Qualification Accredited

Oxford Cambridge and RSA

A LEVEL

Examiners' report

PHYSICS A

H556

For first teaching in 2015

H556/03 Summer 2023 series

Version 1

Contents

Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates.

The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. A selection of candidate answers is also provided. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report.

A full copy of the question paper and the mark scheme can be downloaded from OCR.

Paper 3 series overview

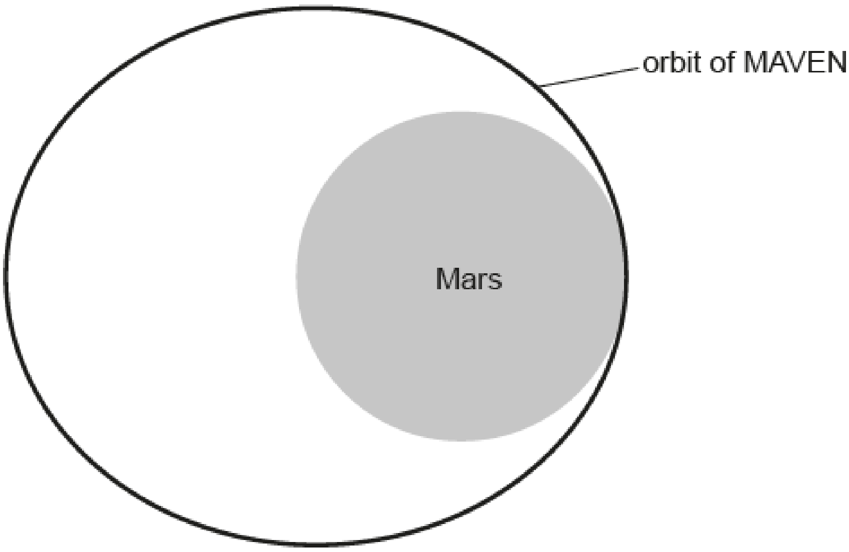
H556/03, 'Unified Physics', is the third of the three examination components for the GCE Physics A qualification. Compared to Papers H556/01 and H556/02, a larger proportion of the questions in H556/03 target the higher assessment objectives (AO2 and AO3). For example, candidates can be asked to analyse and interpret experimental data, as in Question 2, or to design an experiment in order to verify an expression, as in Question 4 (b) (ii). Questions may be set on any part of the specification, including practical skills and techniques. The paper is synoptic, and any individual question could cover material from several different topics. Candidates must be able to apply their knowledge and understanding in unfamiliar contexts in order to gain high marks.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• showed every step in their calculations clearly • provided clear and well-structured responses • used accurate scientific terminology where possible • were confident in using their knowledge in unfamiliar contexts • read the instructions on the two Level of Response (LoR) questions carefully and answered all parts of the question.	• struggled to rearrange formulas correctly • spread their working out in a haphazard manner rather than showing clear logic • made unnecessary arithmetic errors such as using an incorrect power of ten • answered questions in a different way to what was asked, or did not read the question carefully before answering • gave simplistic responses to LoR questions or did not address all parts of the question.

Question 1 (a) (i)

1 The MAVEN spacecraft orbits Mars and studies its upper atmosphere.

(a) The diagram below shows the orbit of MAVEN around Mars.



(i) Mark an **X** on the diagram to show the point in the orbit where MAVEN has maximum acceleration. **[1]**

Most candidates put their cross in the correct place. The most common wrong response was to place a cross placed at the furthest point from Mars.

Question 1 (a) (ii)

(ii) Explain how Kepler's 1st law applies to MAVEN's orbit around Mars.

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.... **[2]**

The main difficulty here was remembering which was Kepler's 1st Law. Many candidates described how a line between Mars and MAVEN would sweep out equal areas in equal times.

Sometimes valuable time was spent describing planetary orbits before restating the salient points for MAVEN.

Question1 (b) (i)

(b) The table shows data for four orbits around Mars.

Phobos and Deimos are moons of Mars.

An areostationary orbit for Mars is the equivalent of a geostationary orbit for Earth.

Orbit	Time period / hours	Average distance from centre of Mars / km
MAVEN	4.5	6500
Phobos	7.7	9400
Deimos	30	23000
Areostationary	25	20000

(i) Show that Kepler's 3rd law applies to this data.

[2]

The majority of candidates remembered Kepler's 3rd Law correctly.

There were a number of different approaches which could gain credit here. The main one used was to find the ratio of T^2/r^3 for corresponding pairs of values, showing that this ratio was approximately constant. Another common approach was calculating the constant k in $T^2 = kr^3$ using the data for MAVEN and then applying it to the distance of Phobos, for example, to show that it gave the correct value for the time period.

The best responses were those where candidates thought carefully about how they were going to set out their calculations, naming the orbits under consideration or tabulating their values, whereas other responses were characterised by a sprawl of figures leaving the examiner to hunt for appropriate values.

Question 1 (b) (ii)

(ii) Suggest **two** reasons why MAVEN was **not** placed in an areostationary orbit.

1 ....

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2 ....

....

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[2]

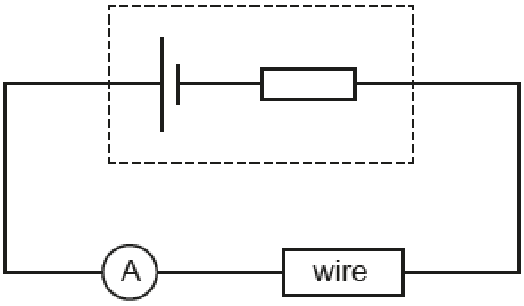
The strongest responses were given in terms of the function of MAVEN, which was to study the upper atmosphere of Mars. An areostationary orbit would be too far from Mars for this purpose, plus it would only allow MAVEN to sample one small part of its atmosphere.

A common approach was to make partial statements such as 'MAVEN would be too far away…' and such responses were often too vague to be creditworthy.

A few candidates misread the question and were obviously attempting to answer the question. 'How do we know that MAVEN is not in an areostationary orbit?'.

Question 2 (a) (i)

2 A student uses the circuit below to investigate the resistivity of a wire.



The cell has e.m.f. ε and internal resistance *r*. The wire has resistivity ρ and diameter *d*.

(a) The student takes five measurements of the diameter of the wire, which are shown in the table below.

Diameter / mm	0.460	0.450	0.455	0.495	0.455

(i) Suggest how the student made these measurements.

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....

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.... **[2]**

There are five measurements listed, so we were expecting candidates to comment on sampling the diameter at various locations/orientations as well as naming the measuring instrument used.

Question 2 (a) (ii)

(ii) The student calculates the value of the diameter as $d = 0.455 \pm 0.005$ mm.

Explain how the student calculated the value of the diameter, and its uncertainty, from the data in the table above.

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.... **[3]**

If you add all 5 results together and divide by 5, the answer does not come to 0.455 mm. So clearly the student in the question has discarded the anomalous result in the table before performing their calculation.

The general rule for giving a single result from a set of data is to calculate the *mean* average (not the mode or the median). The uncertainty is found from half the range.

Giving the uncertainty as ± half of the smallest scale division is the general rule to use when we have only one single reading, which is not the case here.

How to quote a single result from a set of data

- Use the *mean* average
- Uncertainty = half the range

Question 2 (b) (i)

(b) The student varies the length L of the wire in the circuit and records the current I using the ammeter.

(i) Show that

$$\frac{1}{I} = \left(\frac{4\rho}{\pi\varepsilon d^2}\right)L + \frac{r}{\varepsilon}$$

[3]

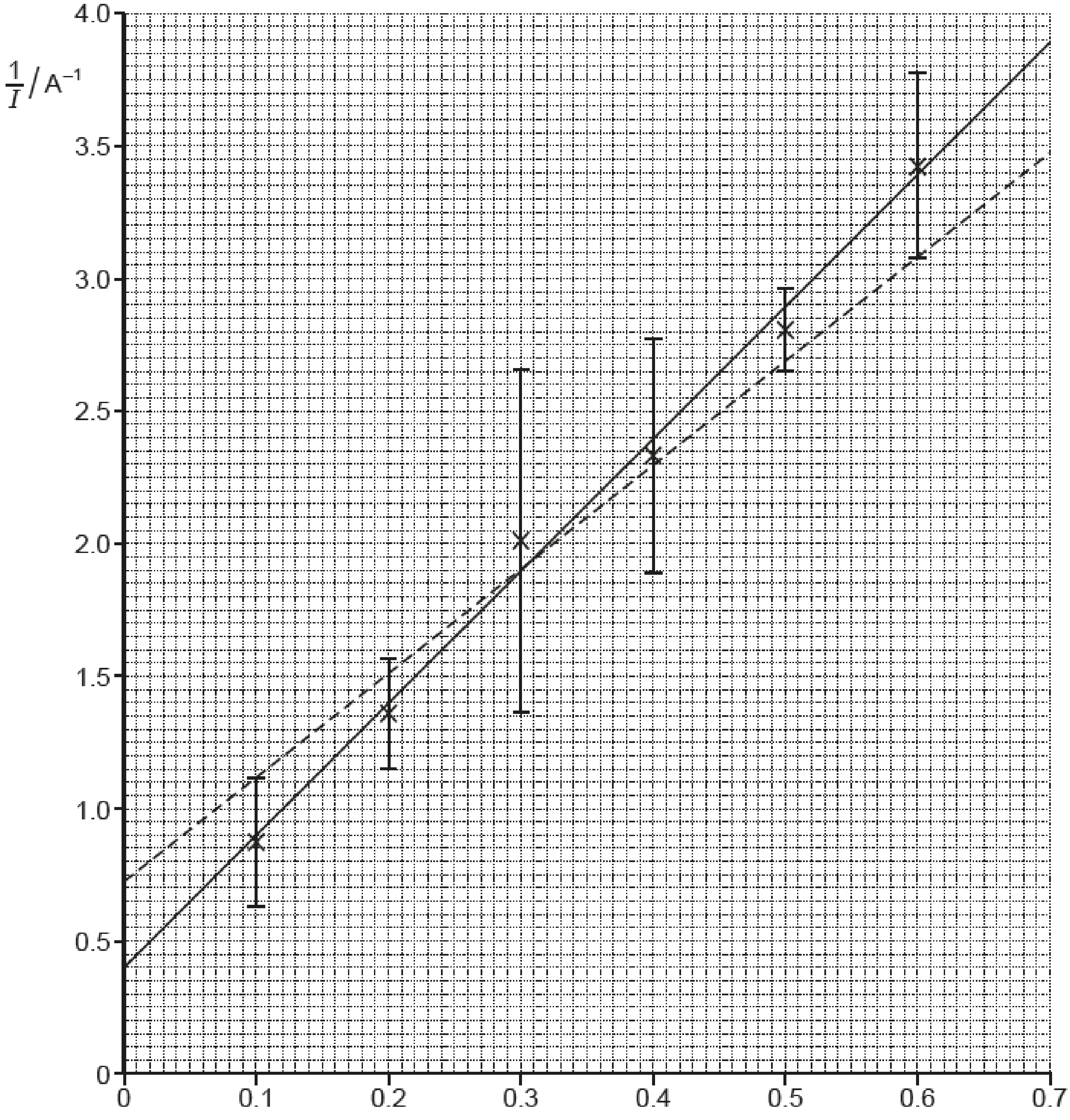
Almost all candidates showed excellent ability in substituting and rearranging equations. The starting point was $\varepsilon = I(R + r)$ where $R = \rho L/A$. Some candidates rearranged $\varepsilon = I(R + r)$ before writing it down, starting with $R = \varepsilon / I - r$ or similar. Centres should encourage starting a proof with the standard form of the equations.

The main difficulty was in substituting $A = \pi r^2 = \pi(d/2)^2$ into the formula for R.

Poor presentation occasionally made responses difficult to mark.

Question 2 (b) (ii) (1)

(ii) The student plots a graph of $\frac{1}{I}$ against L. The data points, error bars, line of best fit and a line of worst fit are shown in the graph below.



The cell has e.m.f. $\varepsilon = 1.45 \pm 0.05$ V

The wire has diameter $d = 0.455 \pm 0.005$ mm

1 Calculate the gradient of the best fit line and use this to determine a value for the resistivity ρ of the wire.

You are **not** required to determine an uncertainty.

ρ = ... Ωm **[2]**

A gradient of 5 was chosen here deliberately to make the question as accessible as possible. Most candidates were able to see from the equation that the gradient would be equal to $4\rho/\pi\varepsilon d^2$. However, a significant number did not remember that d was measured in mm and so they had a power of ten error in their value for ρ.

The question asks, 'Calculate the gradient … and use this to determine … the resistivity ρ'. It was helpful when candidates wrote down 'gradient = ….' to make their working clear.

Question 2 (b) (ii) (2)

2 Determine a value for the internal resistance r of the cell **and** its absolute uncertainty.

r = ... ± .... Ω **[4]**

From the equation, y-intercept = r/ε and so r = y-intercept × ε. This was a relatively simple calculation.

From the question stem, $\varepsilon = 1.45 \pm 0.05$ V and, from the graph, y-intercept = 0.40 ± 0.33. Since r is found by multiplying y-intercept and ε, we can apply the rule: % uncertainty in r = % uncertainty in y-intercept + % uncertainty in ε.

An alternative approach is to find the upper bound for r, which is the greatest value of y-intercept (0.73 from graph) × greatest value of ε (1.45 + 0.05 = 1.5V).

Candidates should be reminded to quote the uncertainty to the same number of decimal places as their value for the internal resistance.

Once again, poor presentation often made responses difficult to mark. For example, it is much easier to award a mark for the statement 'intercept of worst line = 0.7' or 'intercept = 0.4 ± 0.3' than to try and spot it mid-calculation.

Question 3 (a) (i)

3 A pulsar is a rapidly rotating neutron star that emits radio waves.

(a) (i) Describe the formation of a neutron star.

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....

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.... **[2]**

When describing this process, it is crucial to differentiate between the original supergiant star and its core. The original star must have a mass greater than 10 solar masses, and it is the core of the star that must have a mass greater than the Chandrasekhar limit of 1.4 solar masses.

Exemplar 1

When a star runs out of fuel it will begin to collapse in upon itself, due to gravity. If it exceeds the Chandracekhar limit but not by over four times protons will be pushed together forming a neutron star. [2]

The exemplar above shows a typical response where the original star and the remaining core have not been sufficiently distinguished.

Misconception

It is better to refer to a red supergiant star than to a (super) red giant star, as only supergiant stars are able to end their lives as neutron stars.

Question 3 (a) (ii)

(ii) State **one** characteristic of a neutron star.

....

....

....

.... **[1]**

There were several facts about neutron stars mentioned in the stem of the question which could not receive any credit (such as the fact that they spin and emit radio waves). Many candidates made statements that were too general to receive credit, such as neutron stars are small/hot/bright (but compared to what?) or contain neutrons.

Question 3 (b)

(b) A typical neutron star can be modelled as a sphere with mass $\approx 2 \times 10^{30}$ kg and radius $\approx$ 10 km.

Show that the average density of a neutron star is similar to the average density of an atomic nucleus.

- radius of a nucleon $\approx$ 1 fm

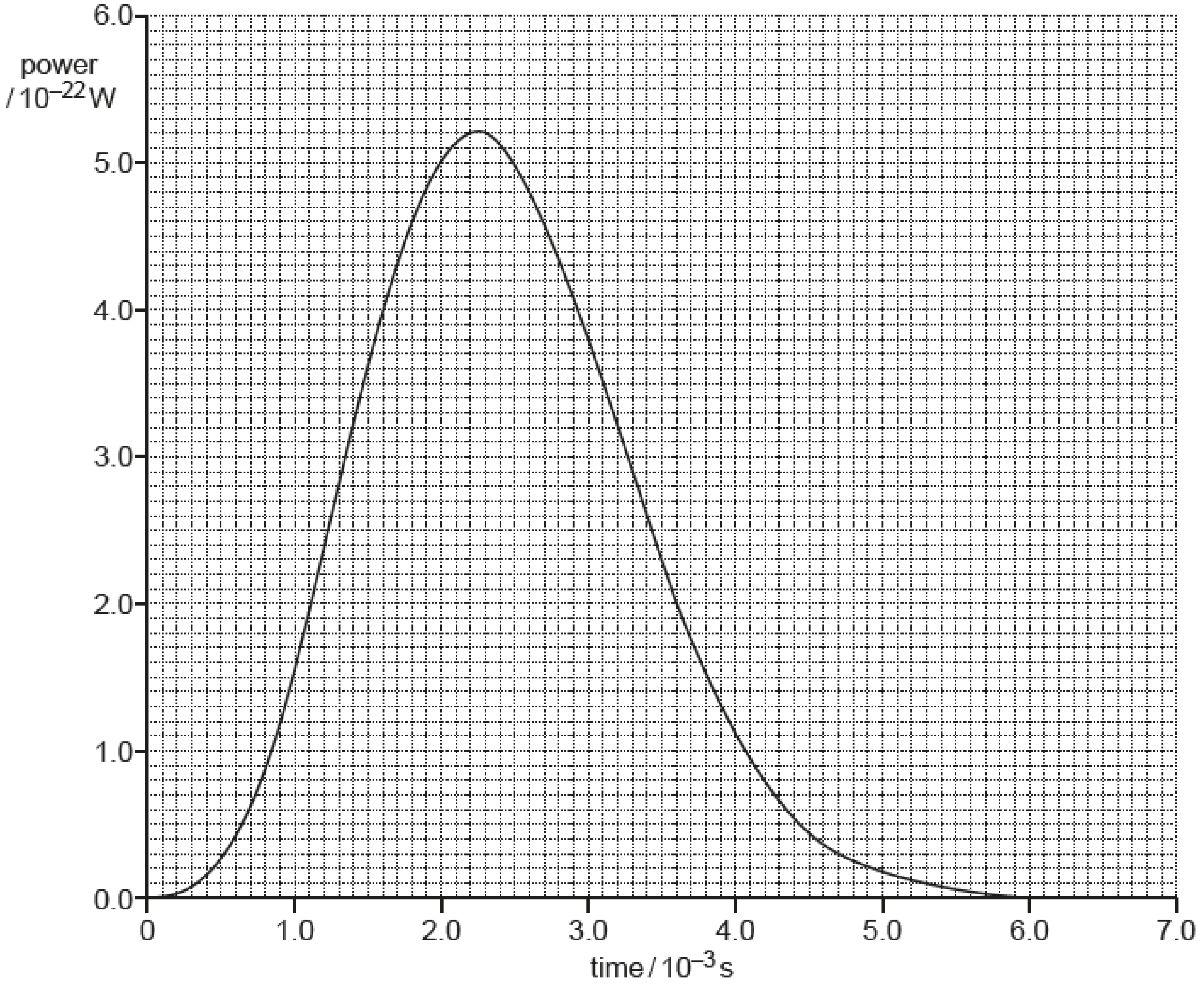
[3]

Most candidates were able to apply the correct formulae for density and for volume of a sphere. The calculation for the density of a neutron star was performed easily. However, rather than calculating the density of a single nucleon (whose radius had been given), many candidates tried to calculate the density of a different nucleus (such as deuteron or helium) whose radius had not been given. Some candidates lost marks through not stating the units in which their calculated densities were measured.

Question 3 (c) (i)

(c) An astronomer uses a radio telescope to observe a pulsar.

The graph below shows the power that the telescope receives due to the radio waves from one full rotation of a pulsar.



(i) By calculating the area between the curve and the horizontal axis, estimate the total energy received by the telescope in one full rotation of the pulsar.

total energy received = ... J **[2]**

Candidates who counted squares underneath the curve almost always got areas within the allowed range. Those who tried to use trapeziums or other regular shapes were usually less successful.

Question 3 (c) (ii)

(ii) The surface area of the telescope is about 3000 m^2.

The distance to the pulsar is about 300 pc.

By assuming that the radiation from the pulsar is emitted equally in all directions, estimate the total energy emitted in one full rotation.

energy emitted = ... J **[3]**

This question stretched even the highest ability candidates. The key was in realising that the intensity of the pulsar = the intensity at the telescope. So the ratio of powers (or energies) = ratio of surface areas.

Most candidates successfully converted 300 pc into metres. However, some did not realise that the surface area of a sphere is $4\pi r^2$, a formula that is in the data, formulae and relationships booklet.

Question 4 (a)

4 A cloud is made up of droplets of water falling at terminal velocity.

(a) Describe and explain the motion of an object falling at terminal velocity.

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.... **[3]**

It is important to read the question carefully here. Many candidates spent unnecessary time describing how an object which has been dropped from rest *reaches* terminal velocity, which was not required. There were several cases of careless terminology. For example, candidates often said that forces were balanced or matched (rather than equal and opposite), or that acceleration of gravity was the same as the drag force, or that acceleration was constant (rather than zero).

Question 4 (b) (i)

(b) (i) The terminal velocity v of a small sphere of density ρ_s and radius r falling through a fluid of density ρ_f is given by the formula:

$$v = \frac{2gr^2(\rho_s - \rho_f)}{9\eta}$$

where η is a constant for the fluid and g is the acceleration of free fall.

Water droplets of rain fall to the ground whereas water droplets in mist appear to float.

Use the formula above to suggest why.

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....

....

.... **[2]**

The density of water is the same in mist droplets and in rain droplets, and in both cases the droplets are falling through air. This means that the only variables in the formula are v and r^2, with v being proportional to r^2. Since mist droplets have a much lower terminal velocity v, this must be because they have a smaller radius than rain droplets.

A reasonable suggestion using the formula, however, is that v is proportional to $(\rho_s - \rho_f)$ and so this was given credit. Although the density of the water droplet, ρ_s, remains the same, some candidates argued that the air through which raindrops fall has a lower density to the water vapour through which mist droplets fall. This argument was much more popular than v proportional to r^2. Unfortunately, many candidates were too vague and struggled to distinguish between water, rain, mist and air. Some thought that density of air/mist > density of water giving a negative terminal velocity, which is impossible.

Question 4 (b) *(ii)

***(ii)** A student models water droplets falling through air using small solid spheres in a liquid.

The table shows properties of the materials available to the student.

Material	**Solid density, ρ_s / kg m^{-3}**	**Liquid density, ρ_f / kg m^{-3}**	**Approximate value of η / 10^{-3} kg m^{-1} s^{-1}**
Water (liquid)		1000	1
Sunflower oil (liquid)		920	50
Steel (solid sphere)	7800		
Lead (solid sphere)	11300		

Describe an experiment to verify the expression given in **(i)** as accurately as possible. As part of your answer, estimate the **lowest** terminal velocity if the student uses a solid sphere of diameter = 1 mm.

....

....

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....

....

.... **[6]**

This experiment is one of the PAGs and it is essential that candidates explain how to verify that the sphere is falling *at a constant velocity* before *v* is measured. It is not enough to state that a long cylinder must be used or that *v* is measured near the bottom. It is important to describe which measuring instruments would be used and how the measurements taken would be combined to calculate *v*, rather than simply stating '*v* is measured using a light gate'.

Some candidates did not read the question carefully and spent precious time explaining how to measure the density of the liquids and the spheres, which had been given in the table. They described carefully how to drop the sphere from exactly the same height each time using exactly the same amount of fluid, not realising that this would have no bearing on the terminal velocity.

Candidates were asked to calculate the lowest terminal velocity possible using a sphere of diameter = 1 mm. Most candidates remembered to attempt this and correctly chose a steel sphere in sunflower oil. However, many used η = 50 rather than 50 × 10^{-3} and the majority used r = 1 mm rather than 0.5 mm.

The purpose of the experiment was to verify the expression given in 4b(i) as accurately as possible. The best way to do this was to use a steel sphere in sunflower oil because then the sphere would be travelling more slowly, making it possible to measure *v* more accurately. The radius of the sphere could be varied and a graph of *v* against r^2 plotted. If the expression given is correct, then the graph would be a straight line *through the origin*. The gradient should be equal to $2g(\rho_s - \rho_f)/9\eta$ and, by using the values given in the table, $g \approx 9.81\ \text{m s}^{-2}$ could be verified.

It is also possible to use the 4 different combinations of liquid and solid sphere of constant radius and plot a graph of *v* against $(\rho_s - \rho_f)/\eta$.

Candidates should make sure that they state very clearly how their experiment can be used to verify the expression. A typical response was along the lines of 'I would measure *v* several times and take an average, then plot the results on a graph'. How are you going to get more than one result (you need at least four for a reasonable graph)? What are you going to plot and on which axis? Have you taken all the variables into account? How will you use your graph to show that the expression is correct?

Exemplar 2

- plot a graph of v on the y axis and r^2 on the x axis.
- Draw a line of best fit straight through the origin.
- calculate gradient of the graph.

$$v = \frac{2gr^2(\rho_s - \rho_f)}{9\eta}$$

$$v = \frac{2g(\rho_s - \rho_f)}{9\eta} \times r^2$$

$$y = m\,x$$

, use this to determine the value of g. If g = 9.81 then ~~value~~ the expression is valid.

This response demonstrates good practice.

Question 5 (a) (i)

5 Large power stations generate an electrical power of about 1 GW.

Current methods of energy production that use nuclear fusion are unable to produce enough energy for large-scale energy production. A proposed method of controlling nuclear fusion is inertial confinement fusion (ICF). ICF uses a large number of powerful lasers to create the high temperatures required for nuclear fusion to occur.

One ICF experiment uses a network of capacitors to store the energy needed to power the lasers. When the network is fully charged:

- potential difference across the network = 24 kV
- total energy stored in the network = 400 MJ

(a) **(i)** Calculate the total capacitance, *C*, of the network.

C = ... F **[2]**

Most candidates seemed to find this quite straightforward and easily calculated the capacitance using $W = ½CV^2$. A common error was using $W = QV$ (then $C = Q/V$) instead of $W = ½QV$. Some candidates clearly confused the use of *C* for capacitance with C for Coulombs as they had calculated charge rather than capacitance.

Question 5 (a) (ii)

(ii) Explain why the individual capacitors in the network should be connected in parallel in order to produce this total capacitance.

....

.... **[1]**

A few candidates lost the mark here by discussing voltage/energy across capacitors in series versus parallel without linking this idea to capacitance.

Question 5 (b)

(b) The total stored energy must be released in a time of less than 1 millisecond.

Explain, using a calculation, why the lasers are powered by the network of capacitors instead of being connected directly to the mains electricity supply.

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....

....

....

.... **[2]**

Candidates were expected to link the power output of a conventional power station (1GW) given at the start of the question to the power requirement of the fusion reactor (400 MJ in less than 1 ms). Alternative approaches which received credit were finding the energy supplied by a conventional power station in 1 ms, or calculating the time required for a conventional power station to release 400 MJ. A common incorrect approach involved attempting to calculate the time constant of a capacitor.

Many candidates disregarded the instruction to use a calculation in their response and thus were unable to earn any marks despite a good understanding of the problem.

Question 5 (c)

(c) The fusion reaction in the ICF experiment is

deuterium + tritium $\rightarrow$ alpha particle + neutron

Calculate the number of fusion reactions that must occur for the energy released by fusion to be equal to the electrical energy stored in the network of capacitors.

- mass of deuterium = 2.014102 u
- mass of tritium = 3.016049 u
- mass of alpha particle = 4.002603 u
- mass of neutron = 1.008665 u

number of fusion reactions = ... **[4]**

Most candidates seemed to have a very good understanding of this question, suggesting good preparation by centres. Those who dropped marks often made arithmetical errors in calculating mass defect or forgot to convert atomic mass units into kilograms. A lack of clarity in setting out mathematical procedures made some candidates' thought processes difficult to follow.

Question 6 (a)

6 A 3D printer can manufacture small objects.

Some 3D printers use polylactic acid (PLA). PLA is supplied in the form of long filaments. The 3D printer melts the PLA and builds up the shape of the desired object in layers.

The electrical supply to the heater in the printer has an e.m.f., ε, of 12 V. The power of the heater is 40 W.

(a) Calculate the resistance, R, of the heater.

R = ... Ω **[2]**

The most common mistakes here were in rearranging the formula and/or forgetting to square the voltage in $P = V^2/R$.

Question 6 (b) (i)

(b) The specific latent heat of fusion of PLA is $9.4 \times 10^4\ \text{J kg}^{-1}$ and its melting point is 160 °C.

(i) Define **specific latent heat of fusion**.

....

....

.... **[1]**

There were several reasons why responses to this question did not gain credit:

- constant temperature was not mentioned
- per unit mass (or per kg) was omitted
- the phase change was not stated, or was incorrect
- it was stated that energy was required to turn a liquid into a solid.

Question 6 (b) (ii)

(ii) Calculate the **maximum** mass *m* of PLA that the heater could melt in one minute.

m = ... kg **[2]**

This question was well answered by most candidates. However, some tried to use $E = mc\Delta\theta$ with $\Delta\theta$ = 160 °C and a few gave their answer to only 1 sf.

Question 6 (b) (iii)

(iii) Explain why the printing process is slower in practice than your answer to **(ii)** suggests.

....

....

....

.... **[2]**

The most common correct response related to energy dissipated to the surroundings. A smaller number of correct responses mentioned that energy was needed to raise the temperature to melting point.

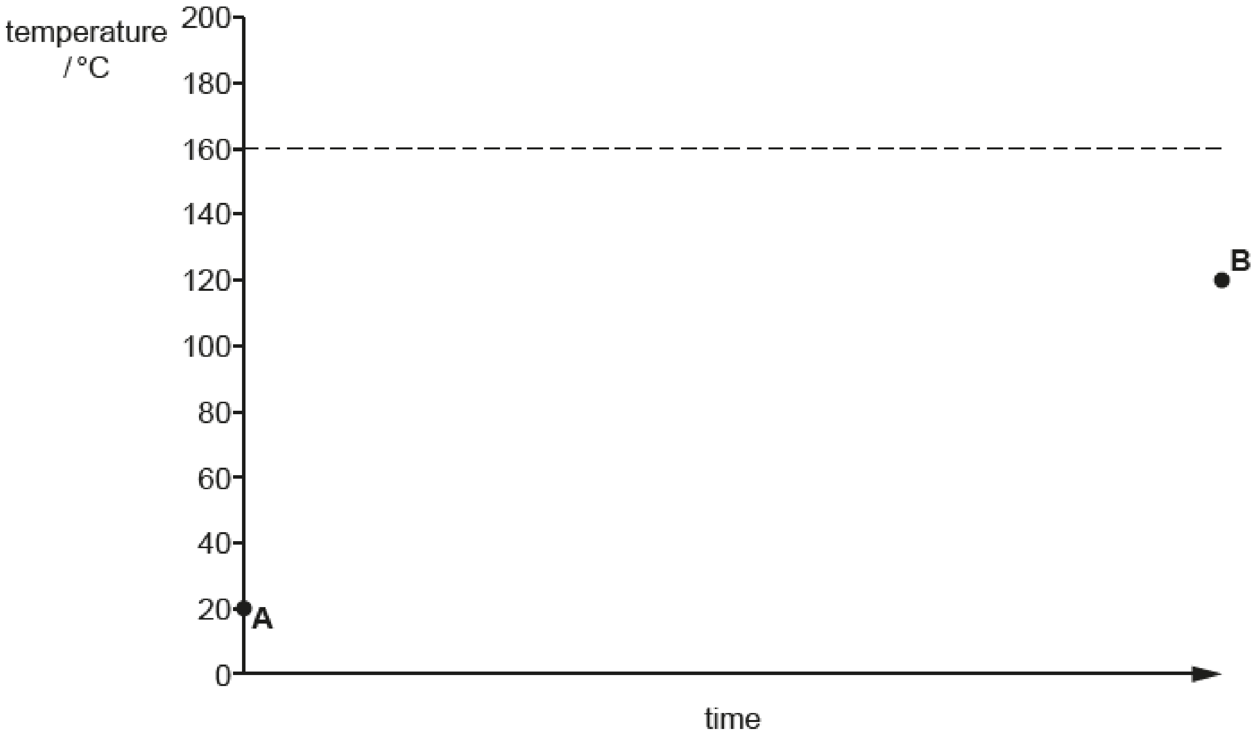
Some candidates incorrectly referred to energy used for other parts of the system (e.g. motors to drive the mechanism) which was not relevant to the question.

Question 6 (b) (iv)

(iv) **Fig. 6.1** shows the initial and final temperature of the PLA during the printing process.

Initially (point **A**), the solid PLA is at 20 °C and is just entering the heater. Later (point **B**), the PLA has been added to the object and is solid again.

Fig. 6.1



Complete **Fig. 6.1** to show how the temperature of the PLA changes between **A** and **B**.
You are **not** required to label the time axis. **[3]**

Most responses gained 2 marks for a line from point A followed by a flat section at 160 °C and then a line down to point B. A small minority of candidates also gained the 3rd mark for a 'blip' within the flat section, rising above 160 °C. Responses that went from A to B without a flat section at 160 °C gained no credit.

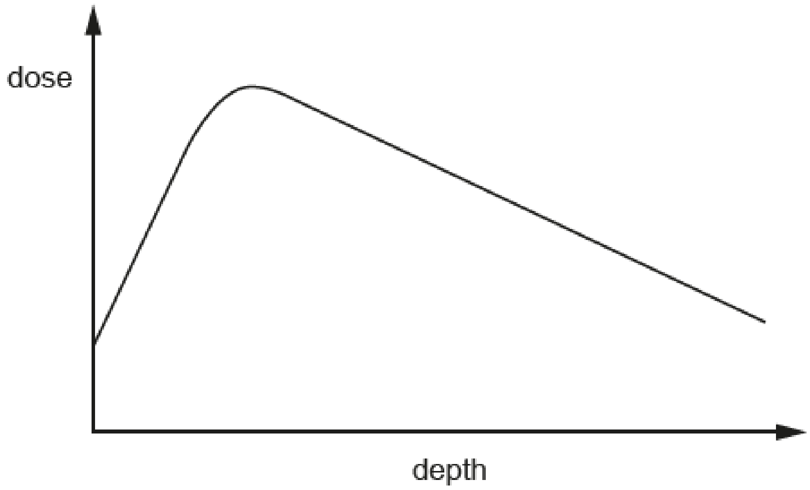
Question 6 (c) (i)

(c) High-energy X-ray photons can destroy living cells. In radiotherapy, these photons are targeted at cancer cells.

The radiation **dose** is the amount of energy that a patient's body absorbs from the high-energy X-ray photons.

Fig. 6.2 shows how this dose changes with depth below the surface of the skin.

Fig. 6.2



The dose initially rises with depth because the high-energy X-ray photons produce electrons and positrons as they pass through the body. These electrons and positrons are quickly absorbed, increasing the dose.

(i) Explain why high-energy X-ray photons produce electrons **and** positrons as they pass through the body.

....

....

....

.... **[2]**

The most common correct responses related to photons interacting with nuclei and to "pair production". Candidates who scored no marks often simply reworded the stem of the question, or referred to photons interacting with atoms or electrons.

Question 6 (c) *(ii)

***(ii)** A 3D object called a **bolus** is used in radiotherapy for patients with skin cancer. A bolus targets the maximum radiation dose near the surface of the skin. So using a bolus makes the radiotherapy more effective.

A bolus can be made from PLA using a 3D printer. The bolus must fit the shape of the patient's body exactly. This shape is found beforehand by giving the patient either a CAT scan or a PET scan.

- Explain how CAT scans and PET scans work.
- Discuss the advantages and disadvantages of having a scan to produce a bolus for radiotherapy.

....

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....

Most candidates were familiar with CAT and PET scans. Centres had prepared them well for discussing how they work plus their advantages and disadvantages. The most common errors were in thinking that:

- X-rays are reflected/deflected in a CAT scan
- technetium-99m is used as a tracer for a PET scan
- gamma rays are fired at patients in CAT and/or PET scans.

Exemplar 3

advantages: an accurate image of patients body can be produced with the scan without any invasive surgical techiques. no risk of infection

Disadvantages: Patient is exposed to radiation which poses a risk to cause mutation and cancer.

Some candidates did not respond adequately to the second part of the question, often merely rewording information from the stem. Some did not realise that the purpose of the scan in this question was to find the exact shape of a patient's body in order to produce a well-fitting bolus. This resulted in many potential Level 3 responses scoring Level 2 . The exemplar above gives an example of this, where the candidate is discussing 'What are the advantages and disadvantages of having a scan as opposed to surgery?'

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