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Eton College 13+ Science 2023

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CONTENTS

Eton College King's Scholarship Examination 2023

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]

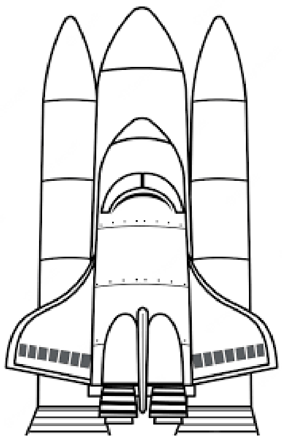
Do not turn over until told to do so.

1. This question is about forces.

A rocket similar to that which launched NASA's space shuttle has a total mass before take-off of 2000 tonnes (1 tonne = 1 x 10^3 kg), and provides a thrust at take-off of 24 MN (1 MN = 1 x 10^6 N).

The thrust remains constant and g, the gravitational field strength, remains constant at 10 N/kg. Air resistance can be neglected.

(a) Label the diagram below using arrows to represent the forces acting upon the rocket during take-off. Include numerical values – *calculations are required.* **[4]**



Newton's second law of motion states that if an object has an unbalanced force, F, acting upon it the object will accelerate in proportion to its mass, m, according to the formula:

$$F = ma$$

(b) Calculate the acceleration, a, of the rocket at take-off. Your answer should include a suitable unit.

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____ **[3]**

The acceleration of an object can be considered to be the *change in speed* of an object per second.

(c) To reach orbit, the shuttle has to achieve a speed of 8.0 km/s. Calculate the time taken, in seconds, for the shuttle to achieve this speed given the acceleration calculated in (b).

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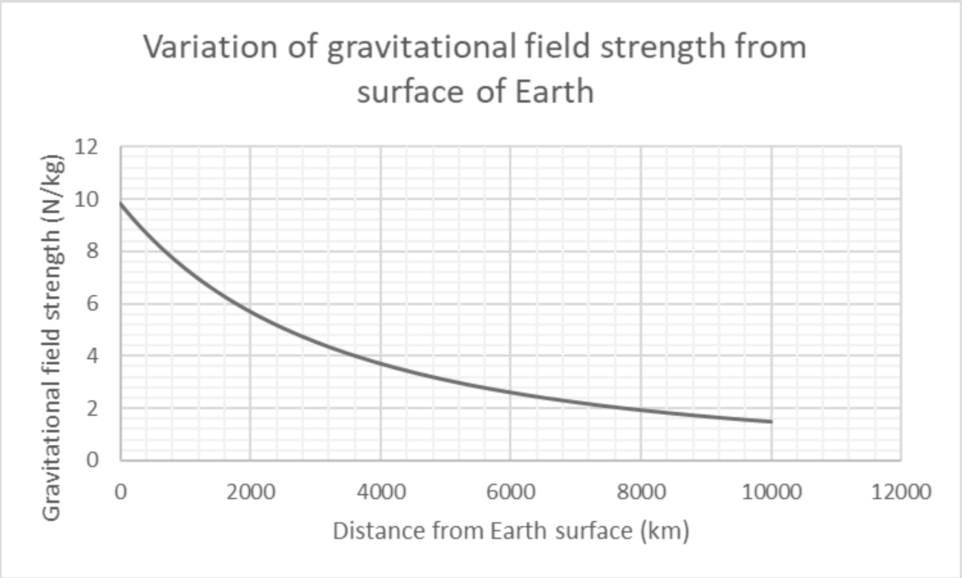
____ **[3]**

In fact, the gravitational field strength is not constant during the rocket's journey. The graph below illustrates the variation in the Earth's gravitational field with height above the Earth's surface.



(d) In part (c) we assumed that gravitational field strength, g, was constant. State the effect of varying gravitational field strength on the time taken for the rocket to reach a speed of 8 km/s.

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____ **[1]**

(e) Using your understanding of physics, explain your answer to part (d).

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____ **[3]**

2. This question is about organisms.

One of the ways scientists can confirm that organisms belong to a particular Kingdom is by looking at their cells. The cells of organisms in different Kingdoms will have similarities and differences in their structures.

(a) Complete the table below by placing a tick in the box if a structure is present, and a cross if it is not.

Organelle	**Plant Cell**	**Animal Cell**
Cell Membrane		
Cell Wall		
Chloroplast		
Mitochondrion		
Nucleus		

[2]

(b) Fungi are organisms that belong to a kingdom of their own, separate to plants and animals. They share features with both. Fungal cells have cell membranes, cell walls, mitochondria and nuclei. They can be single-celled or multicellular.

Discuss whether fungi are more closely related to animals or plants.

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____ **[2]**

(c) Many fungi act as decomposers. They are responsible for breaking down and consuming any dead organisms that don't get eaten by another consumer. Read the passage below, then produce a food web featuring every organism mentioned, **plus fungi.**

"The grey squirrel is an invasive species in the United Kingdom. Owing to its size, it can often outcompete native red squirrels for food. Both like to store acorns from oak trees for the winter months. Despite its many advantages, the grey squirrel is still hunted by foxes just as much as the red squirrel is. Foxes will supplement their diets with rabbits, which are easy to hunt as they cannot climb oak trees and often forage for grasses at ground level."

[4]

(d) Suggest what would happen to the population of fungi in the ecosystem from part (c), above, if a viral disease spread through the squirrel population and killed all the squirrels.

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____ **[2]**

(e) A lichen is an organism composed of a fungus and a cyanobacterium, living in a symbiotic relationship.

There are three types of symbiotic relationships:

- Mutualism – where two different species benefit each other.
- Commensalism – where two species have no significant impact on each other.
- Parasitism – where one species has a negative effect on another.

In this case, the fungus relies on the cyanobacterium to live. Cyanobacteria are able to live as part of a lichen with a fungus, or on their own entirely.

Design an experiment that would confirm whether the parts of a lichen (fungus and cyanobacterium) were exhibiting a mutualistic, commensal, or parasitic relationship.

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____ **[4]**

3. This question is about plants.

Photosynthesis is a process by which plants, algae and certain bacteria use the energy from sunlight to make food.

(a) Write the word equation for photosynthesis in the space below.

____ **[1]**

(b) Explain why photosynthesis is such an important process for life on Earth.

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____ **[3]**

One of the most famous experiments to investigate photosynthesis in plants was carried out by the chemist Jan Baptist van Helmont in 1648. He weighed a young willow tree before planting it in a large pot containing a known mass of dry soil, after which he did nothing other than water it regularly for the next five years. After five years, he discovered that the willow tree weighed 74 kg more than it did at the start and that the dry mass of the soil was largely unchanged, having declined just a few grams. Van Helmont concluded that the plant had grown by drinking water.

(c) Explain whether or not you agree with his conclusion.

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____ **[3]**

(d) Suggest a reason why the mass of the soil had declined.

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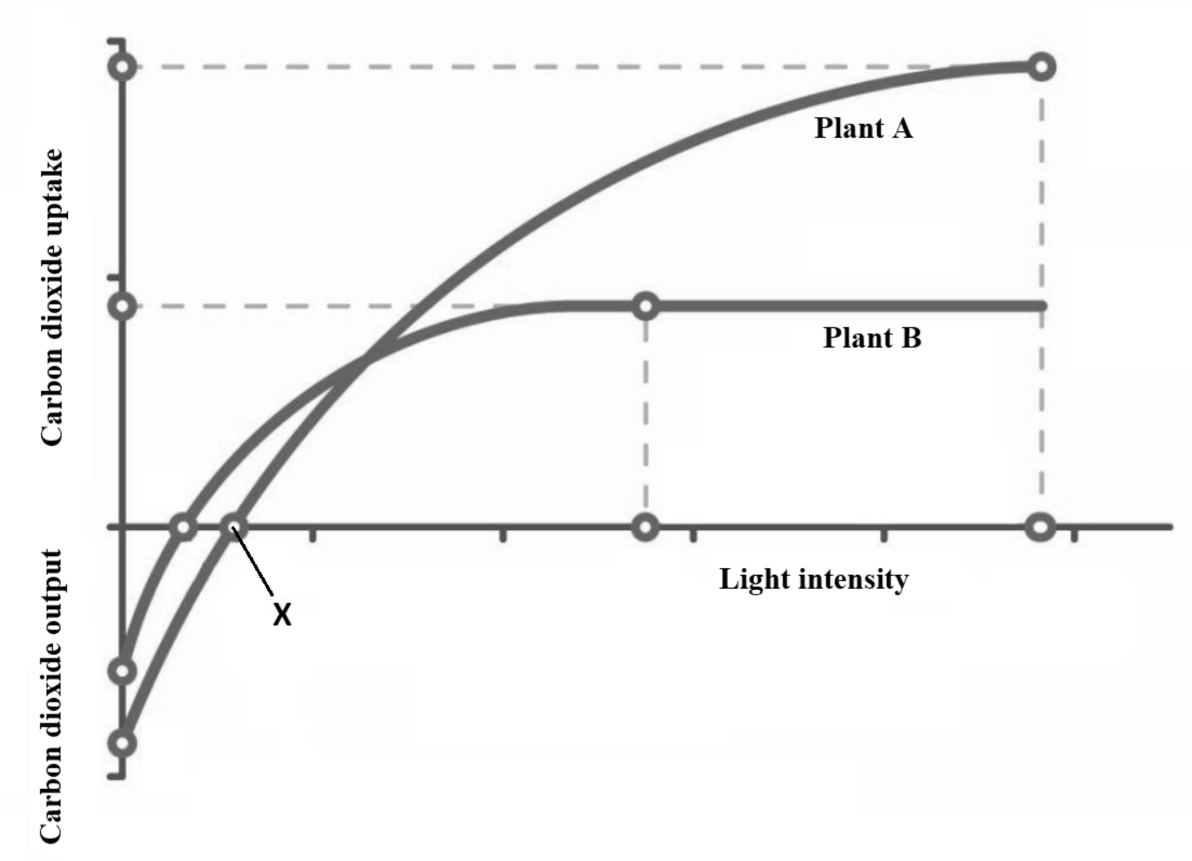
____ **[2]**

Another experiment was carried out to investigate the effect of light intensity on gas exchange in two different plant species. The graph below shows the volume of CO_2 (carbon dioxide) taken up or given out per hour at different light intensities for the two species, A and B.



(e) Explain why there is no net gas exchange at point X for plant A.

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____ [2]

(f) One of these two plant species has evolved to survive, grow, and reproduce on the forest floor, below a canopy of taller plants. State which one you think it is and explain your choice using the information provided.

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____ [3]

4. This question is about carbon dioxide and its associated chemical reactions.

Some of the reactions described are reversible: they can go in either direction, depending on the conditions. The symbol $\rightleftharpoons$ indicates a reversible reaction.

Calcium carbonate occurs in chalk and limestone. It is used to produce the solids calcium oxide and calcium hydroxide. Calcium carbonate decomposes when strongly heated in an open container:

$$CaCO_3 \rightleftharpoons CaO + CO_2 \qquad \textbf{Reaction 1}$$

Calcium oxide reacts readily with water to form calcium hydroxide:

$$CaO + H_2O \rightarrow Ca(OH)_2 \qquad \textbf{Reaction 2}$$

"Limewater" is a solution of calcium hydroxide in water. Its reaction with carbon dioxide is:

$$Ca(OH)_2(\quad) + CO_2(\quad) \rightarrow CaCO_3(\quad) + H_2O(\quad) \qquad \textbf{Reaction 3}$$

(a) State symbols, (s, l, g or aq), are sometimes included in chemical equations to indicate whether each substance is present as a solid, a liquid, a gas, or dissolved in water as a solution (aqueous). Fill in the empty brackets in the equation for **Reaction 3** to show the correct state symbols. **[1]**

(b) Some calcium oxide was placed in a dish on a laboratory bench and weighed each day. Suggest two reasons why an increase in mass might be observed.

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______________________________ **[2]**

(c) It has been suggested that **Reaction 3** could be used to remove carbon dioxide from the atmosphere and so prevent global warming. Use the information in the question to suggest one difficulty with this approach.

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______________________________ **[1]**

Calcium carbonate, carbon dioxide and water will combine together in a reversible reaction to produce an aqueous solution of calcium hydrogencarbonate, $Ca(HCO_3)_2$.

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca(HCO_3)_2 \qquad \textbf{Reaction 4}$$

(d) Carbon dioxide was bubbled into a test tube of limewater. The bubbling was continued for a long time. What would you expect to see?

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______________________________ **[2]**

(e) Tap water containing dissolved calcium hydrogencarbonate is known as "hard water". Abigail heated some hard water in an evaporating basin, and then told her teacher that she had produced some solid calcium hydrogencarbonate. The teacher said this was not correct. Explain what had happened.

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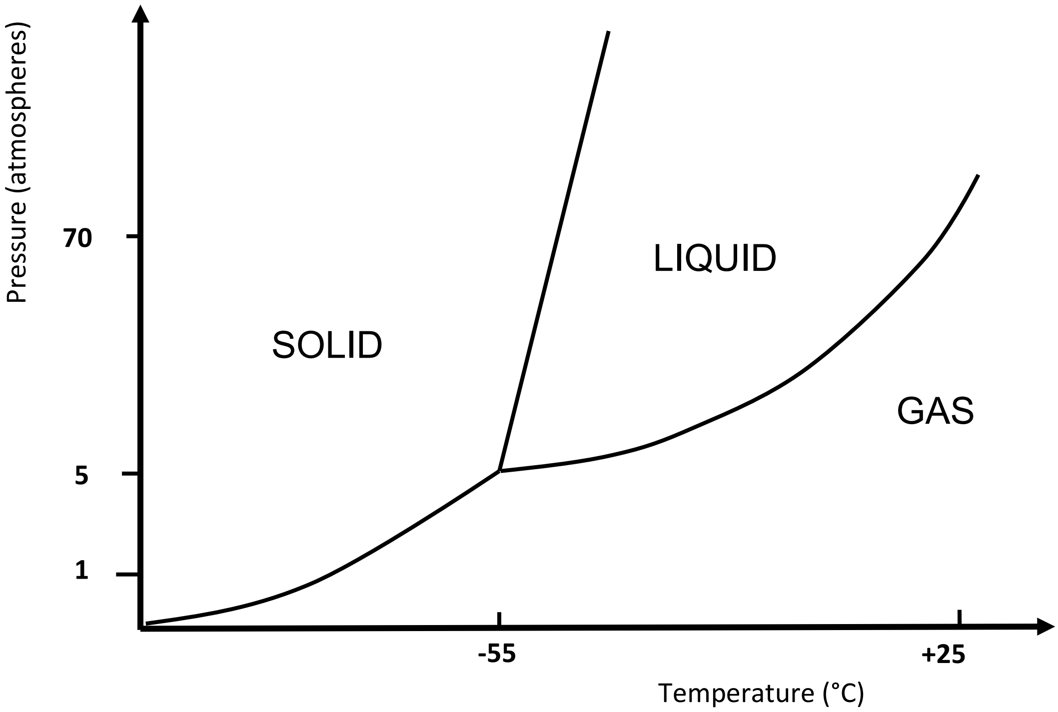
____ **[2]**

A "phase diagram" is used to show at which temperatures and pressures a substance will exist as a solid, a liquid or a gas. The phase diagram for carbon dioxide is shown. One "atmosphere" is the normal pressure at sea level on the Earth. The scales on the axes have been adjusted to make the important features of the diagram stand out clearly.



(f) Use the phase diagram to explain what will happen if a test tube of carbon dioxide gas is cooled to a very low temperature. Show on the diagram how you deduced your answer.

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____ **[2]**

(g) Explain how a fire extinguisher, kept in a building at 25°C, can contain liquid carbon dioxide.

____ **[1]**

(h) Beatrice commented, "The phase diagram tells me that liquid carbon dioxide is less dense than solid carbon dioxide". Explain how Beatrice deduced this from the diagram. You may add notes to the diagram if this helps your answer.

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____**[2]**

(i) Some bacteria can produce energy from the reaction of carbon dioxide with hydrogen:

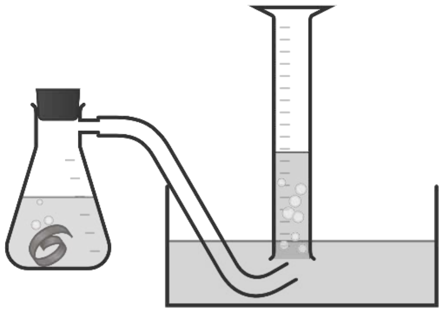
$$CO_2 + \ldots\ldots H_2 \rightarrow CH_4 + \ldots\ldots H_2O$$ **Reaction 5**

The equation shown needs to be balanced, by adjusting the numbers of molecules so that for each type of atom, the total number present before the reaction is the same as the total number in the products. Add numbers to the two dotted lines to balance the equation.

[1]

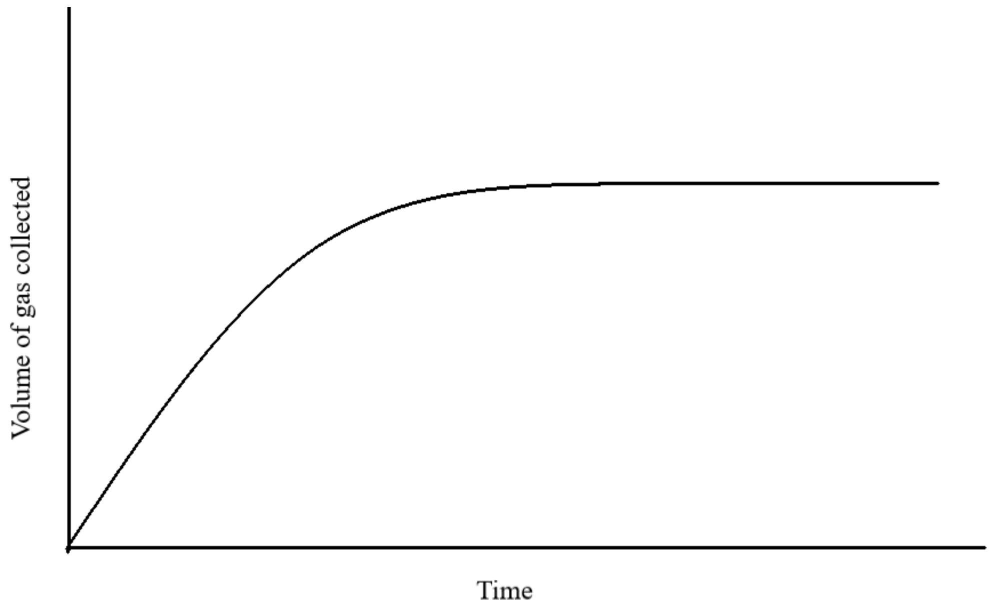
5. This question is about rates of reaction.

The rate of a chemical reaction between magnesium and hydrochloric acid is measured by Cassandra. Cassandra uses the following experimental set up with the hydrogen gas produced being collected over water in a measuring cylinder:



The temperature is maintained at a steady 25°C by a heater, and a magnetic stirrer ensures that the acid concentration is even throughout. The magnesium is present as a coil of thin ribbon, so all sides are exposed to the acid. There is excess acid present.

The following results are obtained:



(a) Explain, in terms of particles, the shape of the graph.

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____ **[3]**

The reaction is performed again with everything the same except that the magnesium ribbon is half the length.

(b) State and explain in terms of particles what is different about the new graph plot of results compared to the old graph plot (you may draw on the graph plot above if you wish).

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____ **[3]**

Another student, Thomas, decides to use the same equipment to examine the rate of reaction between calcium carbonate and hydrochloric acid, collecting carbon dioxide gas this time.

(c) Explain what would be different about the shape of the graph plot obtained in this case.

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____ **[3]**

A third student, William, researches into reactions between two chemicals which take place in solution.

The equation for the reaction is:

$$CH_3CH_2CH_2CH_2Br + OH^- \rightarrow CH_3CH_2CH_2CH_2OH + Br^-$$

William finds that when the concentration of $CH_3CH_2CH_2CH_2Br$ is doubled the rate doubles and when the concentration of OH^- doubles the rate also doubles. William theorises that this is because the reaction takes place in just one step and so depends on a collision between $CH_3CH_2CH_2CH_2Br$ and OH^-.

He writes the relationship between rate and concentration down as a rate equation:

$$\text{Rate} = k[CH_3CH_2CH_2CH_2Br][OH^-]$$

$[CH_3CH_2CH_2CH_2Br]$ means 'concentration of $CH_3CH_2CH_2CH_2Br$' and k is a constant of proportionality.

He then looks at a similar reaction:

$$C(CH_3)_3Br + OH^- \rightarrow C(CH_3)_3OH + Br^-$$

This time William finds that the rate doubles when the concentration of $C(CH_3)_3Br$ doubles, but is unaffected by the concentration of OH^-

(d) Write the rate equation for the reaction.

____ **[1]**

He says that this means that the reaction cannot take place in a single step.

(e) Explain why William is correct.

____

____ **[2]**

William then suggests that the reaction takes place in two steps:

1. $C(CH_3)_3Br \rightarrow C(CH_3)_3^+ + Br^-$

2. $C(CH_3)_3^+ + OH^- \rightarrow C(CH_3)_3OH$

Further research shows this to be correct.

(f) Explain which of the two steps must be the slower.

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____

____ **[2]**

[End of paper]

Paper Notes: 13+ Science Question Paper (13+ Science Past Paper (2023))

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 Science 1 (Theory) paper** from **2023**, a genuine past paper set for candidates applying for the prestigious King's Scholarship at Eton. The examination is aimed at **13+ entry** (Year 9) and assesses a broad range of scientific knowledge and problem-solving skills across physics, biology, and chemistry within a **60-minute time limit**.

The paper comprises **five major questions** worth **70 marks in total**, each targeting a distinct scientific discipline. Question 1 explores **forces and Newton's laws** in the context of rocket propulsion; Question 2 examines **biological classification, cell structure, and ecosystems**; Question 3 focuses on **photosynthesis and plant physiology**; Question 4 tackles **chemical reactions involving calcium compounds and carbon dioxide phase behaviour**; and Question 5 investigates **rates of chemical reactions and collision theory**. All working must be shown for calculations, and a calculator is permitted.

This paper is designed for academically able students competing for one of Eton's most selective scholarships. The questions demand high-level reasoning, the ability to interpret graphs and diagrams, and fluency in applying scientific principles across unfamiliar contexts. It is an excellent resource for students preparing for rigorous 13+ science entrance exams at independent schools.

How this paper is organised

The paper is divided into **five questions** of varying length, together worth **70 marks**. Each question is subdivided into multiple parts (a, b, c, etc.), with individual mark allocations shown in square brackets after every sub-question. The layout provides generous white space for written and drawn responses, and every page reminds candidates to write their candidate number at the top.

Question 1 (forces) is worth **14 marks** across five parts; Question 2 (organisms) is worth **10 marks** across five parts including a food-web diagram; Question 3 (photosynthesis) is worth **14 marks** across six parts; Question 4 (carbon dioxide chemistry) is worth **14 marks** across nine parts; and Question 5 (rates of reaction) is worth **18 marks** across six parts. The total exam duration is **60 minutes**, which works out to roughly 51 seconds per mark, so efficient time management is essential.

Candidates are instructed to attempt **all questions** and to write answers in the spaces provided on the paper itself. The document runs to **14 pages** and includes diagrams, data tables, and a phase diagram that candidates must interpret and annotate.

Topics covered

- Newton's second law and calculation of unbalanced forces on a rocket with varying gravitational field strength
- Cell organelles in plant, animal, and fungal cells, including comparative analysis of kingdom-level structures
- Food webs and trophic relationships in UK woodland ecosystems, including invasive species and decomposers
- Designing controlled experiments to distinguish mutualism, commensalism, and parasitism in lichen symbiosis
- Photosynthesis word equation, its importance to life on Earth, and interpretation of van Helmont's willow tree experiment
- Gas exchange in plants at varying light intensities, including compensation points and adaptations to low-light forest-floor environments
- Reversible reactions of calcium carbonate, including thermal decomposition, limewater tests, and the chemistry of hard water
- Phase diagrams for carbon dioxide, including pressure-temperature relationships and predictions about solid, liquid, and gas phases
- Rate equations for organic substitution reactions, including first-order and second-order kinetics and multi-step reaction mechanisms
- Particle theory explanations of reaction rates, including surface area effects and collision frequency in heterogeneous reactions

How to use this paper for revision

- Practise converting units carefully (e.g. tonnes to kilograms, meganewtons to newtons, km/s to m/s) before substituting into formulae, as careless unit errors lose marks even if the method is correct.
- For food-web questions, draw arrows pointing from prey to predator and double-check that every organism mentioned appears in your web, including producers and decomposers.
- When asked to explain using particle theory, always refer explicitly to particles (atoms, molecules, ions) and their motion, collisions, or concentration, not just to abstract 'reactions'.
- For phase diagram questions, trace a vertical or horizontal line on the diagram to show your reasoning and annotate it clearly so examiners can follow your logic.
- In rate-of-reaction questions involving changing conditions (e.g. halving the magnesium), sketch a second curve on the original graph to compare visually and explain differences in both gradient and final volume.
- When balancing chemical equations, count each type of atom separately on both sides and adjust coefficients systematically; don't rush this step under time pressure.
- If a question asks you to 'suggest' or 'discuss', you must give a reasoned argument, not just a one-word answer; aim for at least two sentences with a clear because-clause or comparison.

Common mistakes to avoid

- Forgetting to include the weight (gravitational force) of the rocket when calculating the net force in Question 1(a), leading to an incorrect acceleration value in part (b).
- Confusing the direction of arrows in food webs (prey to predator) or omitting fungi entirely despite the instruction to include it, which loses straightforward marks.
- Stating that van Helmont was correct without mentioning carbon dioxide from the air, or failing to explain that photosynthesis uses CO_2 as a carbon source for the tree's mass gain.
- Misreading the phase diagram and predicting that carbon dioxide gas will turn into liquid when cooled at atmospheric pressure, when in fact it sublimes directly to solid (dry ice).
- In the rate equation questions, writing Rate = $k[C(CH_3)_3Br][OH^-]$ when the experimental data shows the rate is independent of $[OH^-]$, indicating poor attention to the given observations.
- Leaving reaction mechanism questions blank because they appear unfamiliar; even partial reasoning about which step must be slower (the one that matches the rate equation) earns credit.

Exam technique

Start by reading through the entire paper quickly to identify which questions look most familiar and which will require the most thought. Tackle straightforward recall or calculation questions (e.g. cell organelles, force diagrams) first to bank easy marks, then return to extended explanations and experimental design tasks. Each mark is worth roughly 51 seconds, so if a question is taking significantly longer than its mark allocation, flag it and move on.

For calculation questions, always write down the formula you are using, substitute values with units, and show each arithmetic step. Even if your final answer is incorrect, clear working earns method marks. If a question provides a graph or diagram, annotate it directly as part of your answer (e.g. drawing lines on the phase diagram, sketching a second curve for the magnesium experiment) because examiners are looking for visual reasoning as well as written explanation.

Leave time at the end to review your answers, particularly checking that you have answered every part of every question. It is easy to miss a sub-part on a long question like Question 4 or Question 5. Use any remaining minutes to expand one-sentence answers into fuller explanations, as marks are often awarded for additional reasoning even if the initial point is already made.

What to revise alongside this paper

Students working through this paper should ensure they are confident with **GCSE-level physics calculations** (particularly forces, mass, acceleration, and energy) and can manipulate algebraic formulae fluently. Revision of **graph interpretation skills** is essential, especially reading off values, identifying trends, and sketching comparative plots for changed experimental conditions.

For the biology content, review **food chains and webs, energy transfer through ecosystems, and the five kingdoms classification** in detail. A solid understanding of **plant and animal cell structures** at electron-microscope level will support Question 2. In chemistry, revisit **balancing equations, writing word and symbol equations, and understanding reversible reactions and Le Chatelier's principle**, which underpin the calcium carbonate sequence in Question 4.

Beyond this paper, students aiming for Eton's King's Scholarship should practise with other independent school 13+ science papers (for example, Westminster, St Paul's, Winchester) and work through **ISEB Level 3 science past papers**, which cover similar breadth and demand comparable reasoning. Extension work on **collision theory, activation energy, and organic reaction mechanisms** (SN1 and SN2 pathways) will deepen understanding of Question 5.

Key terms

> **Newton's second law (F = ma)**, **Gravitational field strength**, **Organelle (chloroplast, mitochondrion, nucleus, cell wall, cell membrane)**, **Symbiosis (mutualism, commensalism, parasitism)**, **Food web / trophic level / decomposer**, **Photosynthesis (reactants and products)**, **Compensation point (gas exchange equilibrium)**, **Reversible reaction (⇌ symbol)**, **Limewater (calcium hydroxide solution)**, **Phase diagram (solid, liquid, gas regions)**, **Sublimation (solid to gas without liquid phase)**, **Rate equation (k[reactant] notation)**, **First-order and second-order kinetics**, **Reaction mechanism (multi-step pathway)**, **Rate-determining step (slowest step in a mechanism)**

Eton College King's Scholarship Examination 2023

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.

For examiners' use only.

Total [30]	

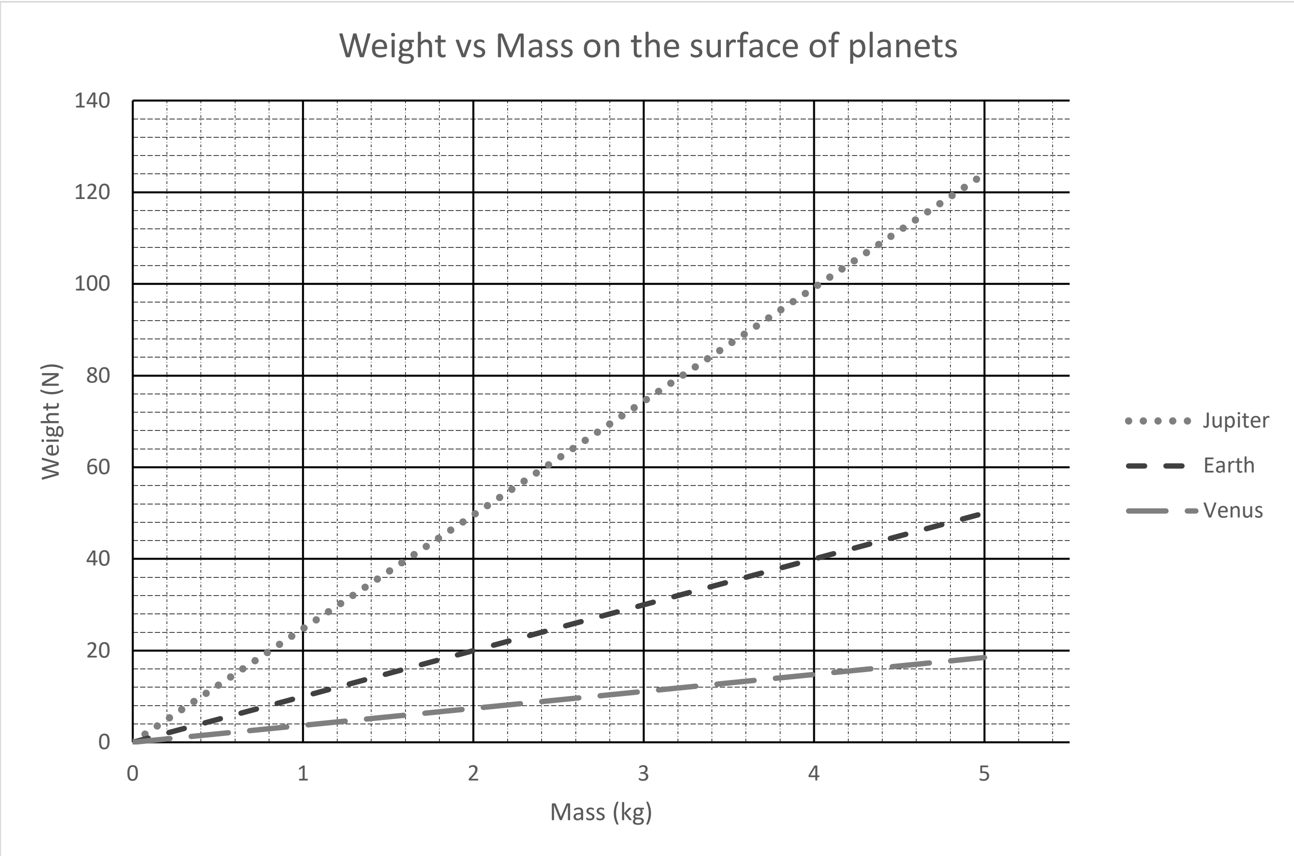
Do not turn over until told to do so.

1. This question is about mass and weight and requires the use of:

$$W = mg$$

Here, W is the weight of an object, m is the mass of an object and g is the gravitational field strength.

Mr Spock wants to investigate gravity on the surface of three planets in our solar system. He collects data and draws the graph below.



(a) What feature of the lines allows Spock to calculate the gravitational field strength for each planet?

____ **[1]**

(b) Spock has a mass of 80 kg. Using the graph, complete the table.

Planet	**Gravitational Field Strength, *g* (N/kg)**	**Spock's Weight (N)**
Venus		
Earth		
Jupiter		

[6]

(c) Describe two differences in the flight of the ball that Spock would observe when throwing a ball up on Earth and throwing a ball up on Venus (assuming the balls are thrown up at the same speed).

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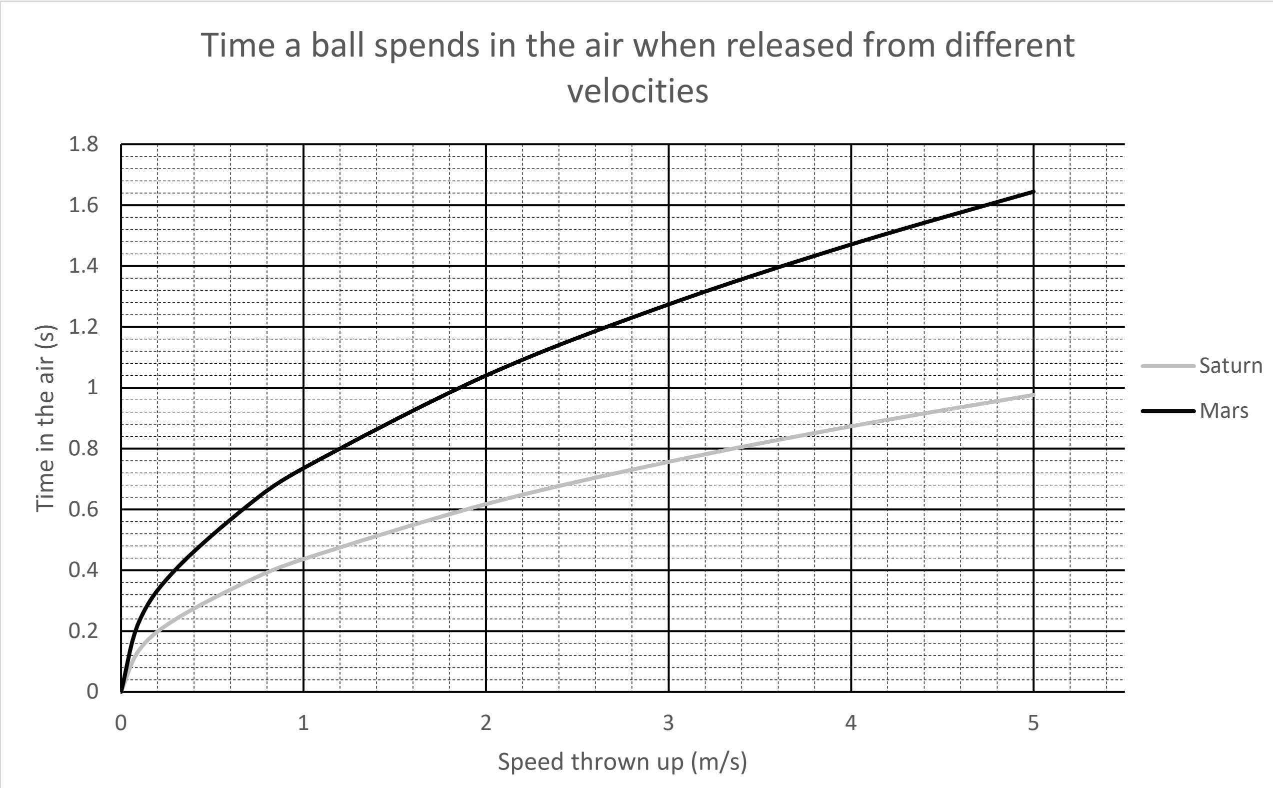
____ **[2]**

Spock travels to Saturn and Mars to examine how long his ball stays in the air having been thrown up at different speeds. His findings are shown by the graph below.



(d) Circle the correct relationship between time spent in the air, T, and the speed thrown up, u. g is the gravitational field strength of the planet in question. Justify your choice using data from the graph.

$$T = \sqrt{\frac{2g}{u}} \qquad T = \sqrt{\frac{2u}{g}} \qquad T = \frac{2u}{g} \qquad T = \sqrt[3]{\frac{2u}{g}}$$

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____ **[4]**

(e) Using the graph, determine the value of g on Saturn.

____ **[3]**

(f) How does the mass of the ball thrown affect the time it spends in the air?

____ **[1]**

Spock conducts some further research around Earth regarding how gravitational field strength varies with height above the Earth's surface.

Height above Earth's surface (km)	Gravitational Field Strength, g (N/kg)
1000	7.3
2000	5.7
3000	4.5
4000	3.7

(g) Plot a graph of Spock's data, including a suitable line of best fit.

[5]

(h) What does the y-intercept of your graph represent? (Note that the y-intercept may not be visible with your choice of scale.)

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____ **[2]**

(i) Mount Everest is 9 km tall. Comment on the value of the gravitational field strength at the summit of Mount Everest.

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____ **[2]**

(j) The Moon is 400,000 km away from the Earth. Comment on the value of the Earth's gravitational field strength at the location of the Moon.

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____ **[1]**

(k) Spock makes a journey in his spaceship, leaving from the surface of the Earth and travelling to the Moon in a straight line. Describe the forces acting on Spock throughout the journey.

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____ **[3]**

[End of paper]

Paper Notes: 13+ Science Question Paper (13+ Science Past Paper (2023))

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

Overview

This is **Science 2 (Data Analysis)**, published by **Eton College** as part of the **King's Scholarship Examination 2023**. The paper is a **30-minute assessment** worth **30 marks** that tests candidates' ability to interpret scientific data, apply quantitative reasoning, and analyse relationships between physical variables. Calculators are permitted and all working must be shown.

The entire paper focuses on **gravitational field strength**, weight, and mass across different planetary environments. Candidates work with **W = mg** throughout, extracting data from graphs, plotting their own graphs with lines of best fit, and making predictions based on trends. The scenario follows Mr Spock investigating gravity on Venus, Earth, Jupiter, Saturn, and Mars, then examining how gravitational field strength varies with altitude above Earth.

This paper suits candidates preparing for **13+ entrance** to top independent schools, particularly those applying for the King's Scholarship at Eton. It demands fluency with graph interpretation, gradient calculation, and the ability to comment critically on the reliability of extrapolation. The inclusion of a complete data-handling cycle (reading graphs, calculating from them, plotting new graphs, and evaluating their scope) makes this a rigorous test of scientific literacy.

How this paper is organised

The paper comprises **one extended question** with **11 sub-parts (a to k)**, totalling **30 marks**. The question begins with graph interpretation tasks worth 1 and 6 marks, followed by short-answer comparisons and a formula selection with justification worth 4 marks. Candidates must then perform calculations from graphical data (3 marks) and consider the effect of mass on projectile motion (1 mark).

Midway through, the paper shifts to **independent graph plotting**. Candidates are given a table of gravitational field strength values at different altitudes and must plot these points with a suitable line of best fit (5 marks). The next section requires interpretation of the y-intercept (2 marks) and commentary on the validity of using the graph to estimate field strength at Mount Everest (9 km) and at the Moon (400,000 km), testing understanding of interpolation versus extrapolation.

The final part (3 marks) asks for a description of forces acting on Spock during a journey from Earth to the Moon. All answers are written in spaces provided on the paper itself. The layout is clear, with graphs reproduced at a readable scale and ample space for calculations, encouraging candidates to show full working as instructed.

Topics covered

- The relationship between weight, mass, and gravitational field strength using W = mg
- Extracting and interpreting gradient from linear graphs to determine physical constants (gravitational field strength)
- Using graphical data to calculate the weight of an object on different planets (Venus, Earth, Jupiter)
- Comparing projectile motion under different gravitational conditions (flight time, maximum height)
- Identifying functional relationships between variables (time in air vs. initial speed) and justifying formula selection with numerical evidence
- Calculating gravitational field strength from time-of-flight data using algebraic rearrangement
- Understanding that mass does not affect time in the air for a projectile in a uniform gravitational field
- Plotting a graph from tabular data, choosing appropriate scales, and drawing a line of best fit
- Interpreting the physical meaning of the y-intercept of a graph (gravitational field strength at Earth's surface)
- Evaluating the validity of interpolation and extrapolation, including commenting on reliability when extending far beyond the data range
- Describing the behaviour of gravitational forces over long distances, including the transition between Earth's and the Moon's gravitational influence

How to use this paper for revision

- Revise how to calculate the **gradient** of a straight-line graph accurately, using a large triangle and showing clear working. Gradient is rise over run, and in this paper it represents gravitational field strength.
- Practise rearranging **W = mg** confidently in both directions. You should be able to find m given W and g, or g given W and m, without hesitation.
- When asked to select a formula, **test each option** with real numbers from the graph. Substitute one or two data points and see which formula gives a consistent answer.
- For graph-plotting tasks, choose a scale that uses **more than half the grid** in both directions. Label axes with units, plot points with crosses or dots, and draw a single smooth line of best fit.
- Understand the difference between **interpolation** (estimating within the data range) and **extrapolation** (predicting beyond it). Examiners often ask you to comment on reliability when extrapolating far beyond the measured range.
- Review the physics of **projectile motion** under gravity. The time a ball spends in the air depends only on initial speed and gravitational field strength, not on the mass of the ball.
- When a question asks you to 'comment', provide a **specific judgement** backed by reasoning. For example, 'The value will be slightly lower because...' is better than 'It will be different'.

Common mistakes to avoid

- Confusing **mass** and **weight**. Mass is measured in kg and does not change with location; weight is measured in N and depends on gravitational field strength.
- Misreading graph scales, especially when one square represents an unusual increment (e.g. 0.2 or 5 units). Always count the divisions carefully before reading off values.
- Forgetting to **show all working** in calculations. Even if you reach the correct answer, marks are often awarded for method, so write down each step clearly.
- Drawing a line of best fit that goes through every single point, creating a zig-zag. A best-fit line should be **smooth** and balance points above and below, not connect them dot-to-dot.
- Extrapolating confidently without acknowledging uncertainty. When a question asks about a value far outside the data range (e.g. 400,000 km when the table goes up to 4000 km), recognise that the trend may not continue and the estimate is unreliable.
- Stating that a heavier ball will spend longer in the air. In a vacuum or when air resistance is negligible, **mass does not affect time of flight** for a projectile thrown vertically.

Exam technique

With only **30 minutes** for 30 marks, you have roughly one minute per mark. Start by reading through the entire paper to identify which parts require calculations, which need graph work, and which are short explanations. Tackle the early graph-reading questions (parts a and b) first to build confidence, then move to the plotting task in part (g) while the graph skills are fresh.

When selecting the correct formula in part (d), do not guess. **Substitute actual values** from the graph (e.g. u = 4 m/s and T = 1.6 s for Mars) into each option and see which gives a sensible, consistent value for g. Show this working clearly. For the graph-plotting task, spend a moment planning your scale so that your points spread across most of the grid, and draw your line of best fit with a ruler.

In the commentary questions (parts i, j, and k), the examiner is looking for **physical reasoning**, not just a number. For instance, when asked about Mount Everest, note that 9 km is close to the data range (1000-4000 km) so interpolation or slight extrapolation is reasonable. For the Moon at 400,000 km, acknowledge that this is a huge extrapolation and the relationship may not hold. Always link your answer back to the physics: gravitational field strength decreases with distance from Earth's centre, but at the Moon's distance Earth's gravity is very weak and the Moon's own gravity dominates.

What to revise alongside this paper

Before attempting this paper, make sure you are confident with **straight-line graphs** and calculating gradients, including understanding that gradient represents rate of change. Revise the distinction between vector and scalar quantities, and why weight is a force (vector) while mass is a scalar. Practise using the formula **W = mg** in different contexts, including rearranging it to find unknown quantities.

After completing this paper, extend your study to **gravitational potential energy** (GPE = mgh) and how it links to weight. Investigate how gravitational field strength varies with distance according to the **inverse square law**, which explains why g decreases rapidly with altitude. Consider the motion of satellites and planets, where gravitational force provides centripetal acceleration, and explore how orbits depend on speed and distance from the central body.

For further graph-work practice, try papers that involve **non-linear relationships** (e.g. quadratic or inverse proportion) and require you to linearise data by plotting y against x^2 or 1/x. This builds the analytical skills needed for advanced data interpretation at GCSE and beyond.

Key terms

> **Weight**, **Mass**, **Gravitational field strength (g)**, **Newton (N)**, **Kilogram (kg)**, **Gradient**, **Line of best fit**, **Interpolation**, **Extrapolation**, **Y-intercept**, **Projectile motion**, **Time of flight**, **Inverse square law**, **Altitude**, **Force**