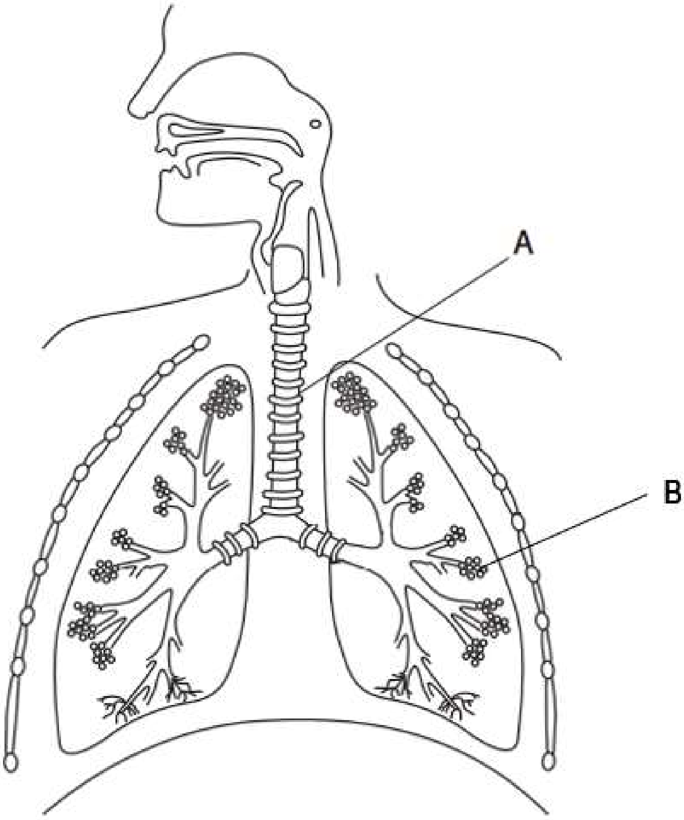
____ **[1]**

(h) Name one mineral ion that is absorbed by these roots and what it is needed for.

____ **[1]**

5. This question is about the human respiratory system.

The diagram below shows the breathing system in humans.



(a) Name structure A.

____ [1]

(b) Name the process that occurs at B.

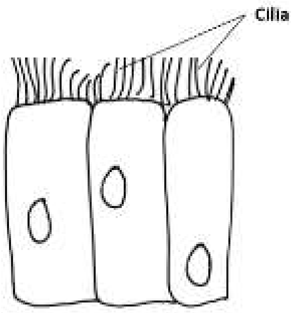
____ [1]

(c) Explain how B are adapted to their function.

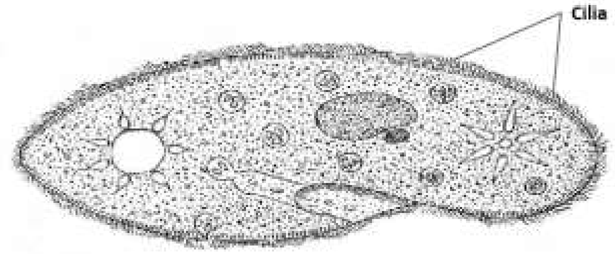
____

____ [2]

Structure A is lined with specialised cells called ciliated cells. Their structure is shown below.



Unicellular organisms such as *Paramecium* also have cilia. The diagram below shows a *Paramecium*.



(d) Suggest how the function of the cilia in the human breathing system differ to that of the *Paramecium*.

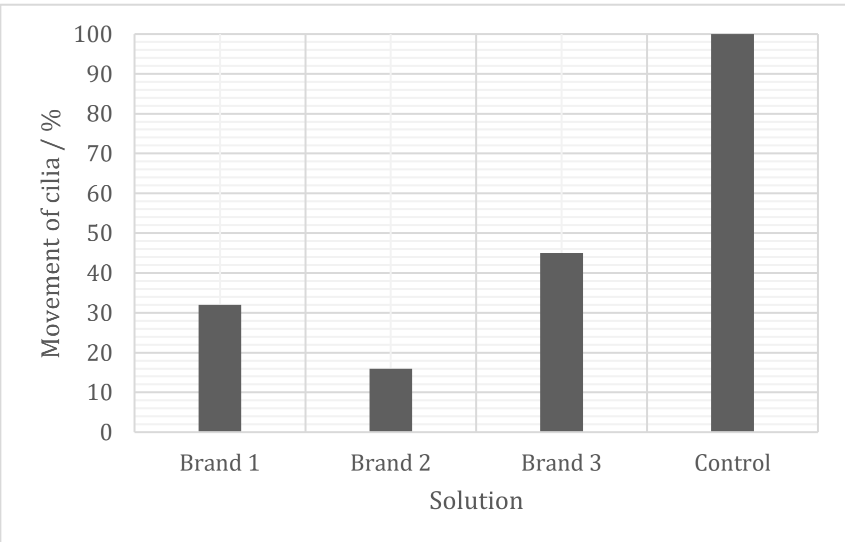
____

____ **[2]**

Chemicals in cigarette smoke affect the cilia in the airways.

An experiment was set up to investigate the effect of different cigarette brands on cilia activity. The scientists used *Paramecium* to show cilia movement. The chemicals in the tobacco from different brands were dissolved in water. One *Paramecium* was then placed in the solution from each brand and a microscope was used to observe the proportion of cilia movement. A control solution was used to enable comparison.

The results are shown below.



(e) Suggest what the scientists used as a control solution.

____ [1]

(f) The scientist conducting the research made the statement that 'smoking tobacco reduces the movement of cilia in human airways'. Justify why this conclusion may not be valid.

____

____

____

____ [3]

Chronic obstructive pulmonary disease (COPD) is the collective name of a group of lung conditions that can cause breathing difficulties. Smoking is the main cause of COPD.

(g) Name two other conditions caused by smoking.

____

____ [2]

There is currently no cure for COPD, however people may use inhalers to reduce their symptoms. The inhalers deliver drugs called corticosteroids into their airways.

The image shows a person using an inhaler.

(h) Suggest the effect of using an inhaler to treat symptoms of COPD.

____

____

____

____ [2]

[End of paper]

Paper Notes: 13+ Science Question Paper (13+ Science Past Paper (2022))

Compiled by SATs-Papers.co.uk to help you get the most from this paper.

Overview

This is **Eton College King's Scholarship Examination 2022 Science 1 (Theory)**, a 60-minute question paper designed to test candidates applying for the **King's Scholarship** at **Eton College**. The paper is aimed at **13+ candidates** (Year 9 entry) and carries a total of **70 marks** across five substantial questions. It covers biology, chemistry, and physics in roughly equal measure, requiring both conceptual understanding and the ability to apply knowledge to unfamiliar contexts.

Candidates must attempt **all questions**, writing their answers in the spaces provided on the paper itself. **Calculators are allowed**, and all working must be shown for calculation questions. The paper tests a wide range of skills: interpreting graphs and data, performing multi-step calculations, explaining scientific principles in detail, and drawing on knowledge from across the science curriculum.

The Eton King's Scholarship is one of the most prestigious academic awards in UK independent education, and this paper reflects that rigour. Questions are designed to stretch able candidates, with several requiring higher-order thinking and the ability to link concepts across different areas of science. This is not a routine school test; it is a competitive entrance exam for the top academic places at one of the country's leading schools.

How this paper is organised

The paper is divided into **five questions**, each focusing on a different area of science. Question 1 (14 marks) explores solutions, solubility curves, and paper chromatography, including Rf value calculations. Question 2 (14 marks) addresses pressure, forces, and Archimedes' principle, with calculations involving buoyancy and atmospheric pressure at altitude. Question 3 (14 marks) covers momentum and energy conservation, using a ballistic pendulum scenario to test understanding of kinetic and gravitational potential energy.

Question 4 (14 marks) examines plant growth, biomass production, and root systems, requiring interpretation of a growth chart and biological reasoning. Question 5 (14 marks) focuses on the human respiratory system, including the structure and function of cilia, experimental design, and the effects of smoking. Each question is broken into multiple parts, labelled (a), (b), (c), and so on, with mark allocations clearly shown in square brackets after each part.

The layout is clean and spacious, with ruled lines for written answers and generous space for calculations. The paper includes diagrams, graphs, and data tables that candidates must interpret and use in their responses. The total examination time is **60 minutes**, which means candidates must work at a brisk pace to complete all five questions thoroughly.

Topics covered

- Solubility and saturation: interpreting solubility curves for copper sulfate, calculating masses of solute that dissolve or crystallise at different temperatures, and understanding factors that affect dissolution rates
- Paper chromatography and Rf values: calculating retention factors to three decimal places, identifying unknown dyes by comparing Rf values, and explaining why some substances do not move up the chromatogram
- Pressure in fluids: applying Archimedes' principle to calculate the depth of a boat below the waterline, understanding buoyancy changes in water of different densities, and calculating pressure changes with depth underwater and altitude
- Conservation of momentum: calculating momentum in kg m/s, applying conservation laws to collisions, and determining the velocity of combined objects after an inelastic collision
- Kinetic and gravitational potential energy: using KE = ½ × mass × speed^2 and GPE = mass × 10 × height to calculate energy transfers, and applying conservation of energy to a swinging pendulum system
- Plant biomass production and growth patterns: interpreting seasonal growth charts for shoots and roots, explaining why root growth ceases in winter due to temperature and photosynthesis limitations, and comparing advantages of different root system architectures
- Root structure and function: identifying root hair cells as the microscopic structures responsible for mineral and water uptake, explaining their adaptations (large surface area), and naming mineral ions such as nitrate for protein synthesis
- Human respiratory system anatomy: naming the bronchus, identifying the alveoli as the site of gas exchange, and explaining alveolar adaptations including thin walls, large surface area, and good blood supply
- Function of cilia: comparing ciliated epithelial cells in the human airway (mucus transport) with cilia in Paramecium (locomotion), and understanding how tobacco chemicals impair ciliary function
- Experimental design and validity: evaluating whether a Paramecium-based experiment can support conclusions about human ciliary function, identifying suitable control solutions, and naming smoking-related diseases such as lung cancer, emphysema, or chronic bronchitis

How to use this paper for revision

- Practise reading and interpreting graphs accurately. The solubility curve and plant growth chart require you to extract precise values at specific temperatures or months, so take care with scales and units.
- Refresh your understanding of the standard equations for momentum, kinetic energy, and gravitational potential energy. Make sure you can rearrange them confidently and substitute values correctly.
- When calculating Rf values, measure distances from the baseline (not the top of the paper) to the centre of each spot. Always express your answer to the number of decimal places requested.
- For multi-step calculations such as Question 1(e) or Question 2(a), write out each step clearly. Examiners can award method marks even if your final answer is incorrect, but only if your working is visible.
- In explain questions, aim for at least two or three distinct points. For example, when explaining why solubility increases with temperature, mention particle kinetic energy, frequency of collisions, and overcoming intermolecular forces.
- Use correct scientific terminology throughout. Words like 'buoyancy', 'conservation', 'saturated solution', 'inelastic collision', and 'ciliated epithelial cells' show precision and earn credit in mark schemes.
- For the experimental evaluation question (5f), think about whether the model organism (Paramecium) is a good proxy for human cells. Consider differences in structure, environment, and the complexity of the human respiratory system.

Common mistakes to avoid

- Confusing solubility (grams per 100 g of solvent) with the total mass dissolved. In Question 1(e), you must scale up for 200 g of water and then calculate the difference between two temperatures.
- Forgetting to show all working in calculations. Even if you arrive at the correct answer, you risk losing method marks if the examiner cannot follow your steps.
- Misreading graphs or scales. For example, estimating the solubility at 50 °C as 42 g instead of 40 g can propagate through subsequent calculations and cost marks.
- Not stating units. In Question 3(a), the answer without a unit (kg m/s) is incomplete. Always check what unit the question requires and include it in your final answer.
- Providing vague biological explanations. Saying 'roots grow because they need water' is too superficial. Instead, explain that mineral ions are required for processes like protein synthesis, and water is needed for photosynthesis and turgor pressure.
- Overlooking the difference between 'describe' and 'explain'. A description states what happens (e.g. 'the boat rises slightly'); an explanation gives the reason (e.g. 'the upthrust is unchanged but the weight has decreased, so the boat rises until equilibrium is restored').

Exam technique

Start by reading through the entire paper quickly to identify which questions look most familiar and which may require more thought. The five questions are worth equal marks, so do not spend too long on any one part if you are stuck. Move on and return later if time permits.

For calculation questions, write down the formula you are using, substitute the numbers with units, and show each step. This makes it easier to spot errors and helps you earn partial credit. Use the space provided generously; examiners prefer clear, well-spaced working to cramped, illegible scribbles. If you make a mistake, cross it out neatly with a single line and continue; do not waste time erasing.

In longer written answers (such as Question 1(c) or Question 4(c)), plan a brief response in your head before you start writing. Aim for two or three well-developed points rather than a single sentence. Use scientific vocabulary accurately and refer to specific details from the question (e.g. the graph, the diagram, or the experimental setup). Finally, keep an eye on the clock: with 60 minutes for 70 marks, you have slightly less than one minute per mark, so pace yourself accordingly and leave a few minutes at the end to review your answers.

What to revise alongside this paper

To prepare fully for this paper, revise the particle model of matter, particularly how temperature affects particle motion and solubility. Make sure you are confident with density, mass, and volume calculations, as these underpin both the chemistry and physics questions. Review the principles of gas exchange in the lungs and the transport of oxygen and carbon dioxide in the blood, as these may appear in follow-up questions or alternative scenarios.

Strengthen your understanding of conservation laws in physics. Beyond momentum and energy, look at how these principles apply to collisions in two dimensions and to systems involving friction or air resistance. For the biology content, revise plant nutrition (photosynthesis, mineral requirements, and transport in xylem and phloem) and the effects of lifestyle factors on health, including smoking, diet, and exercise.

Finally, practise experimental design and evaluation questions. The ability to identify controls, suggest improvements, and assess the validity of conclusions is a key skill tested in competitive science exams. Work through past papers from other independent schools' 13+ entrance exams to build familiarity with the style and level of challenge you will encounter.

Key terms

> **Solubility**, **Saturated solution**, **Solute and solvent**, **Paper chromatography**, **Rf value (retention factor)**, **Archimedes' principle**, **Buoyancy**, **Pressure**, **Conservation of momentum**, **Inelastic collision**, **Kinetic energy**, **Gravitational potential energy**, **Photosynthesis**, **Biomass**, **Root hair cells**, **Mineral ions (nitrate, phosphate, potassium)**, **Alveoli**, **Gas exchange**, **Cilia and ciliated epithelial cells**, **Control solution**, **Validity of conclusions**

Eton College King's Scholarship Examination 2022

SCIENCE 2 (Data Analysis)

(30 minutes)

Candidate Number: ___________________________

<u>Remember to write your candidate number on every sheet in the space provided.</u>

You should attempt ***ALL*** *the questions. Write your answers in the spaces provided.*

The maximum mark for each question or part of a question is shown in square brackets.

Calculators are allowed. In questions involving calculations, all your working must be shown.

Total Marks Available: 30

For examiners' use only.

Total [30]	

Do not turn over until told to do so.

1. Limestone is a rock composed mainly of calcium carbonate. Some students were asked to estimate the purity of the limestone from a quarry. They heated samples of the limestone, so that the calcium carbonate decomposed and the solid decreased in mass:

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

They used a more powerful version of the normal Bunsen burner, as a very high temperature is required. Each student was given a sample of the limestone and told to follow the instructions below:

Instructions

1. Weigh your sample using a balance which measures to one decimal place in grams and record the mass of the sample.
2. Heat the sample strongly for 30 minutes to ensure that the decomposition of calcium carbonate is complete.
3. Weigh the solid which remains and record its mass.

Here are the results:

Experiment number	Initial mass of sample (g)	Final mass of solid (g)	Mass lost (g)
1	2.0	1.2	0.8
2	4.4	2.8	1.6
3	6.4	4.6	1.8
4	8.2	5.1	3.1
5	9.8	6.1	
6	12.0	7.5	

(a) Complete the final column of the results table.

[1]

(b) Look at the instructions for the experiment, and suggest why no student was given a sample with a mass of more than 12 grams.

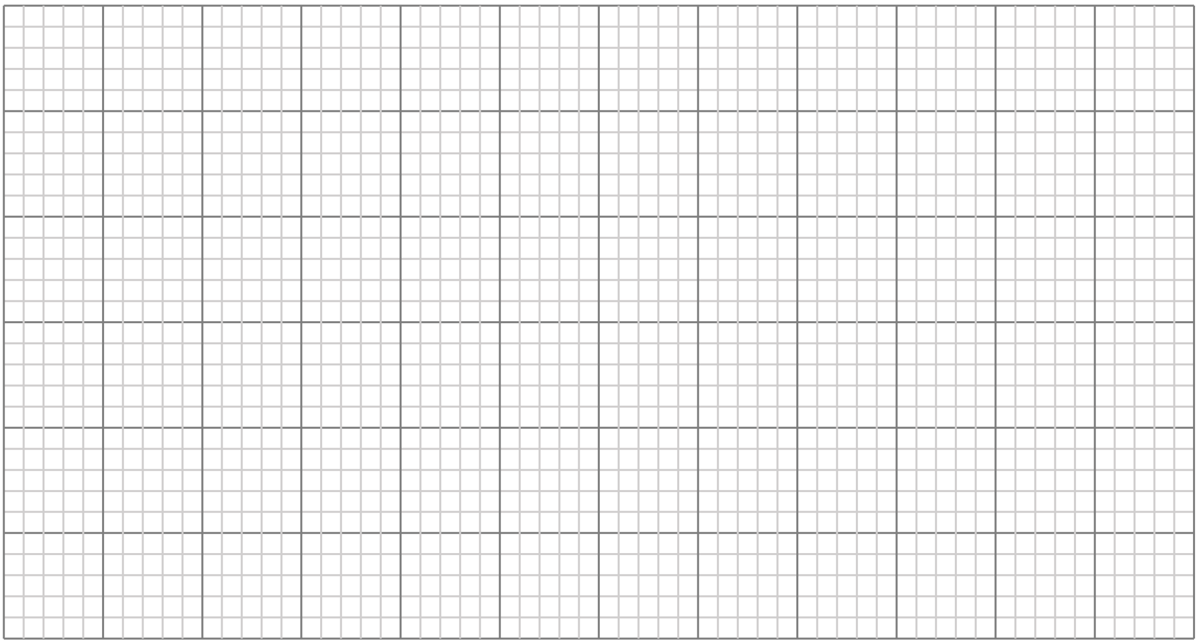
[1]

(c) Look at the instructions for the experiment and suggest why no student was given a sample with a mass of less than 2 grams.

[1]

(d) Using the grid below, plot a graph of **mass lost** against **initial mass of sample**. Choose suitable scales, label the axes, and include the origin.

[4]



(e) One of the points from experiments 1 to 4 is anomalous. Label this point, and draw a straight line of best fit using the other five points. The line of best fit must pass through the origin.

[2]

(f) Suggest an explanation for the anomalous point you have labelled in part (e). You should assume the student did not simply make an error in recording the mass.

[1]

Scientists use a **relative atomic mass** scale to compare the masses of atoms of different elements. The relative atomic masses of some elements are shown below, together with the equation for the thermal decomposition of calcium carbonate.

Ca	C	O
40	12	16

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

(g) Use this information to calculate the decrease in mass of solid if 10.0 grams of pure calcium carbonate decomposed according to the equation given. Show your working.

[4]

(h) Use the graph, and your answer to (g), to estimate the percentage of calcium carbonate in the limestone. Mark on the graph the measurement you have made, and show your working and answer in the space below. (If you were unable to complete part (g), you should assume the answer to that calculation was 4.0 grams, although this is not the correct value.)

[4]

(i) What has been assumed here about the impurities in the limestone?

[1]

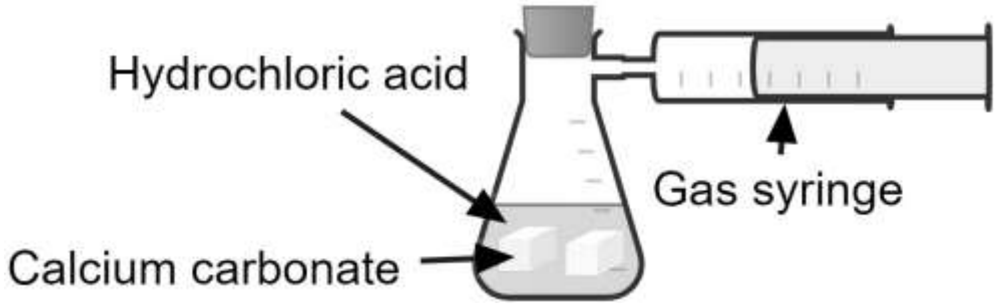
2. Arabella and Beatrice were asked to investigate the reaction of calcium carbonate with hydrochloric acid:

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

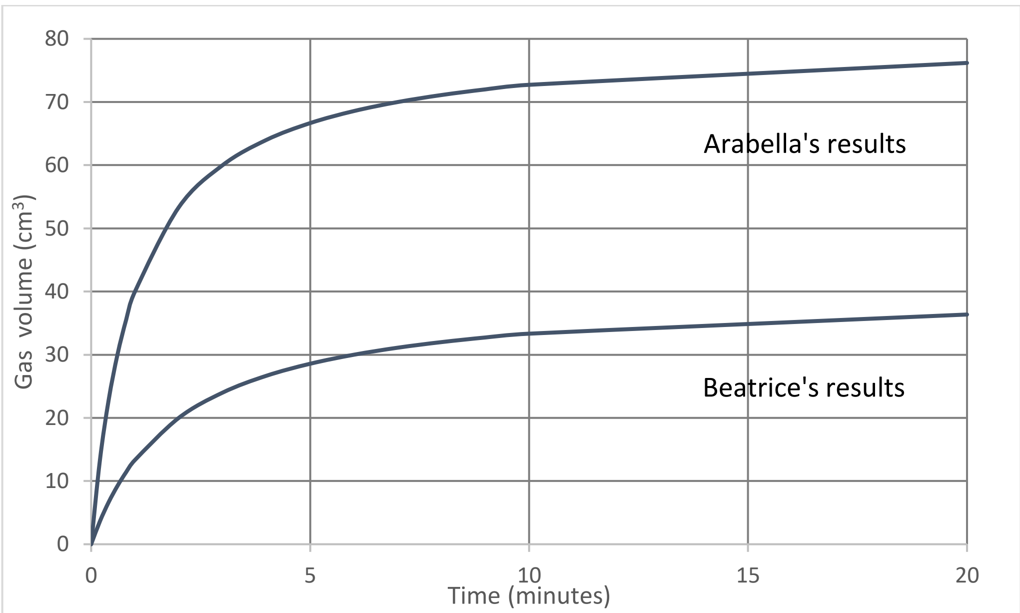
They were each given an identical sample of calcium carbonate, 100 cm^3 of hydrochloric acid, and the apparatus shown below. They were instructed to:

1. Add the acid to the flask.
2. Add the calcium carbonate to the flask and immediately fit the bung.
3. Record the volume of gas produced at suitable time intervals.
4. Plot a graph of the results and draw a line of best fit.

.



Their graphs are shown below. There was some calcium carbonate left over at the end of both experiments.



(a) Their teacher said that Arabella's acid was twice as concentrated as Beatrice's. How did the teacher deduce this from the results? **[1]**

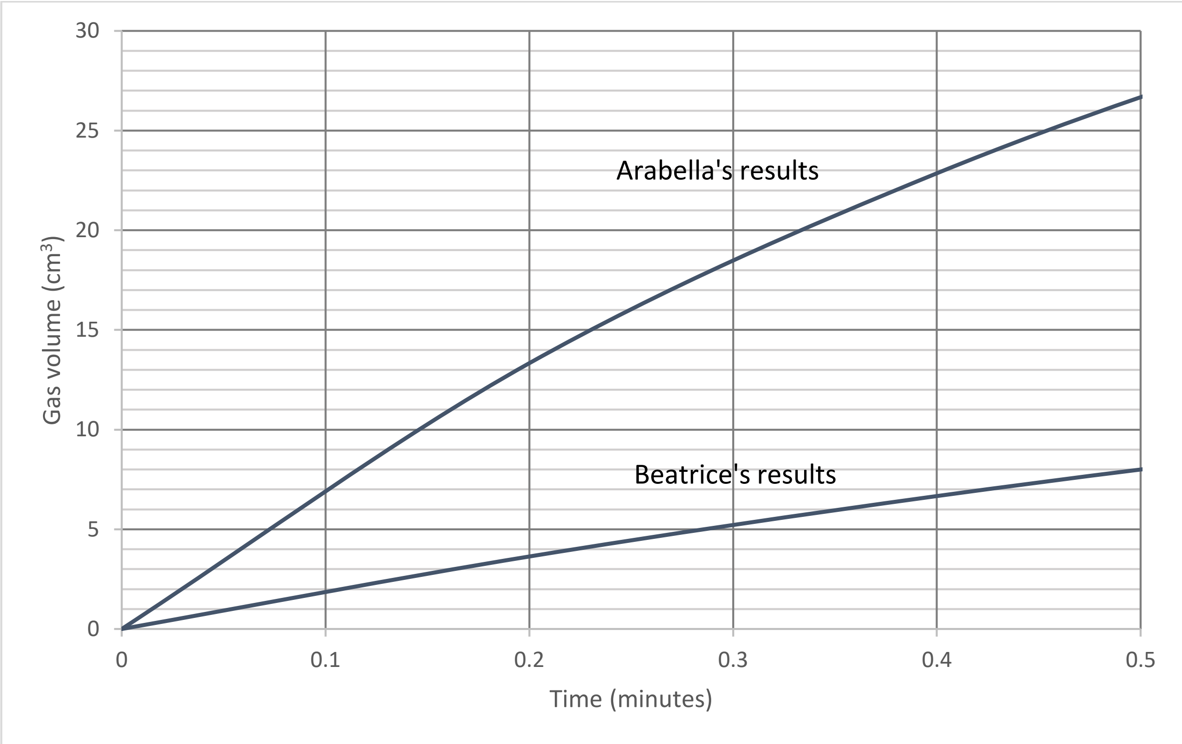
The rate of the reaction depends on the concentration of the acid. Two possibilities are:

[Rate of reaction] is proportional to [Concentration of acid]

or

[Rate of reaction] is proportional to [Concentration of acid]^2

To decide which is correct requires an estimate of the *initial* rate of the reaction (the rate when time=0). This can be done by measuring the rate of gas production (the gradient of the graph) during a short time interval at the start of the reaction. The graph below shows the start of each experiment in more detail.



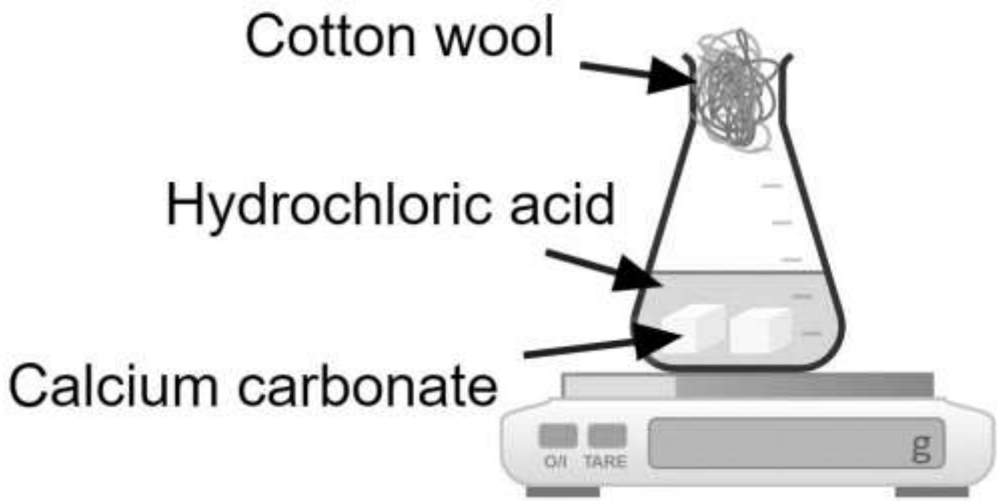
(b) Use the graph to find the volume of gas produced during the first 0.2 minutes in each experiment. Hence calculate the rate of gas production during this period for each experiment, showing your working. Remember to state the units of your answers.

[4]

(c) Your answers to (b) should represent approximately the initial rate of each reaction. Hence explain which of the two possible relationships between rate and concentration (shown at the top of the previous page) is correct.

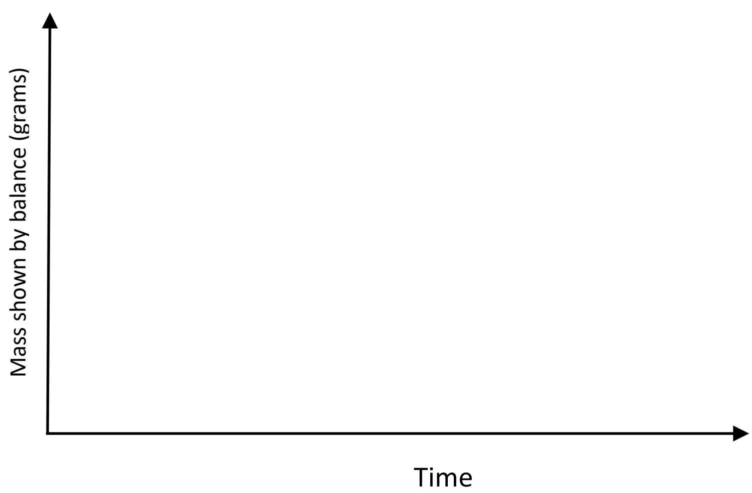
[3]

Charlotte investigated the same reaction, but using the apparatus shown below. She placed the reaction flask on a balance and recorded the mass shown by the balance at suitable time intervals.



(d) Using the axes below, sketch the form of the graph which Charlotte should obtain when she plots her results. You do not need to estimate any numerical values or add scales to the axes.

[2]



(e) What was the purpose of the cotton wool in the neck of the flask? Put a cross in the correct box.

☐ To stop carbon dioxide escaping from the flask.

☐ To stop liquid droplets escaping from the flask.

☐ To stop calcium carbonate escaping from the flask.

☐ To stop air entering the flask.

[1]

[End of Paper]

Paper Notes: 13+ Science Question Paper (13+ Science Past Paper (2022))

Compiled by SATs-Papers.co.uk to help you get the most from this paper.

Overview

This is **Eton College's King's Scholarship Examination 2022, Science 2 (Data Analysis)**, a 30-minute paper designed to assess candidates' ability to interpret experimental data, construct and analyse graphs, perform stoichiometric calculations, and deduce rate laws from experimental results. The paper is one component of Eton's **13+ entrance examination** for boys applying for a King's Scholarship (a prestigious award covering full fees), and it focuses exclusively on data handling and quantitative reasoning in a chemistry context rather than testing breadth of knowledge.

The paper comprises **two multi-part questions** with a combined total of **30 marks**. Calculators are permitted and all working must be shown. The first question centres on the thermal decomposition of limestone (calcium carbonate) and requires candidates to complete a results table, plot a graph, identify an anomalous data point, perform a molar mass calculation, and estimate the purity of a sample using the line of best fit. The second question investigates the reaction between calcium carbonate and hydrochloric acid, requiring interpretation of gas-volume graphs, calculation of initial reaction rates, determination of the order of reaction with respect to acid concentration, and a sketch of mass-loss data.

This paper is suitable for high-achieving Year 8 students preparing for competitive 13+ entry to independent schools, particularly those aiming for academic scholarships. It assumes fluency with graph-plotting, basic stoichiometry, and the concept of proportionality, and it rewards precision, clear reasoning, and the ability to synthesise numerical and graphical information.

How this paper is organised

The paper is divided into **two questions** with a total of **30 marks** available. Question 1 (worth 18 marks across nine sub-parts) focuses on the decomposition of calcium carbonate and requires candidates to complete a table (1 mark), suggest experimental design rationale (2 marks), plot and analyse a graph (6 marks combined for plotting, identifying an anomalous point, and drawing a line of best fit), perform a stoichiometric calculation (4 marks), use the graph to estimate purity (4 marks), and state an assumption about impurities (1 mark).

Question 2 (worth 12 marks across five sub-parts) examines the reaction of calcium carbonate with hydrochloric acid. Candidates must deduce relative acid concentrations from graph data (1 mark), calculate initial reaction rates from a zoomed-in graph (4 marks), determine the correct rate law by comparing the ratio of rates to the ratio of concentrations (3 marks), sketch a mass-loss graph for an alternative experimental method (2 marks), and identify the purpose of cotton wool in the apparatus (1 mark, multiple-choice).

The **time allowed is 30 minutes**, which means candidates must work efficiently, allocating roughly 11 minutes to Question 1 and 7 minutes to Question 2, with time reserved for checking. The paper is printed across eight pages including the cover sheet, with graph grids and answer spaces provided.

Topics covered

- Thermal decomposition of calcium carbonate: writing and interpreting the equation $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$, understanding mass loss due to gas evolution
- Experimental design and limitations: justifying sample size constraints based on balance precision and heating time requirements
- Graph construction: selecting appropriate scales, plotting points accurately, labelling axes with quantities and units, ensuring the origin is included
- Identifying anomalous data: recognising outliers on a scatter plot, drawing a line of best fit that excludes anomalous points and passes through the origin
- Stoichiometric calculations using relative atomic masses: calculating the mass of CO_2 lost when a given mass of pure $CaCO_3$ decomposes, showing all working steps
- Using a calibration graph to estimate purity: reading mass loss from the line of best fit for a 10.0 g sample, calculating percentage purity by comparing experimental to theoretical mass loss
- Reaction of calcium carbonate with hydrochloric acid: interpreting volume-time graphs, understanding that total gas volume indicates the limiting reagent (acid), deducing relative concentrations from plateau values
- Rate of reaction and concentration: calculating initial rate from the gradient of a tangent or initial slope, comparing rates when concentration is doubled to determine whether rate is proportional to [acid] or $[acid]^2$
- Alternative experimental methods: sketching a mass-loss graph for the same reaction measured on a balance, understanding that mass decreases as CO_2 escapes, with the curve levelling off when reaction is complete
- Experimental safety and technique: recognising the purpose of cotton wool (to prevent liquid droplets escaping without obstructing gas release)

How to use this paper for revision

- Practise plotting graphs with sensible scales: aim to use at least half the grid in both directions, and ensure your axes are labelled with both quantity and unit (e.g. 'Mass lost (g)' not just 'Mass').
- When identifying anomalous points, check whether each point follows the overall trend. An anomaly typically arises from incomplete reaction, measurement error, or impure samples.
- For stoichiometry, always start by calculating the relative formula mass (Mr) of all reactants and products in the equation, then use ratios to find the mass change.
- When drawing lines of best fit, use a ruler and ensure the line passes through or very close to the origin if the relationship is directly proportional (i.e. zero input gives zero output).
- To calculate rate from a graph, draw a tangent to the curve at the point of interest (or use the initial straight section) and find the gradient: rate = change in y ÷ change in x, with correct units.
- If asked to compare two rates, form a ratio (e.g. rate A ÷ rate B) and see whether it matches the ratio of concentrations (linear relationship) or the square of the ratio (quadratic relationship).
- When sketching a graph, focus on the overall shape rather than precise numbers: show whether the curve rises or falls, whether it levels off, and where it starts and ends.

Common mistakes to avoid

- Forgetting to include units in answers, particularly when calculating rates (e.g. writing '65' instead of '65 cm^3/minute') or when labelling graph axes.
- Drawing a line of best fit that does not pass through the origin when the relationship is directly proportional, or forcing the line through every point (including anomalies) instead of showing the general trend.
- Miscalculating Mr by forgetting to multiply the relative atomic mass by the number of atoms in the formula (e.g. treating $CaCO_3$ as 40 + 12 + 16 = 68 instead of 40 + 12 + 3×16 = 100).
- Confusing concentration with volume of gas produced: a higher concentration of acid means the reaction goes faster initially, but if the same amount of calcium carbonate is used, the total volume of gas depends on which reagent is limiting.
- Incorrectly reading values from a graph, especially when the scale does not go up in ones or tens; always count grid squares carefully and interpolate between gridlines if necessary.
- In part (c) of Question 2, stating which rate law is correct without explaining the reasoning (i.e. comparing the ratio of rates to the ratio of concentrations or their squares).

Exam technique

With **30 minutes** for 30 marks, you have an average of one minute per mark, but some questions (particularly graph-plotting and multi-step calculations) require more time than single-mark recall questions. Read each question carefully and note the mark allocation in square brackets; if a question is worth 4 marks, your answer should include four distinct pieces of working or reasoning.

Attempt **Question 1 first** if you are confident with graph work and stoichiometry, as it carries more marks (18 out of 30) and the later parts depend on earlier results. If you cannot complete part (g), use the substitute value given in part (h) so you can still access those 4 marks. Show all working for calculations; even if your final answer is incorrect, you can earn method marks for a correct approach. When plotting graphs, use a sharp pencil and work methodically: mark each point with a small cross or dot, double-check coordinates, and use a ruler for the line of best fit.

For **Question 2**, read the graphs carefully and note that the second graph is a zoomed-in version of the first 0.5 minutes, which allows you to measure initial rates more accurately. When calculating gradients, choose two points that are easy to read and far apart (to minimise percentage error), and always subtract in the correct order (rise over run). If you run short of time, Question 2(e) is a quick one-mark multiple-choice question that you should not miss. Finally, check that all answers have appropriate units and significant figures, and that your line of best fit in Question 1 passes through the origin as instructed.

What to revise alongside this paper

Students should be confident with **mole calculations and reacting masses**, including how to calculate Mr from Ar values and how to use the molar ratio from a balanced equation to find the mass of products formed. This requires fluency with the relationship: moles = mass ÷ Mr, and the ability to scale quantities proportionally.

Reaction kinetics is central to Question 2: revise how temperature, concentration, surface area, and catalysts affect the rate of reaction, and practise interpreting rate graphs (recognising that a steeper gradient means a faster reaction, and that the curve levels off when a limiting reagent is used up). Understanding the difference between **zero-order, first-order, and second-order** relationships is important for the rate law question, though the paper guides you through the comparison rather than requiring prior knowledge of formal definitions.

For progression, students should explore **collision theory** (explaining why concentration and temperature affect rate at a particle level), more complex stoichiometry (including limiting reagents and percentage yield), and practical skills such as measuring gas volumes with a gas syringe or using a balance to monitor mass loss during a reaction. Familiarity with **error analysis** (percentage uncertainty, systematic versus random errors) will help explain anomalies and improve experimental design.

Key terms

> **Thermal decomposition**, **Calcium carbonate ($CaCO_3$)**, **Calcium oxide (CaO)**, **Relative atomic mass (Ar)**, **Relative formula mass (Mr)**, **Stoichiometry**, **Anomalous data point**, **Line of best fit**, **Percentage purity**, **Rate of reaction**, **Initial rate**, **Gradient (of a graph)**, **Concentration**, **Order of reaction**, **Proportionality (directly proportional, proportional to the square)**