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Examiners' report

PHYSICS B (ADVANCING PHYSICS)

H557

For first teaching in 2015

H557/02 Summer 2024 series

Contents

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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.

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Paper 2 series overview

Paper 2 – Scientific Literacy in Physics is a synoptic paper that includes questions on an Advance Notice article. The three questions in Section A are of medium length, usually contributing a total of around 30 marks each to the paper. Section B comprises three longer questions, including a level of response (LOR) question. Section C is based on the Advance Notice article and includes short and long questions and a level of response question.

The Advance Notice information focused on the James Webb Space Telescope and gave candidates some idea of the major areas tested but this is a challenging examination. As in previous series, most of the candidates attempted all the questions and there was little evidence of candidates running out of time.

Once again, more able candidates demonstrated the ability to apply physics to novel areas, accurately used technical vocabulary and had prepared carefully for the questions on the Advance Notice article.

The majority of the responses gained marks in one or two-stage arithmetic questions whereas more extended calculations proved more discriminating. As usual, explanatory answers revealed misunderstandings of some fundamental ideas in weaker responses.

In this session there were more errors due to not reading the question stem carefully enough and not following the instructions given.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• laid out calculations logically and showed full working • showed good understanding and use of technical vocabulary • showed understanding and familiarity of the physics covered in the Advance Notice article • used the answer line in all calculations rather than leaving the answer within their working • showed understanding of fundamental physics when answering questions set in novel contexts.	• showed lack of confidence in their use or understanding of technical vocabulary • did not read the question stem with sufficient attention, leading to errors in their answers • lacked familiarity with the physics in the Advance Notice article • had a haphazard approach to laying out their working in longer tasks such as the level of response questions • lacked recall of factual content.

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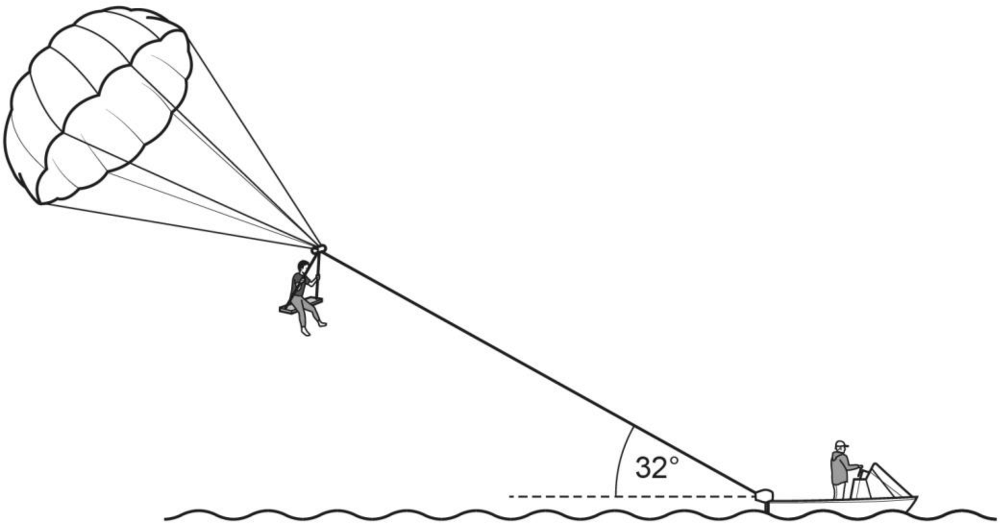
Section A overview

Section A comprises three questions of about 10 marks each. In this examination, the questions focused on materials/dynamics, current electricity and oscillations.

Question 1 (a) (i)

1 Parasailing is an adventure sport. The parasailor is pulled behind a motor boat as shown in **Fig. 1**.

Fig. 1 (not to scale)



The tension in the rope connecting the boat to the parasail is 550 N. The parasailor is moving horizontally at constant velocity.

(a)
(i) Calculate the vertical component of the tension in the rope.

vertical component = ... N **[2]**

The first part of this first question was correctly answered by the majority of the candidates. A small proportion of the candidates incorrectly used cos 32 rather than sin 32 (gaining no marks) and some had their calculators set on 'radian mode' so only gained 1 mark.

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Question 1 (a) (ii)

(ii) The combined weight of the parasailor and sail is 870 N. Calculate the vertical upwards force on the parasailor and sail.

vertical upwards force = ... N **[1]**

This proved challenging for many. Answers of 550 N or 870 N were both common.

Misconception

A proportion of the candidates assumed that the vertical component of the tension acted upwards.

Question 1 (a) (iii)

(iii) Calculate the power required to pull the parasailor and sail through the air at a horizontal velocity of $5.8\,\mathrm{m\,s^{-1}}$. Explain your reasoning.

power = ... W

Explanation: ....

....

.... **[3]**

This calculation was correctly answered by the majority of the candidates. However, fewer managed to explain their choice of the value of force acting on the parasailor and sail at constant velocity.

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Question 1 (b)

(b) Here are some data about the rope that attaches the sail and parasailor to the boat.

diameter = 12.0 mm
Young modulus = 13.2 GPa
length = 240 m

Calculate the extension of the rope when the tension in the rope is 550 N.

extension = ... m **[2]**

Most responses gained both marks for this standard calculation.

Question 1 (c)

(c) The boat accelerates. State whether the tension in the rope will increase, decrease or remain at 550 N when the parasail is moving at a greater constant horizontal velocity. Explain your answer.

....

....

....

.... **[2]**

Although many candidates gained both marks for this part, a minority incorrectly focused on the period of acceleration rather than when the sail was moving through the air at constant velocity. This was the first example of not carefully reading the question in the paper. More confident responses gave the detail required for the third marking point, showing understanding of the equilibrium between the horizontal tension and drag.

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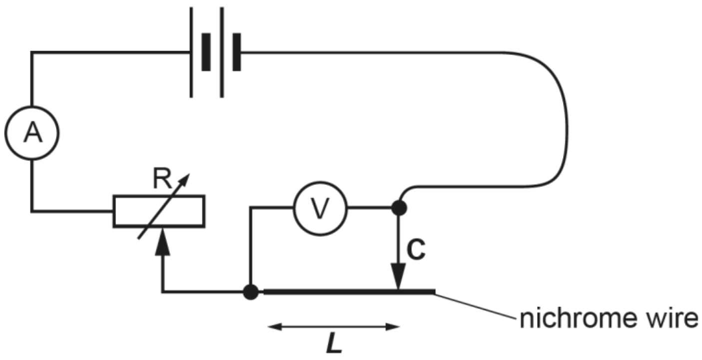
Question 2 (a)

2 The circuit shown in **Fig. 2.1** is used to determine the resistivity of a wire.

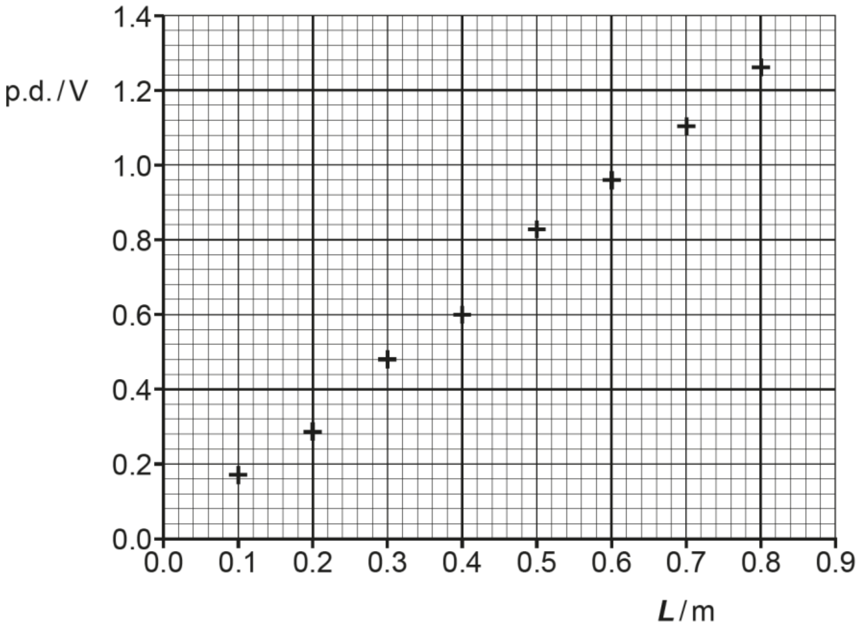
Fig. 2.1



The moving contact **C** changes the length of wire ***L*** in the circuit. The variable resistor is used to keep the current in the wire constant.

Fig. 2.2 shows the graph of the results obtained.

Fig. 2.2



Here are further data used in the determination of the resistivity:

diameter of the wire = $5.2 \times 10^{-4} \pm 0.1 \times 10^{-4}$ m

current in the wire in the circuit = 0.29 ± 0.01 A.

(a) Draw a best-fit line on **Fig. 2.2**. Calculate the gradient of the line.

gradient = ... $\mathrm{V\,m^{-1}}$ **[2]**

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Most candidates gained both marks for this calculation and the majority annotated the graph to show how the gradient was calculated, a practice to encourage.

Question 2 (b)

(b) Use the value of the gradient and the further data to determine the resistivity of the material.

Ignore the uncertainties at this stage.

resistivity = ... Ωm **[2]**

This was the second example of candidates losing marks through not reading the question stem. A significant proportion did not use the gradient but calculated a value of resistance for a particular length and substituted this value into the equation. This suggests a lack of understanding of the reason for using gradients in investigations of this kind.

Question 2 (c)

(c) Use the uncertainty in the diameter and current values to determine the uncertainty in your value for resistivity calculated above. Ignore any possible uncertainties in the length and p.d. values.

uncertainty in value of resistivity = ± .... Ωm **[2]**

Candidates either calculated the maximum or minimum possible values of resistivity to reach a value for the uncertainty or calculated percentage uncertainties in diameter and current, using the combined percentages to find an absolute uncertainty in the value. A significant proportion of those who used the percentage value did not double the percentage uncertainty of the diameter to find the uncertainty in area.

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Question 2 (d)

(d) A student repeats the experiment but does not control the current. This leads to higher current values for shorter lengths of wire. Describe and explain the change to the shape of the graph.

....

....

....

....

....

....

.... **[3]**

Relatively few candidates picked up on the idea that the wire would get hotter and therefore the resistivity of the material would increase, leading to an increase in resistance. Many responses were imprecise; for example: 'the resistance increases for shorter lengths of wire when the current increases' may be read as 'shorter lengths of wire have greater resistance than longer lengths when the current increases' or meaning that, for a given (shorter) length of wire, the resistance will be greater when the current increases. This lack of clarity cost candidates marks.

Question 3 (a)

3 This question is about simple harmonic motion and resonance.

A 0.25 kg mass is hung from a spring of spring constant $23.0\,\mathrm{N\,m^{-1}}$.

(a) Show that the extension of the spring is about 0.11 m. This is the equilibrium position.

[1]

Nearly all candidates gained credit for this standard calculation.

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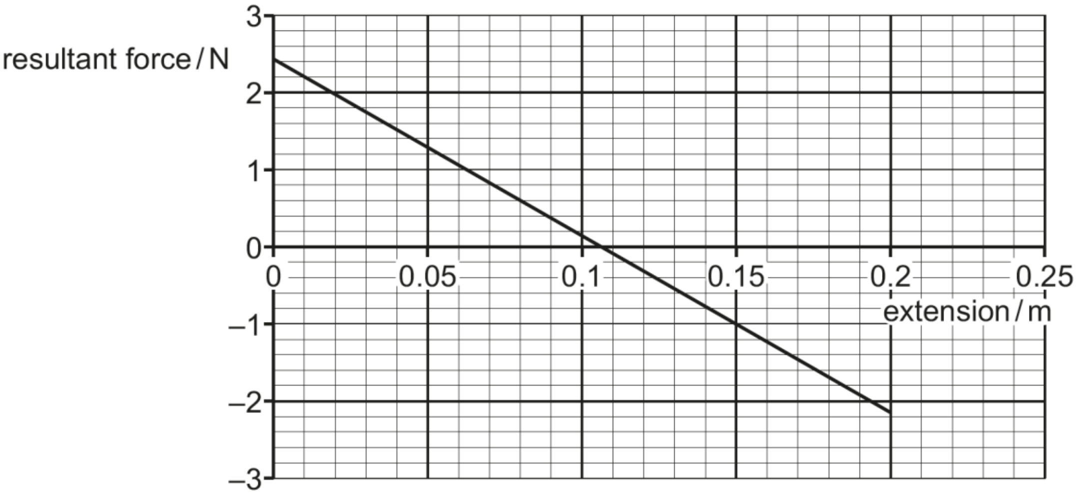
Question 3 (b) (i)

Fig. 3.1 shows how the resultant force on the mass changes with the extension of the spring. Negative force values show that the resultant force is upwards.

Fig. 3.1



(b) The spring is extended a further 0.03 m from the equilibrium position and the mass is released.

(i) Refer to **Fig. 3.1** to explain why the mass will oscillate with simple harmonic motion for oscillations of amplitude less than about 0.11 m.

....

....

....

....

.... **[2]**

This explanatory question proved challenging. Whereas many candidates recognised that the force on the mass is proportional to displacement, only the best answers stated that force is proportional to the negative of the displacement and only the very best linked this proportionality to the condition for simple harmonic motion that acceleration is proportional to the negative of the displacement from the equilibrium position.

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Question 3 (b) (ii)

(ii) Explain why the oscillation will **not** be simple harmonic for oscillations with a greater amplitude than 0.11 m.

....

....

....

....

.... **[2]**

This question was challenging. A common answer suggested inelastic behaviour as the reason for non-harmonic oscillation. This cannot be deduced from the graph and data give in the question. Very few candidates made the link that the maximum downwards force will be the weight of the mass.

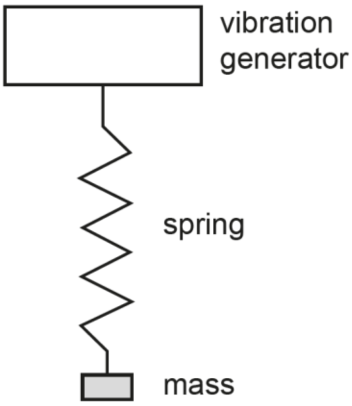
Question 3 (c)

(c) The spring and mass are attached to a vibration generator as shown in **Fig. 3.2**. The vibration generator oscillates the spring through a range of frequencies from 0.1 Hz to 3.0 Hz.

Determine the frequency at which the greatest amplitude of oscillations will be observed.

Explain your reasoning.

Fig. 3.2 (not to scale)



frequency = ... Hz

....

....

....

.... **[3]**

The majority of responses correctly calculated the natural frequency of the system. About two thirds of those candidates went on to make the connection with resonance of the system.

Question 3 (d)

(d) The hydrogen chloride molecule (HCl) can be modelled as a light mass (the hydrogen atom) attached to a much heavier mass (the chlorine atom) by an elastic spring. When the hydrogen oscillates at one end of the 'spring' it can be assumed that the chlorine remains stationary.

Explain, using relevant calculations, why the HCl molecule absorbs infrared radiation of wavelength 3.3×10^{-6} m more strongly than other wavelengths.

spring constant of $HCl = 550\,N\,m^{-1}$
mass of hydrogen atom = 1.7×10^{-27} kg

....

....

....

.... **[3]**

This is a more challenging calculation – although it focuses on the natural frequency of the oscillator as in (c), the context requires careful thought. Most candidates gained both marks for the calculation, linking a calculated natural frequency of the molecule to the frequency of the infra-red radiation or alternative comparisons. Few responses gained the first marking point, that at resonance energy transfer from driver to driven is at a maximum.

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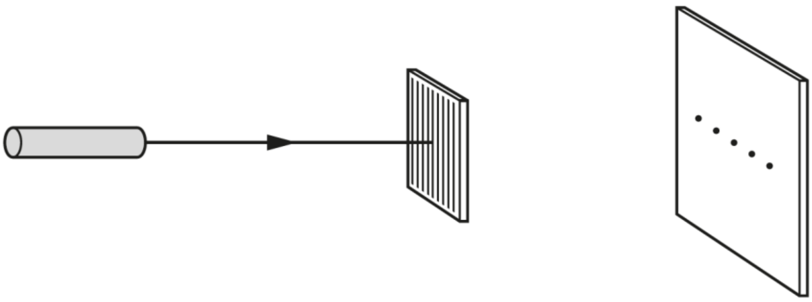
Section B overview

Section B comprises three questions of around 15 marks each. These questions tend to have longer sections, including a level of response question and are typically more challenging than Section A questions.

Question 4 (a)

4 This question is about different models of light. A laser shines monochromatic light perpendicularly on a diffraction grating as indicated in **Fig. 4.1**.

Fig. 4.1 (not to scale)



(a) Explain, using the concepts of path difference and phase, why a series of bright dots is seen across the screen.

....

....

....

.... **[2]**

Question 4 focuses on the wave-like and particle-like properties of light. 4 (a) requires a standard explanation of the formation of maxima when light passes through a grating. Those candidates who did not gain both marks tended to give imprecise explanations. For example, writing ‘multiple of wavelength path difference’ as a condition for a maximum rather than ‘integer multiple’. Some candidates, as usual, confused the terms path difference and phase difference.

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Question 4 (b) (i)

(b) Ultraviolet light of wavelength 175 nm is incident perpendicularly on a grating of 300 lines mm^{-1}.

(i) Calculate the angle to the **third** order maximum.

angle = ... ° **[2]**

Most candidates correctly performed this standard calculation. However, generally less successful responses made errors in calculating the grating spacing by reading '300 lines mm^{-1}' as '300 lines m^{-1}'.

Question 4 (b) (ii)

(ii) Calculate the highest order of maximum that is produced using this apparatus.

highest order of maximum = ... **[2]**

The majority of candidates gained both marks for this calculation, many giving clear working showing understanding of the situation.

Question 4 (b) (iii)

(iii) Ultraviolet light of the same wavelength from a point source is incident on a clean zinc surface. Electrons are ejected from the metal surface.

Use the equation $E_{k(max)} = hf - \phi$ to calculate the maximum kinetic energy of the electrons ejected.

ϕ, the work function of zinc = 4.3 eV

$E_{k(max)}$ = ... J **[2]**

This proved to be one of the most accessible questions on the paper.

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Question 4 (b) (iv)

(iv) Although the energy carried by a wave is proportional to the intensity of the source, it is observed that the maximum kinetic energy of the ejected electrons is independent of intensity.

- Explain this observation using the idea of light as photons.
- Suggest and explain the effect of increasing the intensity of light has on the ejection of electrons.

....

....

....

....

....

.... **[3]**

This is a challenging question and it was encouraging to read some excellent responses. Again, some candidates missed out on credit through incomplete statements. It was common to read that 'intensity is the number of photons striking the plate' rather than 'number of photons striking the plate per second/in unit time'. Many candidates correctly stated that the energy of individual photons is independent of the intensity and also that phenomena such as the photoelectric effect are explained through one-to-one interactions between electrons and photons.

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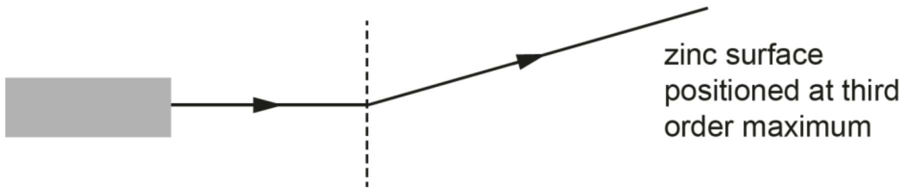
Question 4 (c)

(c) A student suggests the set-up shown in **Fig. 4.2**.

Fig. 4.2



Electrons are ejected from the zinc surface.

Explain how considering light to be **either** only a particle **or** only a wave **cannot** explain **diffracted** light ejecting electrons from the zinc surface. Suggest how the phasor model of light can explain this observation.

....

....

....

....

....

.... **[4]**

Encouragingly, many candidates showed a good understanding and recall of the phasor model and convincingly applied this to photons. However, many responses did not meet marking points through imprecise answers. For example, it was common to read that 'diffraction is explained by the wave model', which is not sufficiently clear as it does not state that the particle model cannot explain diffraction – 'diffraction is *only* explained by the wave model' (or that and the phasor model) would gain the mark, as would 'the particle model cannot explain diffraction'. Similar lapses of clarity were evident in explaining that the wave model cannot account for all the characteristics of the photoelectric effect.

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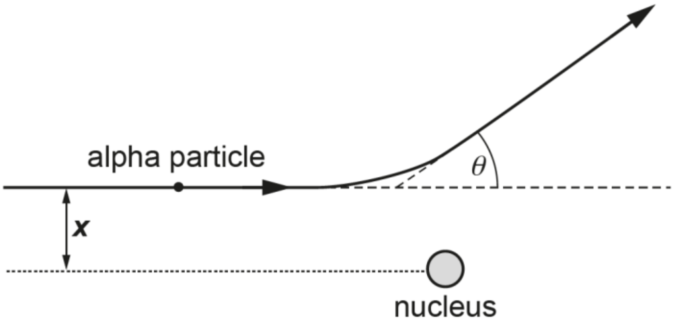
Question 5 (a)

5 **Fig. 5.1** represents the path of an alpha particle that passes near a positively charged nucleus. θ is the deflection angle.

Fig. 5.1



The distance ***x*** is the 'aiming error'.

(a) Describe and explain how the deflection angle of an alpha particle of the same energy with a smaller aiming error compares to the angle θ shown in **Fig. 5.1**.

....

....

....

....

....

.... **[3]**

Most candidates correctly stated that the deflection angle would increase as the alpha particle would experience a greater force, but only the best responses linked this to a greater impulse and therefore greater change of momentum.

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Question 5 (b) (i)

(b) If the aiming error ***x*** is zero, the alpha particle is deflected through 180°. At the distance of nearest approach to the nucleus the alpha particle is instantaneously stationary.

An alpha particle of energy 4.5 MeV is deflected through 180° by a silver nucleus, $^{107}_{47}Ag$.

(i) Calculate the distance of nearest approach of the alpha particle to the silver nucleus.

distance = ... m **[2]**

This standard calculation was performed correctly by about half the candidates. Common errors included confusing the equations for energy and force (using the square of the separation) and forgetting that an alpha particle has a charge of (+) 2*e*.

Question 5 (b) (ii)

(ii) State why this value gives a **maximum** radius for the silver nucleus.

....

.... **[1]**

This question proved challenging. Some responses considered that the alpha particle would be swallowed by the nucleus, others that the alpha particle was somehow deflected by the electrons surrounding the nuclei. Only the best clearly stated that higher energy alpha particles would get closer to the nucleus.

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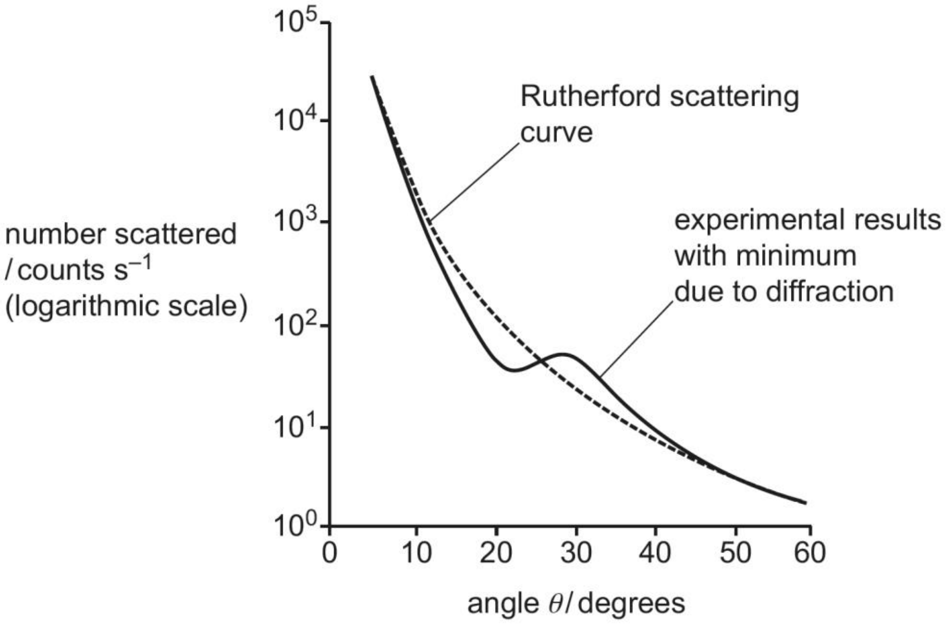
Question 5 (c)*

(c)* Electron diffraction can give a better determination of the radius of a nucleus.

Electrons accelerated to 250 MeV are diffracted by nuclei to give a diffraction minimum at angle θ where $\sin\theta = \frac{1.22\lambda}{d}$, where d is the diameter of the nucleus and λ is the de Broglie wavelength of the electron. (**Fig. 5.2**)

Fig. 5.2



Explain why electrons can get closer to the nucleus than alpha particles.

Calculate the relativistic factor for the accelerated electrons and use this to show that the electrons are moving at nearly the speed of light.

Use the approximation *momentum* $p = \frac{E}{c}$, where E is the energy of the electron, to calculate the de Broglie wavelength and then use information from the graph to calculate a value for the diameter of the nucleus. **[6]**

rest energy of electron = 0.511 MeV

This is the first LOR question on the paper. More than half the candidates gained Level 2 or Level 3. The best responses showed clear discussion of ideas and accurate, carefully laid-out calculations.

Less than half the responses discussed the fact that electrons are negative and hence not repelled by the nucleus. Many candidates concentrated on the lower magnitude of charge or the higher velocity for similar kinetic energy – neither statement worthy of merit.

A common error in calculating the relativistic factor was to use 'k.e./rest energy' rather than 'total energy/rest energy'.

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This was another question in which some candidates did not follow the instructions in the question stem. In this case some candidates ignored the relativistic calculation and went straight to the calculation of momentum.

Not all candidates correctly identified the diffraction minimum shown in the graph.

Assessment for learning

LOR questions can often be broken down into elements of an overall argument. Sometimes, such as in Question 5(c), these elements are explicitly stated. Candidates will find it useful to break down such questions into elements to make sure their answers cover all aspects of the question.

Exemplar 1

Electrons ~~are much~~ have half the charge of the alpha particles and are attracted to the nucleus. They are also much lighter and so it is easier to accelerate them to

$E_{tot} = E_K + E_{rest} = \gamma E_{rest}$

$E_k = E_{rest}(\gamma - 1)$

$250 = 0.511(\gamma - 1)$

$\gamma = 490.2$

$\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = 490.2$

$\frac{v^2}{c^2} = 0.9999958$

$\frac{v}{c} = 0.999998$ ∴ V is very close to c

$p = \frac{E}{c} = \frac{250 \times 10^6 \times 1.6 \times 10^{-19}}{3 \times 10^8}$

$= 1.33 \times 10^{-19}\ kg\,ms^{-1}$

$\lambda = \frac{h}{p} = 4.973 \times 10^{-15}\ m$

$\sin 22^\circ = \frac{1.22(4.973 \times 10^{-15})}{d}$

$d = 1.62 \times 10^{-14}\ m$ in diameter.

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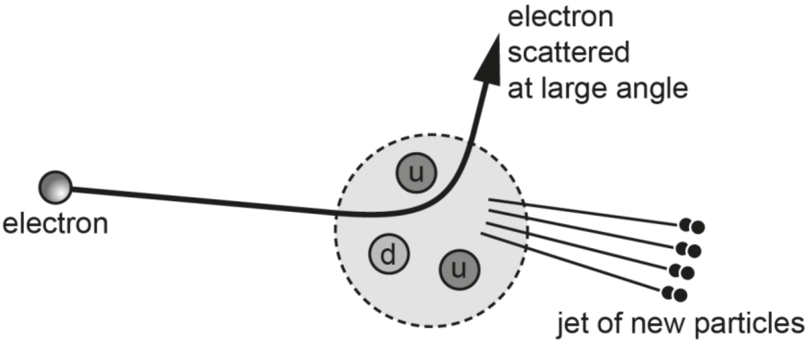
This response gained Level 3. The calculation is very clear, accurate and complete. The candidate identifies that the electron is attracted to the nucleus but shows some misunderstanding about the relationship between potential energies and kinetic energies, considering speed to be crucial rather than energy.

Question 5 (d) (i)

(d) Electrons accelerated to GeV energies are scattered by particles within individual nucleons. **Fig. 5.3** represents such an event.

Fig. 5.3



(i) State the nucleon that is shown in **Fig. 5.3**.

.... **[1]**

Nearly all responses correctly identified the proton.

Question 5 (d) (ii)

(ii) Suggest and explain why the kinetic energy of the electron is lower after it has scattered from the nucleon.

....

....

....

.... **[2]**

Most candidates recognised that the energy had been transferred to the jet of new particles whereas only a few identified 'total energy' of the new particles or kinetic energy and rest energy.

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Question 6 (a) (i)

6 This question is about isotopes of uranium and their uses.

Uranium-238 is the most common isotope of uranium. It decays in a series of steps to the stable isotope, lead-206.

The first step in the decay series is:

$^{238}_{92}U \longrightarrow ^{234}_{90}Th + ^{4}_{2}He$

(a)
(i) Thorium-234 decays into protactinium-234. Identify the particle X in the equation below.

$^{234}_{90}Th \longrightarrow ^{234}_{91}Pa + ^{0}_{-1}e + X$

.... **[1]**

Some candidates half-remembered a beta-minus decay equation but wrote 'neutron' rather than 'anti-neutrino'. A greater number did not gain the mark through writing 'neutrino' rather than 'anti-neutrino'.

Question 6 (a) (ii)

(ii) The masses of the two nuclei in part **(i)** and the beta-minus particle are given below.

Calculate the energy released in the decay.

mass of thorium-234 nucleus: 233.9940 u
mass of protactinium-234 nucleus: 233.9934 u
mass of electron: 0.00055 u
1 atomic mass unit (1 u) = 1.661×10^{-27} kg

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

This standard calculation was performed correctly by the majority of the candidates.

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Question 6 (a) (iii)

(iii) State why your answer to **(a)(ii)** is the **maximum** energy of the beta-minus particle.

.... **[1]**

This is essentially a recall question but only about a third of the responses gained the mark. There were a number of loose statements about 'energy losses' or 'thermal energy losses'.

Question 6 (b) (i)

(b) The age of a sample can be determined by measuring the ratio of uranium-238 to lead-206. It is assumed that all the lead-206 in the sample is produced by the decay series beginning with uranium-238.

The Voyager 1 spacecraft was launched in 1977. It is now moving through space beyond the Solar System. It carries a metal disk giving information about Earth. Included on the disk is a sample of pure uranium-238 with an initial activity of 9.6 Bq.

(i) Calculate the number of uranium nuclei in the sample when the spacecraft was launched.

half-life of uranium-238 = 4.51×10^9 years

number of nuclei = ... **[2]**

About half the responses gained both marks in this calculation. About a quarter of the candidates calculated the decay constant in units year^{-1} but then used this value in a correct calculation and were given one mark for error carried forward.

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Question 6 (b) (ii)

(ii) Calculate how many years it will take for one third of the original nuclei in the sample to become stable lead-206.

Assume that the half-life of uranium is the time for half the original nuclei to decay through the series to lead-206.

....years **[3]**

A common error in this part was not realising that if one-third of the original nuclei have decayed, two-thirds remain.

Question 6 (c) (i)

The isotope uranium-235 is used in nuclear fission reactors.

(c)
(i) Explain how the reaction below can lead to a chain reaction.

$${}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{90}_{37}Rb + {}^{143}_{55}Cs + 3{}^{1}_{0}n$$

....

....

.... **[2]**

This was not well answered by many. Candidates did not gain both marks through insufficient care over their answers. For example, many responses suggested that the three neutrons released could cause three other fission events but did not go on to describe this as a process that could be repeated. The language used to describe fission events was often imprecise – for example, 'the neutron will go on to hit other uranium *atoms*'.

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Question 6 (c) (ii)

(ii) In a reactor, uranium-238 can capture a neutron to become unstable uranium-239. This decays through two beta decays to plutonium-239 which will fission.

$$^{239}_{92}U \xrightarrow{\beta \text{ decay}} {}^{239}_{93}Np \xrightarrow{\beta \text{ decay}} {}^{239}_{94}Pu$$

Some designs of reactor can use a mixture of uranium and plutonium isotopes to produce power.

Calculate the minimum mass of neptunium-239 required to produce a steady power of 2.5 MW from the fission of plutonium in a reactor. Explain your reasoning.

Assume that the plutonium is stable and that all the plutonium nuclei are produced by the decay of neptunium-239.

Data:

decay constant of neptunium-239 ($^{239}_{93}Np$) = $3.4 \times 10^{-6}\,s^{-1}$
energy released per fission of plutonium-239 = 3.3×10^{-12} J
mass of neptunium-239 atom = 3.97×10^{-25} kg

minimum mass required = ... kg

Reasoning: ....

....

.... **[4]**

This question proved to be a good discriminator. More confident candidates gained 3 marks for the extended calculation and the very best showed clear reasoning in their explanation. Most responses gained at least the first marking point (calculating the number of fissions per second).

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Section C overview

Section C is based on the Advance Notice article, which this session concerned the James Webb Space Telescope. Most candidates showed familiarity with the article and, as usual, the best responses in this section were very impressive. Once again, there was little evidence of candidates running out of time at the end of the paper.

Question 7 (a)

7 **Fig. 1** in the article shows how the atmosphere affects the transmission of different wavelengths of electromagnetic radiation.

(a) Suggest why a logarithmic scale is used on the *x*-axis of the graph and why this choice of scale can make interpreting the data more difficult.

....

....

....

.... **[2]**

Most responses correctly stated that logarithmic scales allow a large range of values to be displayed. However, some did not quite make the point, for example 'large powers of ten can be displayed'. The second marking point proved more challenging; many responses wrote the equivalent of 'interpolation is more difficult' without focusing the answer on the specific graph.

Question 7 (b)

(b) **Fig. 1** in the article shows that half the gamma rays incident at the top of the atmosphere are absorbed as they pass through the first 120 km of the atmosphere.

Suggest and explain what may affect the proportion of gamma rays absorbed per km as they pass through the atmosphere.

....

....

....

.... **[2]**

This question was confidently answered by most candidates, some concentrating on the variation of absorption with gamma photon energy and hence wavelength, others considering the variation in density of the atmosphere.

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Question 8 (a)

8 This question is about the resolution of the James Webb Space Telescope (JWST) (lines 19–25 and lines 47–51).

(a) The diameter of the primary mirror is 6.5 m. Show that the angular resolution limit of the telescope operating at a wavelength of 2000 nm is about 0.4 μrad.

[1]

This proved a very accessible question with nearly all candidates reaching the correct answer.

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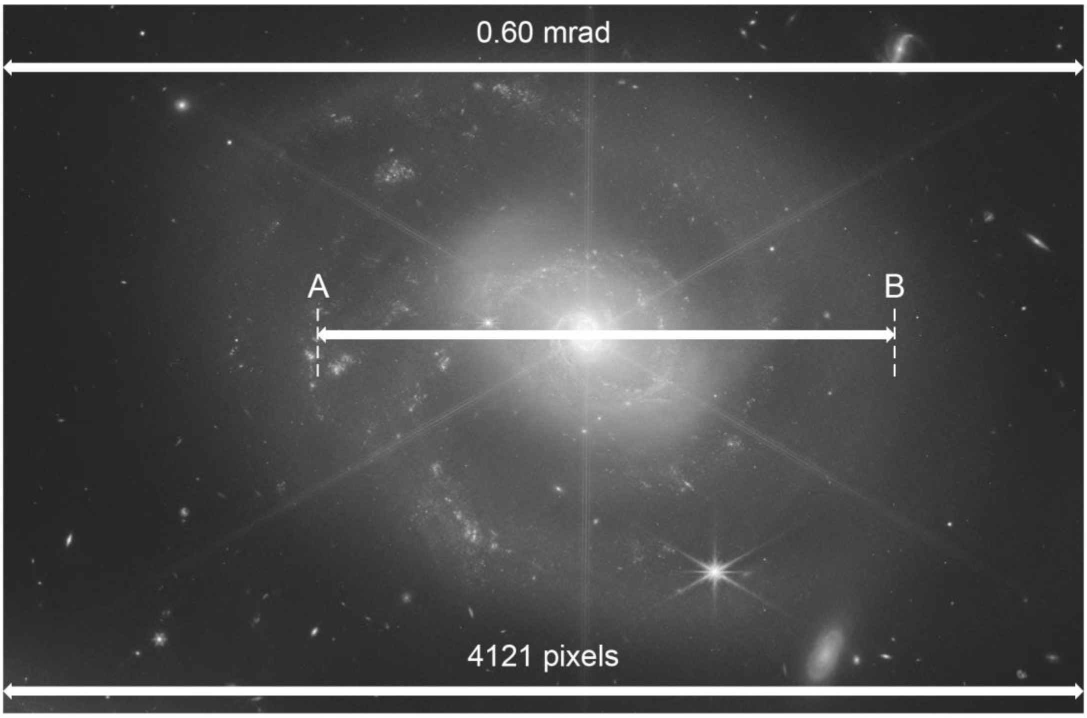
Question 8 (b) (i)

(b) **Fig. 8** shows an image of a galaxy taken by the JWST.

A and B are points marking the edge of the main section of the galaxy.

Fig. 8



(i) Calculate the image resolution in rad pixel^{-1}.

Suggest why the camera is designed to resolve to a smaller angle than that calculated in **(a)**.

image resolution = ... rad pixel^{-1}

Suggestion:

....

.... **[2]**

Once again, the calculation gave few candidates cause for concern but only a minority linked the calculated value to the statement in the Advance Notice article concerning the range of wavelengths imaged – even though the relevant lines from the article were given in the question.

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Question 8 (b) (ii)*

(ii)* Light emitted from the galaxy at wavelength 657 nm is redshifted to a wavelength of 668 nm (lines 53–61).

Calculate the distance to the galaxy in light years and use this value and information from **Fig. 8** to calculate the width, in light years, of the main section of the galaxy between points A and B. Comment on possible causes of error in the value you obtain.

Hubble constant = 73 km s^{-1} Mpc^{-1}
1 megaparsec (Mpc) = 3.1 × 10^{22} m
1 light year = 9.5 × 10^{15} m

Comment: ....

....

....

.... **[6]**

More than half the candidates gained Level 2 or above on this second LOR task. This question can be divided into elements and many responses showed that candidates taking this approach through underlinings and notations in the question stem. Some candidates found it difficult to convert the Hubble constant to units of s^{-1} or did not successfully convert a distance value in megaparsecs to light years, but nearly all responses gained some credit in the question.

Converting an angular separation into an arc length proved challenging for any candidates. Many unnecessarily took the tangent of the small angle in radians. This created difficulties for those who had not set their calculators to radian measure.

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Exemplar 2

Hubble constant = $73\,\text{km}\,\text{s}^{-1}\,\text{Mpc}^{-1}$
1 megaparsec (Mpc) = 3.1×10^{22} m
1 light year = 9.5×10^{15} m

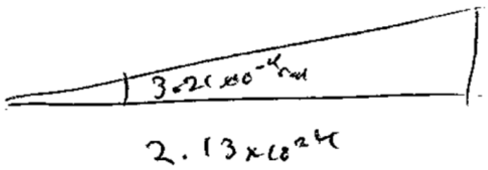
$\frac{668\times10^{-9} - 657\times10^{-9}}{657\times10^{-9}} \times 3\times10^{8}$

~~$657\times10^{-9} - 668\times10^{-}$~~ $= 5022831.05$

$\frac{5\times10^{6}}{73\times10^{3} \div 3.1\times10^{22}} = 2.13\times10^{24}$ m away

$2.13\times10^{24} \div (3\times10^{8}\times3.2\times10^{7}) =$ **2.22×10^{8} light years**

$7.5 \times 4.27\times10^{-5} = 3.21\times10^{-4}$ rad.



$3.21\times10^{-4} \times 2.13\times10^{24}$

$= 6.86\times10^{20}$ m across

$6.86\times10^{20} \div (3\times10^{8}\times3.2\times10^{7}) =$

7.14×10^{4} light years

Comment: Causes of error: ~~uncertainty~~ hubble constant, who's value is agreed to be between 70 and 80, so a high uncertainty. Small angle approximation used, which could cause error. Galaxy probably not emitt only one wavelength of light. so uncertainty in shift. **[6]**

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Exemplar 2 is a Level 3 response; it covers all the points required in the mark scheme. It is not a perfect response though does show a staged calculation. There is some intermediate rounding and a lack of clarity at points, for example the lack of units for the recession velocity and the repetition of the conversion calculation from metres to light years.

The response shows knowledge of the uncertainty in the value of the Hubble constant which will increase the uncertainty in the result. The small angle approximation would not add much to the uncertainty and the candidate is not correct in thinking that the polychromatic output from the galaxy would alter the calculated value of the redshift. Nonetheless, it achieves Level 3.

Question 9

9 This question is about the Chandra X-ray Observatory (lines 26–32).

The Chandra X-ray Observatory has a highly elliptical orbit. The total energy of the satellite remains constant.

At a distance of 1.5×10^{8} m, its furthest point from Earth, the speed of the Chandra is 1.1×10^{3} m s^{-1}.

Calculate the speed of the Chandra at a distance of 1.6×10^{7} m, its nearest approach to Earth.

Ignore the effect of the Sun and the Moon.

Mass of Earth = 6.0×10^{24} kg

speed = ... m s^{-1} **[4]**

This is the most challenging calculation on the paper, requiring a good understanding of the relationship between total energy of an orbiting body and the relative contributions of potential and kinetic energy. The best responses showed a good understanding of total energy in orbit remaining constant and showed an ability to work with energy per kg for both kinetic energy and potential energy. Some candidates gained a mark for stating that the sum of the energies remain constant even though they could not progress convincingly beyond this point.

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Question 10 (a)

10 The JWST orbits at the L2 point (lines 41–49).

(a) Calculate the resultant field strength due to the Earth and the Sun at the L2 point.

Mass of Sun = 2.0×10^{30} kg
Mass of Earth = 6.0×10^{24} kg

resultant field strength = ... $\mathrm{N\,kg^{-1}}$ **[3]**

Responses to this question often incorrectly assumed that gravitational field strength is a positive value. About a third of the candidates gained 2 marks rather than three due to this error. Weaker responses gained 1 mark for one calculation of a correct field strength magnitude, illustrating the importance of candidates attempting parts of a longer calculation even if they do not know how to complete the task.

Question 10 (b) (i)

(b)
(i) Show that the L2 point will make one revolution of the Sun in about 3.2×10^{7} s (one year).

[2]

This question, coming near the end of the examination, was also challenging for less successful responses. Some responses came close to the correct answer but used the field strength of the Sun rather than that of the Sun and Earth combined. Many candidates used Kepler's Third Law to reach a value – this gained a mark but was inaccurate because the contribution of the Earth was ignored. Some candidates also did not use the correct radial distance from the telescope to the Sun (using 1.5×10^{11} m rather than 1.515×10^{11} m).

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Question 10 (b) (ii)

(ii) The mass of the Moon is about 1% that of the Earth. It orbits the Earth at a radius of 3.8×10^8 m.

Suggest and explain the effect of the Moon, if any, on the JWST orbiting around the L2 point.

....

....

....

....

....

.... **[3]**

The majority of the candidates gained at least 1 mark for the final question. Most responses suggested that the Moon would have a very minor effect on the field strength at the L2 point and the better responses stated that the magnitude of the effect would depend on the position of the Moon in its orbit around the Earth. The very best responses included calculations showing the maximum magnitude of the field strength of the Moon at the L2 point.

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Question 8, Figure 8 Image of a galaxy: © Credit: ESA/Webb, NASA & CSA, L. Armus, A. S. Evans

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