



# **Examiners' Report**

## **June 2024**

**GCE Physics 9PH0 02**

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## Introduction

The assessment structure of Advanced Paper 2 is equal to that of Advanced Paper 1. The assessment consisted of ten multiple choice questions, a number of short answer questions, and longer questions. The paper allowed candidates of all abilities to demonstrate their knowledge and understanding of physics, through a variety of structured and unstructured calculations and longer and shorter written responses. They were able to apply their knowledge to familiar and unfamiliar contexts.

All candidates were able to access marks by performing simple calculations, substituting data and rearranging simple formulae. Many candidates were able access marks for the correct use of standard definitions and simple explanations of physical phenomena. The latter included the formation of standing waves in oscillating systems and the analysis of absorption spectra in stars. Longer unstructured calculation questions were more demanding. The conversion of °C to K was generally carried out effectively, although omitting this step did lead to incorrect answers to calculations in some cases.

As always, candidates are encouraged to always include units, as some candidates were not awarded the final mark for unit omission. Higher scoring candidates were able to produce some excellent multi-stage calculations, with elegant use of algebra and valid conclusions. The quality of written communication for the aforementioned group was excellent, with many good examples of longer written responses scoring full marks.

In some questions candidates needed to use extra space to expand or replace their answers. When this is the case, candidates should be reminded to indicate clearly where the additional information can be found. Steady improvement in standards and accessibility of marking points was demonstrated in all areas.

## Question 11

The majority of candidates were able to use the formula for the diffraction grating correctly, giving a correct answer with the correct units and scoring both marks. A small proportion of responses confused the grating spacing with the number of lines per metre and attempted to calculate  $d$  as being  $1/1.6 \times 10^{-6}$  m. In this case this error cost both marks.

- 11 A student shone green light from a laser through a diffraction grating, producing a diffraction pattern on a screen. The student determined the angle of the third order maximum.

Calculate the wavelength of the green light.

angle of third order maximum =  $73.3^\circ$

grating spacing =  $1.67 \times 10^{-6}$  m

$$3\lambda = 1.67 \times 10^{-6} \sin 73.3$$

$$\lambda = \frac{1.67 \times 10^{-6} \sin 73.3}{3}$$

$$\lambda = 5.33 \times 10^{-7} \text{ m (533 nm)}$$

Wavelength = .....



This response scored both marks. The answer is given in nm, but it is a correct and valid use of units. Answers of  $5.33 \times 10^{-7}$  m generally scored 2 marks.



Check which mode the calculator is set to. In this case we need to use degrees, as the angle is expressed in degrees.

- 11 A student shone green light from a laser through a diffraction grating, producing a diffraction pattern on a screen. The student determined the angle of the third order maximum.

Calculate the wavelength of the green light.

angle of third order maximum =  $73.3^\circ$

grating spacing =  $1.67 \times 10^{-6} \text{ m}$

$$n\lambda = d \sin \theta \quad \lambda = \frac{d \sin \theta}{n} = \frac{1.67 \times 10^{-6} \times \sin 73.3^\circ}{3} = 1.6 \times 10^{-6}$$

Wavelength =  $1.6 \times 10^{-6}$



**ResultsPlus**  
Examiner Comments

This response did not score any marks as the answer corresponds to the use of a value of  $n=1$ , which loses MP1. If this had not been the case MP2 would have not been awarded due to the omission of units.



**ResultsPlus**  
Examiner Tip

Unless a calculation question is a 'show that question', the final marking point will always need correct units.

## Question 12 (a)(i)-(b)

This question was testing candidates' knowledge of the photoelectric effect. Part (a)(i) required knowledge of the term 'threshold frequency' and was generally well answered by the majority of candidates. (a)(ii) was more demanding and required a discussion of how the existence of a threshold frequency was not consistent with wave theory. Many candidates were able to correctly state that energy will build up over time, but a smaller proportion linked this to the idea that electrons would be emitted at any frequency if wave theory could be applied. Part (b) required the definition of a photon and many candidates were able to provide this.

12 Study of the photoelectric effect leads to observations that cannot be explained by the wave theory of light.

When ultraviolet light is shone on a charged zinc plate, electrons are released.

When visible light is shone on the zinc plate, electrons are not released.

(a) (i) State what is meant by threshold frequency.

(1)

Its the minimum ~~to~~ frequency required for electrons to leave the surface of the metal.

(ii) Explain why the observation of a threshold frequency is **not** consistent with the wave theory of light.

(2)

As once photons frequency is past the threshold frequency there is an immediate release of electrons. However in wave theory it was believed that electrons will be released at any frequency as there will be a build up of energy until electron is released.

(b) The photoelectric effect can be explained using the idea of photons.

State what is meant by the term photon.

(1)

Photon is a discrete packet of energy.



This response scored all 4 marks.

In (a)(ii) the first 2 lines were not creditworthy, but then the candidate went on to say that with wave theory electrons will be released at any frequency as there will be a build up of energy, which scored both marking points for this part.

12 Study of the photoelectric effect leads to observations that cannot be explained by the wave theory of light.

When ultraviolet light is shone on a charged zinc plate, electrons are released.  
When visible light is shone on the zinc plate, electrons are not released.

(a) (i) State what is meant by threshold frequency.

(1)

Is the minimum frequency required for photons to have enough energy to release electrons according to  $E = hf$

(ii) Explain why the observation of a threshold frequency is **not** consistent with the wave theory of light.

(2)

Because if light were to behave like a wave, it would continuously supply the electrons with energy and therefore increasing the intensity would cause the electrons to release, but that is not the case which makes it inconsistent with the wave theory of light

(b) The photoelectric effect can be explained using the idea of photons.

State what is meant by the term photon.

(1)

Photons are packets of energy that form light



**ResultsPlus**  
Examiner Comments

This response scored 2 marks. (a)(i) was enough to award the marking point.

In (a)(ii) one mark was scored for the idea that energy would be continuously supplied to the electron.

Part (b) did not use the necessary terms 'discrete' or 'quantum'.

12 Study of the photoelectric effect leads to observations that cannot be explained by the wave theory of light.

When ultraviolet light is shone on a charged zinc plate, electrons are released.  
When visible light is shone on the zinc plate, electrons are not released.

(a) (i) State what is meant by threshold frequency.

(1)

because  $E = hf$   $h$  is constant so a certain  
frequency <sup>or higher frequency</sup> is required to give enough energy

(ii) Explain why the observation of a threshold frequency is **not** consistent with the wave theory of light.

(2)

In the photo electric effect the light is  
released as little packets called photons  
so it is not waves so is not consistent  
with wave theory

(b) The photoelectric effect can be explained using the idea of photons.

State what is meant by the term photon.

(1)

a photon is a little packet of  
energy that emits that energy as light



**ResultsPlus**  
Examiner Comments

In (a)(i) the candidate has the idea of minimum frequency required, but does not go on to say "to give enough energy to an electron to be released".

In (a)(ii) stating it is inconsistent with wave theory is insufficient, without the idea that with waves energy builds up over time, so electron would be released regardless of the frequency.

In (b) the terms 'discrete' or 'quantum of energy' were required to score the mark.

## Question 13

This question was generally well answered with the majority of candidates scoring 3 or 4 marks. The first marking point (MP1) for the use of Wein's law was generally awarded to most candidates. They were then required to use the temperature obtained in the formula for the Stephan-Boltzmann law. Some candidates made no further progress at this stage because of attempting to use the formula for Intensity. MP2 was for the use of  $4\pi r^2$  to determine the area, some candidates did not score this mark due to doubling the value of the radius they were given in the question or for the omission of the power of 4 in the formula. Many candidates were able to use the Stephan-Boltzman law correctly and where 3 marks were awarded instead of 4 it was generally due to unit omission or the use of incorrect units.

13 Aldebaran is a red giant star.

For a black body radiator of Aldebaran's surface temperature, the wavelength  $\lambda_{\max}$  at which the intensity is maximum is  $7.43 \times 10^{-7}$  m.

Determine the luminosity of Aldebaran.

radius of Aldebaran =  $3.14 \times 10^{10}$  m

$$\lambda_{\max} T = 2.898 \times 10^{-3}$$

$$T = \frac{2.898 \times 10^{-3}}{7.43 \times 10^{-7}} = 3900 \text{ K}$$

$$L = \sigma A T^4$$

$$= 5.67 \times 10^{-8} \times 4\pi (3.14 \times 10^{10})^2 \times (3900)^4$$

$$= 1.63 \times 10^{29}$$

$$\text{Luminosity} = 1.63 \times 10^{29} \text{ W}$$



**ResultsPlus**  
Examiner Comments

This response scored all 4 marks. The candidate has correctly calculated the area within the Stephan-Boltzmann equation and has correctly identified the unit as being watts.



**ResultsPlus**  
Examiner Tip

When performing multi-stage calculations, ensure brackets are used correctly. If not, the final marking point cannot be scored if the answer is not correct.

13 Aldebaran is a red giant star.

For a black body radiator of Aldebaran's surface temperature, the wavelength  $\lambda_{\max}$  at which the intensity is maximum is  $7.43 \times 10^{-7}$  m.

Determine the luminosity of Aldebaran.

radius of Aldebaran =  $3.14 \times 10^{10}$  m

$$\lambda_{\max} T = 2.898 \times 10^{-3}$$

$$\therefore T = \frac{2.898 \times 10^{-3}}{7.43 \times 10^{-7}}$$

$$= 3900.403769 \text{ K.}$$

$$L = \sigma A T^4$$

$$= (5.67 \times 10^{-8}) (4\pi (3.14 \times 10^{10})^2) (3900 \dots)$$

$$= 2.740070812 \times 10^{18}$$

$$= 2.74 \times 10^{18} \text{ W m}^{-2} \text{ K}^4$$

(3sf) // Luminosity =  $2.74 \times 10^{18} \text{ W m}^{-2}$



**ResultsPlus**  
Examiner Comments

This response scored 2 marks. MP1 for the correct value of T being calculated using Wein's law and MP2 for a correct area calculation as shown in the Stefan-Boltzmann equation. The candidate has not calculated  $T^4$ , which meant they were unable to score MP3 or 4.

13 Aldebaran is a red giant star.

For a black body radiator of Aldebaran's surface temperature, the wavelength  $\lambda_{\max}$  at which the intensity is maximum is  $7.43 \times 10^{-7}$  m.

Determine the luminosity of Aldebaran.

radius of Aldebaran =  $3.14 \times 10^{10}$  m

$$L = \sigma AT^4$$

$$A = 4\pi r^2$$

$$I = \frac{L}{4\pi r^2}$$

$$\lambda_{\max} T = 2.898 \times 10^{-3}$$

$$7.43 \times 10^{-7} = \frac{L}{4\pi (3.14 \times 10^{10})^2}$$

$$L = \dots$$

$$I = \frac{L}{A} =$$

Luminosity = .....



**ResultsPlus**  
Examiners Comments

In this response the candidate has confused the wavelength of maximum intensity, for the intensity, which they have attempted to use with the formula for intensity.

They do score MP2 for the use of  $A = 4\pi r^2$ , so this response scores 1 mark.

## Question 14 (a)-(d)

The first part of this question generally scored very well, with the vast majority of candidates scoring 3 marks. Very occasionally MP3 was not awarded for leaving the final answer as a fraction.

Part (b) was also generally well answered with the majority of candidates being able to apply the thin lens equation effectively. Where incorrect use of distances or misapplication of the formula lead to an incorrect answer, some candidates were able to use this incorrect answer effectively in part (c) to determine the image height and score all 3 marks with error carried forward (ecf).

Part (c) was also well answered, with the majority of candidates correctly calculating the magnification and multiplying this by the object height. Occasionally incorrect units or a power of ten error (POT) meant that MP3 was not scored.

The final part of the question proved the most challenging, with the majority of candidates not scoring the mark for (d). Some candidates who did identify the image as being virtual and erect/upright often did this with the aid of a sketch lens diagram.

14 A student used two converging thin lenses in combination to form an image of an object.

(a) Show that the power of the combination of lenses was about 20D.

focal length of lens 1 = 10 cm

focal length of lens 2 = 15 cm

(3)

$$P = \frac{1}{f}$$

$$\text{lens 1: } P = \frac{1}{0.1} = 10$$

$$10 + 6.67 = 16.67 \text{ D}$$

$$\text{lens 2: } P = \frac{1}{0.15} = \cancel{15} 6.67$$

(b) The object was 4 cm in front of the combination of lenses.

Calculate the image distance.

(2)

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{0.04} + \frac{1}{v} = 16.67 \quad \frac{1}{v} = (-) 8.33 \quad v = (-) 0.12$$

Image distance = 0.12 m

(c) The object height was 1.4 cm.

Calculate the image height.

(3)

$$\frac{h_i}{h_o} = \frac{v}{u}$$

$$\frac{h_i}{0.014} = \frac{0.12}{0.04} \quad \therefore h_i = 0.042 \text{ m}$$

Image height = 0.042 m

(d) The object is magnified.

State **two** other properties of the image.

(1)

Virtual image, erect (same way up)



**ResultsPlus**  
Examiner Comments

This response scored full marks. Centimetres have been converted directly to metres in calculations. In part (c) the candidate has elegantly combined both equations to arrive at the correct answer in fewer steps.

14 A student used two converging thin lenses in combination to form an image of an object.

(a) Show that the power of the combination of lenses was about 20 D.

focal length of lens 1 = 10 cm    0.1  
 focal length of lens 2 = 15 cm    0.15

(3)

$$\frac{1}{10} + \frac{1}{15} = \frac{1}{0.1} + \frac{1}{0.15} = 16.6 \approx 20$$

(b) The object was <sup>0.04</sup> 4 cm in front of the combination of lenses.

Calculate the image distance.

(2)

$$\frac{1}{u} + \frac{1}{v} = 16.6 \quad v = -0.12$$

$$\frac{1}{v} = 16.6 - 25$$

Image distance = 0.12 m

(c) The object height was 1.4 cm.

Calculate the image height.

(3)

$$\frac{1}{0.14} + \frac{1}{v} = 16.6 \qquad \frac{1}{v} = 9.52$$

$$v = 0.105 \text{ m}$$

$$\frac{1}{v} = 16.6 - \frac{50}{7}$$

$$\text{Image height} = 0.105 \text{ m}$$

(d) The object is magnified.

State **two** other properties of the image.

(1)

Virtual & upright



**ResultsPlus**  
Examiner Comments

Parts (a), (b) and (d) scored full marks. In part (c) the candidate had attempted to use the thin lens equation, rather than magnification, so this scored no marks.

14 A student used two converging thin lenses in combination to form an image of an object.

(a) Show that the power of the combination of lenses was about 20 D.

focal length of lens 1 = 10 cm

focal length of lens 2 = 15 cm

(3)

$$P = 1/f$$

$$1/0.1 = 10$$

$$P = P_1 + P_2 \dots$$

$$1/0.15 = 6.67$$

$$10 + 6.67 = 16.67 \approx 20$$

(b) The object was 4 cm in front of the combination of lenses.

Calculate the image distance.

(2)

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

$$\frac{1}{u} - \frac{1}{f} = \frac{1}{v}$$

$$\frac{1}{0.04} - 16.67 = 8.33$$

$$1/v = 8.33$$

$$v = 0.12 \text{ m}$$

Image distance = 0.12 m

(c) The object height was 1.4 cm.

Calculate the image height.

(3)

$$m = \frac{v}{u}$$

$$M u = v$$

Image height = .....

(d) The object is magnified.

State **two** other properties of the image.

(1)

It is inverted

It is real, not ~~virtual~~ virtual



**ResultsPlus**  
Examiner Comments

Part (a) and (b) both scored full marks. In part (c) the candidate identified the correct formula to use, but did not substitute in any values, so scored no marks. In part (d) the answer should have been virtual and erect/upright, so this did not score the mark.

## Question 15 (a)

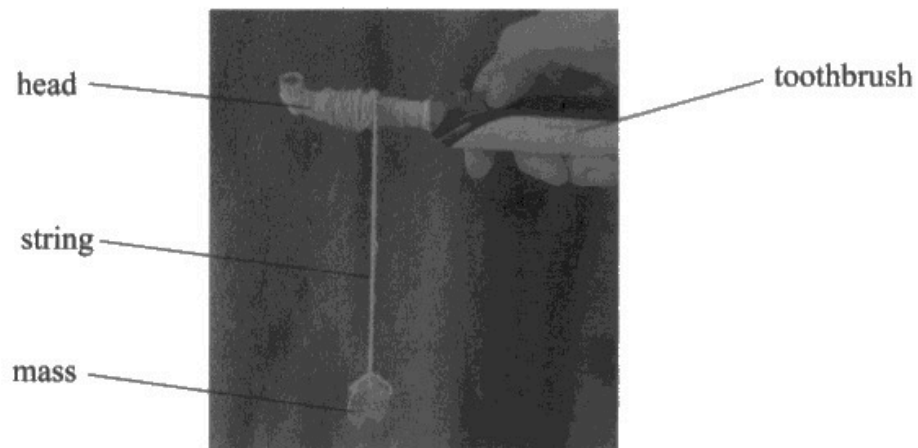
There was a wide spread of marks awarded for this question. There were some excellent responses which scored full marks and the vast majority of candidates were able to score some marks for demonstrating their knowledge of how standing waves are formed or how resonance occurs in simple harmonic motion (SHM).

For MP1 and MP4 to be awarded, both marks required reference to the context of the question, namely the oscillating system. This was the toothbrush and mass-string system. Some candidates did not score MP1 as a vague statement of 'waves reflect and interfere/driving frequency matches the natural frequency' does not refer to the necessary context.

For MP4 to be scored, the location of where the maximum amplitude and hence antinode was formed was required. Candidates could also score MP4 for stating the correct location of the nodes, which are minimum/zero amplitude. MP4 was frequently not scored for not referencing the location of the antinode/nodes.

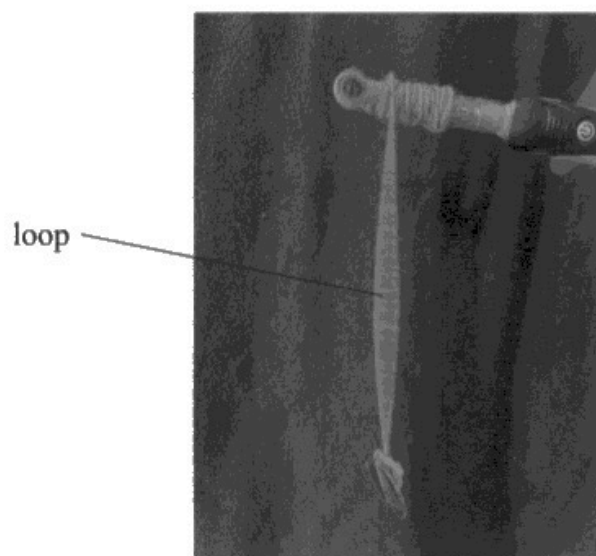
MP2 and MP5 were most commonly scored by the majority of candidates. It is worth noting that MP2 was sometimes not awarded as the candidate had used the term 'superimpose', which is not correct.

- 15 A student wound a piece of string around the head of an electric toothbrush. The student attached a small mass to the other end of the string, as shown in Photograph 1.



**Photograph 1**

The toothbrush was switched on and the head started to vibrate. The student rotated the toothbrush slowly to unwind the string. At a particular length, large vibrations were observed on the string. The string formed a loop, as shown in Photograph 2.



**Photograph 2**

(a) Explain how the vibrations of the toothbrush head caused the loop to form.

(5)

When the toothbrush vibrates, it results in a driving force of a certain frequency acting on the string.

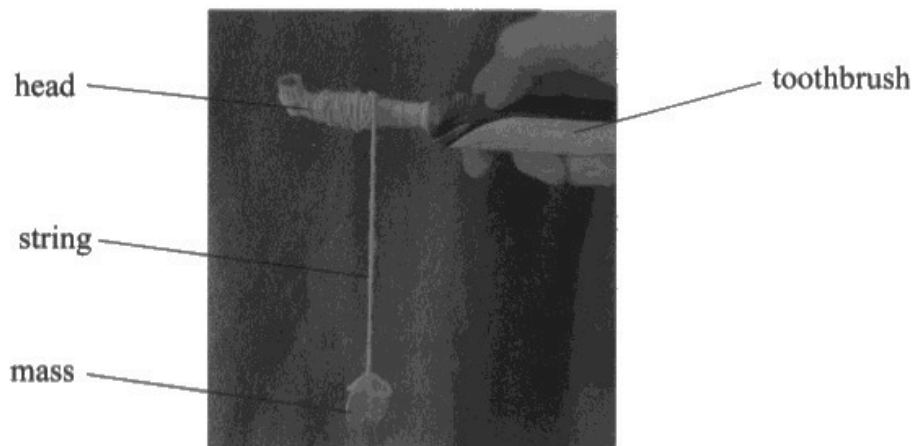
When the toothbrush begins to vibrate, it forms a progressive wave which will rebound off the mass attached. The mass and the toothbrush act as boundaries. As the toothbrush continues to vibrate another wave will superpose with the initially rebounded wave and interfere constructively when the waves are in phase. When large vibrations were observed that means the length of the string is equal to exactly  $\frac{1}{2}$  of the waves. The toothbrush produces\* and an antinode is produced in the middle, as the waves are in phase and interfere constructively, to give the maximum amplitude.

\* As a standing wave is produced in order for the loop to form.



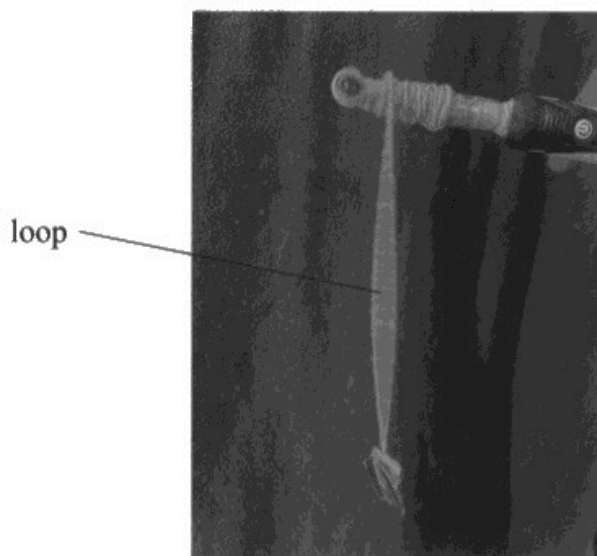
This response scored all 5 marks. It was clear that the candidate was talking about the superposition of waves travelling on the oscillating system and they correctly identified the position of the antinode.

- 15 A student wound a piece of string around the head of an electric toothbrush. The student attached a small mass to the other end of the string, as shown in Photograph 1.



**Photograph 1**

The toothbrush was switched on and the head started to vibrate. The student rotated the toothbrush slowly to unwind the string. At a particular length, large vibrations were observed on the string. The string formed a loop, as shown in Photograph 2.



**Photograph 2**

(a) Explain how the vibrations of the toothbrush head caused the loop to form.

(5)

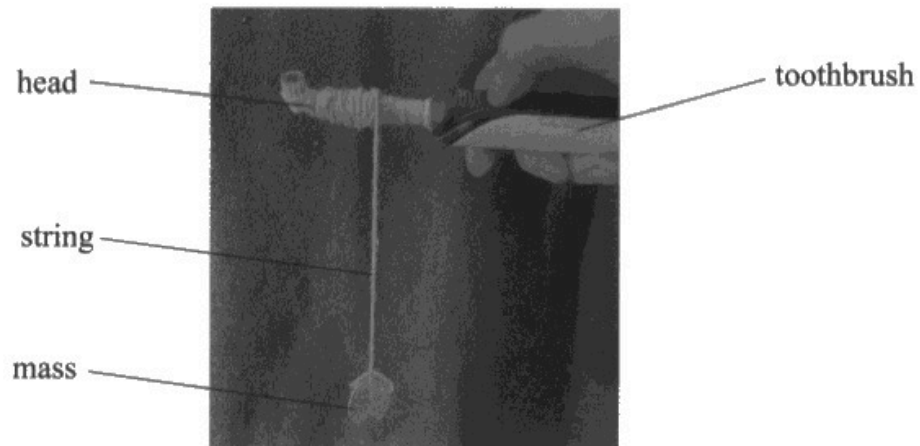
When toothbrush vibrates, it causes the string to oscillate. ~~A~~  
Progressive waves travel ~~from~~ <sup>to and fro</sup> the toothbrush end ~~to~~ <sup>and the</sup> mass end ~~and~~.  
~~travel~~ ~~but~~ the waves superpose and form a standing wave  
~~when~~ If they ~~no~~ ~~superpose~~ reach in  $n\lambda$  [where  $n$  is an integer] then they  
~~just~~ interfere constructively and form an antinode; if they meet  
in  $(n + \frac{1}{2})\lambda$ , then they interfere destructively and form a node.  
The length of string was adjusted so it is exactly half a wavelength  
 $\therefore$  loop produced.



**ResultsPlus**  
Examiner Comments

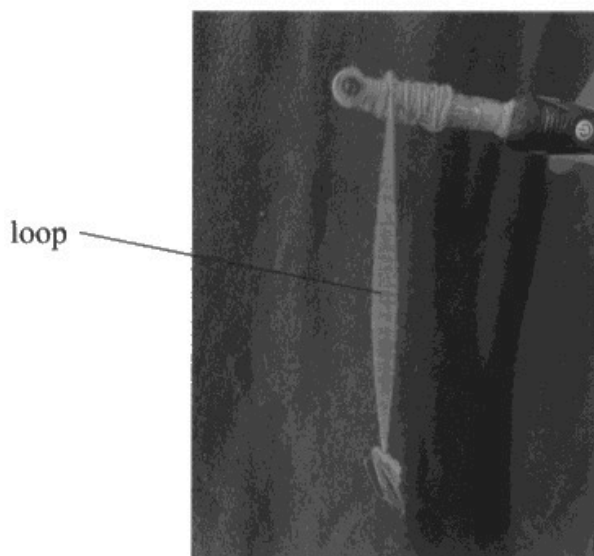
This response scored 3 marks. Here the candidate has scored MP1, 2 and 5 within the first 3 lines. They then went on to talk about waves meeting with a path difference of  $n\lambda$ , which was not awarded any further marks. To score MP3 candidates were required to talk about waves being in phase for constructive interference or antiphase for destructive interference. MP4 required the location of either the antinode or the nodes on the string, as well as reference to maximum/minimum amplitude respectively.

- 15 A student wound a piece of string around the head of an electric toothbrush. The student attached a small mass to the other end of the string, as shown in Photograph 1.



**Photograph 1**

The toothbrush was switched on and the head started to vibrate. The student rotated the toothbrush slowly to unwind the string. At a particular length, large vibrations were observed on the string. The string formed a loop, as shown in Photograph 2.



**Photograph 2**

(a) Explain how the vibrations of the toothbrush head caused the loop to form.

(5)  
Toothbrush vibrates at set frequency and has set wavelength  
string is ~~was~~ excited to this wavelength when it  
is  $\frac{1}{2}$  wavelength a standing wave is created  
as the wave goes from peak to trough a loop  
appears to be formed.



**ResultsPlus**  
Examiner Comments

This response scored MP5 only for reference to a standing wave being formed.

## Question 15 (b)

As with many of the calculation questions on the paper, this question was generally very well answered with many candidates scoring the full 5 marks. The most problematic marking point to award was MP3 for determining the wavelength as candidates needed to realise the length of the string they had been given in the question had 4 loops which corresponds to 2 wavelengths. Where candidates used the length of string or a quarter of the length of the string, MP3 and hence MP5 were not awarded. Occasionally candidates misinterpreted the question as being about a simple pendulum and attempted to find a value for T using  $T=2\pi\sqrt{l/g}$ . In this case MP2 and 5 were not awarded as the T they had found was a time period, not the tension in the string and therefore not dimensionally correct.

- (b) The student continued to unwind the string and the loop disappeared. When the length of the unwound string was twice that shown in Photograph 2 two loops were seen. Three loops were seen when the unwound length was three times that shown in Photograph 2 and so on.

Determine the frequency of vibration of the toothbrush head.

unwound length of string with 4 loops = 0.69 m

mass on string = 0.010 kg

mass per unit length of string =  $9.1 \times 10^{-4} \text{ kg m}^{-1}$

(5)

$$v = \sqrt{\frac{T}{\mu}} \quad v = f\lambda$$

$$T = 0.010 \times 9.81 = 0.0981 \text{ N}$$

$$v = \sqrt{\frac{0.0981}{9.1 \times 10^{-4}}}$$

$$= 10.38 \text{ m s}^{-1}$$

$$\lambda = \frac{0.69}{2} = 0.345 \text{ m}$$

$$f = \frac{v}{\lambda} = \frac{10.38}{0.345}$$

$$= 30.095$$

$$\text{Frequency} = 30.1 \text{ Hz}$$



**ResultsPlus**  
Examiner Comments

This response scored all 5 marks. The candidate has carried out correct substitutions, calculations and included the correct unit with the final answer.

- (b) The student continued to unwind the string and the loop disappeared. When the length of the unwound string was twice that shown in Photograph 2 two loops were seen. Three loops were seen when the unwound length was three times that shown in Photograph 2 and so on.

Determine the frequency of vibration of the toothbrush head.

unwound length of string with 4 loops = 0.69 m

mass on string = 0.010 kg

mass per unit length of string =  $9.1 \times 10^{-4} \text{ kg m}^{-1}$

$$v = \sqrt{\frac{T}{\mu}}$$

$$v = f\lambda$$

$$T = ?$$

$$\frac{0.010 \times 9.81}{9.1 \times 10^{-4}} = v^2 \quad (5)$$

$$v^2 = 107.8 \text{ m}^2 \text{ s}^{-2} \quad v = 10.4 \text{ m s}^{-1}$$

$$v = f\lambda$$

$$10.4 = f \times 0.69$$

$$f = 15 \text{ Hz}$$

Frequency = 15 Hz



**ResultsPlus**  
Examiner Comments

Here the candidate has scored MP1 and 2 for calculating the tension and then the wave speed. They used 0.69 m as the wavelength, so did not score MP3 or MP5. However, they have used a dimensionally correct wavelength, so they scored MP4 for use of the wave speed equation.

- (b) The student continued to unwind the string and the loop disappeared. When the length of the unwound string was twice that shown in Photograph 2 two loops were seen. Three loops were seen when the unwound length was three times that shown in Photograph 2 and so on.

Determine the frequency of vibration of the toothbrush head.

unwound length of string with 4 loops = 0.69 m

mass on string = 0.010 kg

mass per unit length of string =  $9.1 \times 10^{-4} \text{ kg m}^{-1}$

(5)

$$\lambda = \frac{0.69}{2} = 0.345 \text{ m}$$

$$v = \sqrt{\frac{T}{\mu}}$$

$$f\lambda = \sqrt{\frac{T}{\mu}}$$

$$f^2\lambda^2 = \frac{T}{\mu}$$

$$f^3 = \frac{1}{\mu\lambda^2}$$

$$f = \sqrt[3]{\frac{1}{9.1 \times 10^{-4} \times 0.345^2}}$$

$$= 20.99 \text{ Hz} \approx 21 \text{ Hz}$$

Frequency = 20.99 Hz 21 Hz



**ResultsPlus**  
Examiner Comments

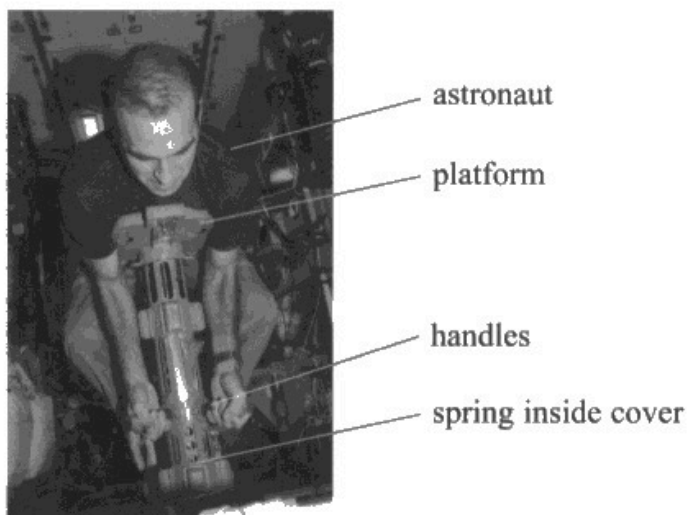
Here the candidate has scored MP1 for correctly determining the wavelength. They then go on to attempt to derive an equation to determine the frequency in just one step. Whilst this can be a valid method, in this case they had replaced  $T$  in the formula by the number 1 and scored no further marks.

## Question 16 (a)

This question was very well answered by the vast majority of candidates, where most responses scored the full 4 marks. The main issue which prevented full marks from being scored was forgetting to correct for the mass of the platform, which meant that MP3 and MP4 could not be awarded.

- 16 On the International Space Station (ISS), astronauts measure their mass once a month using a Body Mass Measurement Device (BMMD).

The BMMD is constructed from a large spring attached to the floor of the ISS, with a platform and handles attached to the spring. The spring is compressed and the astronaut puts his body onto the platform and holds onto the handles, as shown.



(Source: <https://www.nasa.gov/content/nasa-astronaut-rick-mastracchio-3>)

The spring is released and the astronaut and platform oscillate with simple harmonic motion.

An astronaut used the BMMD. The frequency of oscillation was 0.34 Hz.

- (a) Determine the mass of the astronaut.

spring constant =  $350 \text{ N m}^{-1}$

mass of platform =  $5.7 \text{ kg}$

(4)

$$T = \frac{1}{f} = \frac{1}{0.34} = 2.9415$$

$$T = 2\pi \sqrt{\frac{m}{k}} \Rightarrow \frac{T}{2\pi} = \sqrt{\frac{m}{k}}$$

$$\frac{T^2}{4\pi^2} = \frac{m}{k}$$

$$m = \frac{T^2 \times k}{4\pi^2} = \frac{2.941^2 \times 350}{4\pi^2}$$

$$= 76.69 \text{ kg}$$

$$\text{mass of astronaut} = 76.69 - 5.7 = 70.99 \text{ kg}$$

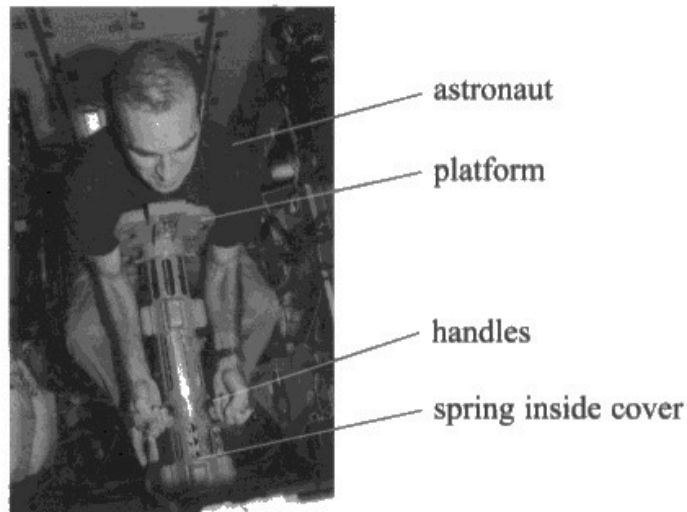
$$\text{Mass of astronaut} = 71 \text{ kg}$$



This response scores all 4 marks, clearly laid out and with correct units.

16 On the International Space Station (ISS), astronauts measure their mass once a month using a Body Mass Measurement Device (BMMD).

The BMMD is constructed from a large spring attached to the floor of the ISS, with a platform and handles attached to the spring. The spring is compressed and the astronaut puts his body onto the platform and holds onto the handles, as shown.



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The spring is released and the astronaut and platform oscillate with simple harmonic motion.

An astronaut used the BMMD. The frequency of oscillation was 0.34 Hz.

(a) Determine the mass of the astronaut.

$$\text{spring constant} = 350 \text{ N m}^{-1}$$

$$\text{mass of platform} = 5.7 \text{ kg}$$

(4)

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

$$0.34 = \frac{1}{2\pi} \sqrt{\frac{350}{5.7+m}}$$

$$5.7+m = 76.69$$

$$m = 71 \text{ kg}$$

Mass of astronaut = 71 kg



This also scores all 4 marks. The candidate has derived an equation correctly to directly determine the mass of the astronaut, leading to a correct answer.

- 16 On the International Space Station (ISS), astronauts measure their mass once a month using a Body Mass Measurement Device (BMMD).

The BMMD is constructed from a large spring attached to the floor of the ISS, with a platform and handles attached to the spring. The spring is compressed and the astronaut puts his body onto the platform and holds onto the handles, as shown.

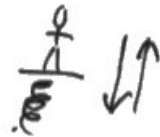


astronaut

platform

handles

spring inside cover



(Source: <https://www.nasa.gov/content/nasa-astronaut-rick-mastracchio-3>)

The spring is released and the astronaut and platform oscillate with simple harmonic motion.

An astronaut used the BMMD. The frequency of oscillation was 0.34 Hz.

- (a) Determine the mass of the astronaut.

spring constant =  $350 \text{ N m}^{-1}$   
mass of platform =  $5.7 \text{ kg}$

$$f = 0.34$$

$$F = k \Delta x$$

$$k = 350$$

(4)

$$T = \frac{1}{f} = 2.94 \text{ s}$$

$$\omega = 2\pi f = 2.14$$

$$T = 2\pi \sqrt{\frac{m}{k}} \quad \cancel{2\pi} (2\pi T)^2 = \frac{m - 5.7}{k}$$

$$\left(\frac{\cancel{2\pi} T}{2\pi}\right)^2 \times k + 5.7 = m = 82.33$$

$$2.94 = 2\pi \sqrt{\frac{m - 5.7}{350}}$$

Mass of astronaut =  $82.33 \text{ kg}$



MP1 and MP2 have been scored here. Correcting for the mass of the platform has been incorrectly applied, leading to an incorrect answer, and MP3 and 4 not being awarded.

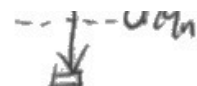
## Question 16 (b)(i)-(ii)

This question has proved to be one of the more challenging calculation questions. Whilst a significant number of candidates did score the full 6 marks, they were in the minority. Part (i) commonly scored MP2 and MP3 for calculating  $\omega$  and then determining a value for the acceleration. However MP1 was often not awarded as candidates did not realise the value for the distance travelled by the astronaut was equal to double the amplitude. This led to an incorrect value for the acceleration and hence MP4 could not be scored.

In part (ii) candidates were not penalised further for using the incorrect amplitude as an ecf was applied as long as they had used a dimensionally correct value of 0.29 m. A small number of candidates had used their value for the acceleration from the previous part as the value of A. In this case MP1 and 2 could not be awarded. MP2 was frequently not awarded when MP1 had been, due to not converting radians.

Some candidates had attempted to answer the question using kinematic equations of motion (suvat equations). As the acceleration is not constant, this method was not awarded any marks.

(b) The distance between the upper and lower points of the first oscillation is 0.29 m.



(i) Calculate the magnitude of the maximum acceleration of the astronaut.

(4)

$$d = 0.29 = 0.145 \quad A = 0.145$$

$$\omega = 2\pi f = 2\pi \times 0.34 = 2.1363$$

$$a = \omega^2 A = 2.1363^2 \times 0.145 = 0.662 \text{ m s}^{-2}$$

Magnitude of maximum acceleration =  $0.662 \text{ m s}^{-2}$

(ii) Calculate the speed of the astronaut 3.5 s after the start of the oscillations.

(2)

$$\begin{aligned} v &= \omega A \sin(\omega t) \quad t = 3.5 \\ &= 2.1363 \times 0.145 \times \sin(2.1363 \times 3.5) \\ &= 0.288 \text{ m s}^{-1} \end{aligned}$$

Speed =  $0.288 \text{ m s}^{-1}$



**ResultsPlus**  
Examiner Comments

This response scored full marks. It is likely the candidate had the calculator set to radians mode, leading to a correct answer in part (ii).

(b) The distance between the upper and lower points of the first oscillation is 0.29 m.

$\downarrow 0.29$   
3

(i) Calculate the magnitude of the maximum acceleration of the astronaut.

(4)

$$a_{\max} = -A \omega^2 = -A (2\pi f)^2$$



$$a_{\max} = -0.29 \times (2\pi \times 0.34)^2 = -1.32 \text{ m s}^{-2}$$

Magnitude of maximum acceleration =  $1.32 \text{ m s}^{-2}$

(ii) Calculate the speed of the astronaut 3.5 s after the start of the oscillations.

(2)

$$v = -A \omega \sin \omega t = -A (2\pi f) \sin((2\pi f) \times 3.5)$$

$$v = -0.29 \times (2\pi \times 0.34) \sin(2\pi \times 0.34 \times 3.5) = -0.081 \text{ m s}^{-1}$$

~~$= -0.81 \text{ m}$~~

Speed =  ~~$8.1 \times 10^{-2} \text{ m s}^{-1}$~~   
 $8.1 \times 10^{-2} \text{ m s}^{-1}$



Part (i) shows an example of a common error, where the candidate has used 0.29 m as the amplitude. This meant that MP1 and 4 could not be awarded. Therefore, this response scored 2 marks.

Part (ii) scores MP1 as an ecf, as they have already been penalised for using the incorrect amplitude in part (i). However, another common issue prevented this candidate from scoring MP2 as radians had not been converted.



When carrying out calculations which involve performing sine or cosine functions with quantities in radians, always make sure the calculator is in radians mode.

This response shows another good example which scores all 4 marks for part (i). In part (ii) the calculation is correct, but radians have not been converted, so scores MP1 only.

(b) The distance between the upper and lower points of the first oscillation is 0.29 m.

(i) Calculate the magnitude of the maximum acceleration of the astronaut.

(4)

$$a_{\max} = A\omega^2$$

$$\omega = 2\pi f$$

$$a_{\max} = \left(\frac{0.29}{2}\right) (2\pi \times 0.34)^2$$

$$a_{\max} = 0.66 \text{ m s}^{-2}$$

Magnitude of maximum acceleration = 0.66 m s<sup>-2</sup>

(ii) Calculate the speed of the astronaut 3.5 s after the start of the oscillations.

(2)

$$v = -A\omega \sin \omega t$$

$$v = -\left(\frac{0.29}{2}\right) (2\pi \times 0.34) \sin(2\pi \times 0.34 \times 3.5)$$

$$v = -0.040 \text{ m s}^{-1}$$

Speed = 0.040 m s<sup>-1</sup>



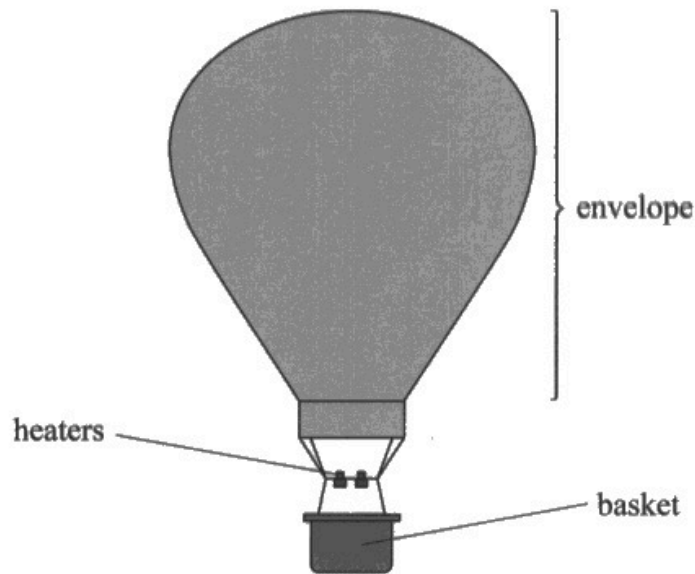
**ResultsPlus**  
Examiner Comments

In part (i) the candidate scores all four marks.

## Question 17 (a)

This question also proved to be fairly demanding. A significant number of candidates did score all 6 marks for a series of correct calculations and a valid conclusion, that upthrust was greater than the weight of the balloon so it can take off. These were in the minority, with the majority of candidates scoring 3 marks or less. In order to access MP1 and 2 candidates needed to realise the pressure would be the same and correctly use  $pV = NkT$ , with temperature in kelvin (K). Sometimes MP2 was awarded for a correct conversion to K in an incorrectly used formula. The most commonly awarded mark was MP5 for calculating any weight correctly. MP3 was also commonly scored, although sometimes with the volume of the air at 20 °C, which would not lead to the correct final answer.

17 (a) A hot air balloon consists of a fabric envelope, heaters and a basket, as shown.



When the balloon is set up, the envelope is partly filled with air at  $20^{\circ}\text{C}$ . The air is then heated to  $120^{\circ}\text{C}$  and expands to fill the envelope and becomes less dense.

The air pressure inside the envelope is always equal to the air pressure outside the envelope because the envelope is open at the bottom. ~~10000 Pa~~

The balloon takes off when the upthrust is more than the total weight of the balloon, the air in the envelope and the passengers.

Deduce whether the balloon can take off.

volume of air at  $120^{\circ}\text{C}$  in inflated envelope =  $2800\text{m}^3 = V$

density of air at  $20^{\circ}\text{C} = 1.2\text{kgm}^{-3}$

mass of balloon =  $380\text{kg}$

mass of passengers =  $340\text{kg}$

upthrust when the envelope is full =  $33000\text{N}$

$$P_{\text{inside}} = \frac{NkT_1}{V_1} \quad (6)$$

$$\frac{P_1(V_1)}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{2800}{273+20} = \frac{P(V_2)}{273+120}$$

$$P(V_2)$$

$$P_{\text{outside}} = \frac{NkT_0}{V_0}$$

$$? \quad \frac{T_1}{V_1} = \frac{T_2}{V_2}$$

$$W_{\text{parachutes}} = 340 \times 9.81 = 3335.4 \text{ N}$$

$$W_{\text{ballon}} = 380 \times 9.81 = 3727.8 \text{ N}$$

$$W_{\text{air}} = m_{\text{air}} \times g$$

$$pV = nRT \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{2800}{273+10} = \frac{V_2}{273+20} \quad V_2 = 2087.5 \text{ m}^3$$

$$m_{\text{air}} = 2087.5 \times 1.2 = 2505.04 \text{ kg}$$

$$3335.4 \text{ N} + 3335.4 + 3727.8 + (2505.04 \times 9.81)$$

$$= 31,637.6 \text{ N}$$

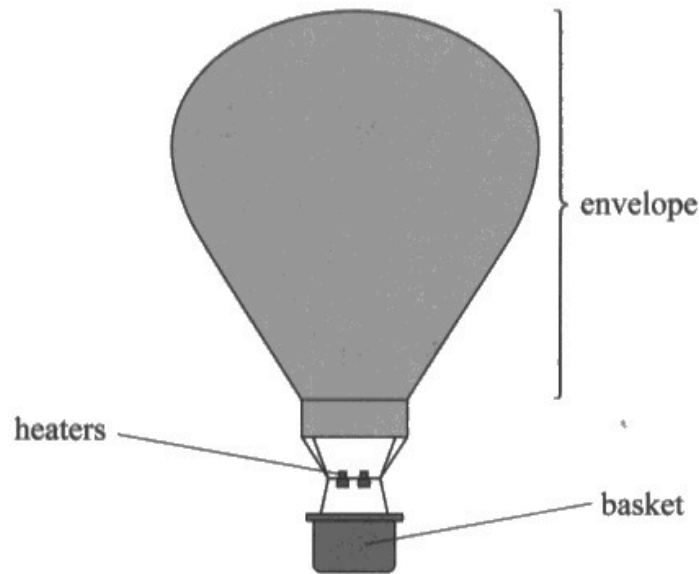
33000 N > 31,637 N so up thrust is greater than <sup>the total</sup> weight so balloons can take off.



**ResultsPlus**  
Examiner Comments

This response scored all 6 marks. Calculations have all been carried out correctly and the conclusion is valid.

17 (a) A hot air balloon consists of a fabric envelope, heaters and a basket, as shown.



When the balloon is set up, the envelope is partly filled with air at  $20^{\circ}\text{C}$ . The air is then heated to  $120^{\circ}\text{C}$  and expands to fill the envelope and becomes less dense.

The air pressure inside the envelope is always equal to the air pressure outside the envelope because the envelope is open at the bottom.

The balloon takes off when the upthrust is more than the total weight of the balloon, the air in the envelope and the passengers.

Deduce whether the balloon can take off.

$$a = 6.022 \times 10^{-22}$$

- volume of air at  $120^{\circ}\text{C}$  in inflated envelope =  $2800\text{ m}^3$
- density of air at  $20^{\circ}\text{C}$  =  $1.2\text{ kg m}^{-3}$
- mass of balloon =  $380\text{ kg}$
- mass of passengers =  $340\text{ kg}$
- upthrust when the envelope is full =  $33000\text{ N}$

Weight of balloon + passengers =  $7063\text{ N}$  (6)

At $20^{\circ}\text{C}$	At $120^{\circ}$
$p: 1.2$	$p =$
$m: 2504\text{ kg}$	$m =$
$v: 2087$	$v = 2800$

$$PV = NkT$$

$$33000 - 7063 = \frac{25937}{9.81} = 2644\text{ kg}$$

$$\text{Total weight of balloon} = (380 + 340) \times 9.81$$

$$+ \text{Passengers} = 7063 \text{ N} \quad \rho \frac{m}{V}$$

$$\rho_1 \frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \rho \frac{m}{V} \quad PV = nkT$$

$$T_1 = 20 + 273 = 293 \text{ K}$$

$$T_2 = 120 + 273 = 393 \text{ K}$$

$$\frac{V_1}{293} = \frac{2800}{393}$$

mass of air at  $20^\circ\text{C}$

$$V_1 = \frac{2800}{393} \times 293 = 2087 \text{ m}^3 \quad = 1.2 \times 2087 = 2504 \text{ kg}$$

$$\text{At } 120^\circ\text{C}: m = \quad V = 2800 \quad \rho =$$

$$\text{At } 20^\circ\text{C}: m = 2504 \quad V = 2087 \quad \rho = 1.2$$

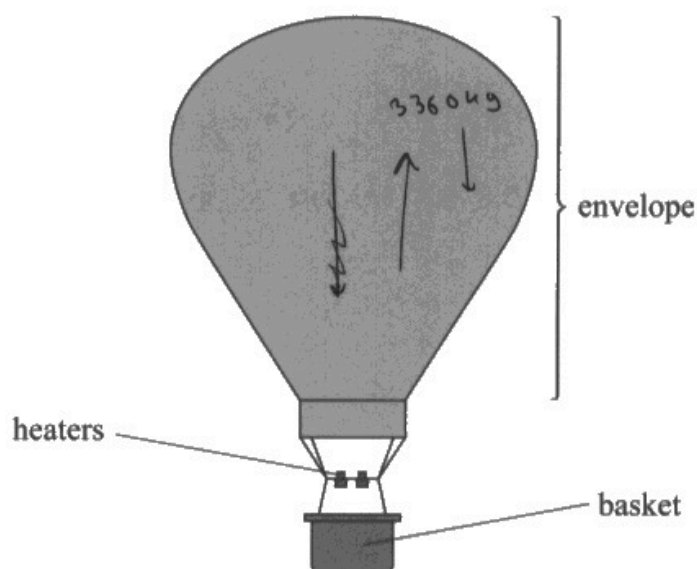
$$\Delta V = \frac{3300}{2800 + 9.81} = \Delta V = 2800 - 2087 = 713 \text{ m}^3$$



**ResultsPlus**  
Examiner Comments

Here we see that MP1 and 2 have been scored, as temperature has been converted to K and a correct volume of air at  $120^\circ\text{C}$  has been calculated. This has then been used in the equation for density to calculate the mass effectively, scoring MP3. The candidate has used  $W = mg$  to calculate weight, so scores MP4. However, the candidate has not added up the masses and has not provided a conclusion. Therefore MP4 and 6 have not been awarded.

17 (a) A hot air balloon consists of a fabric envelope, heaters and a basket, as shown.



When the balloon is set up, the envelope is partly filled with air at  $20^{\circ}\text{C}$ . The air is then heated to  $120^{\circ}\text{C}$  and expands to fill the envelope and becomes less dense.

The air pressure inside the envelope is always equal to the air pressure outside the envelope because the envelope is open at the bottom.

The balloon takes off when the upthrust is more than the total weight of the balloon, the air in the envelope and the passengers.

Deduce whether the balloon can take off.

volume of air at  $120^{\circ}\text{C}$  in inflated envelope =  $2800\text{ m}^3$

density of air at  $20^{\circ}\text{C}$  =  $1.2\text{ kg m}^{-3}$

mass of balloon =  $380\text{ kg}$

mass of passengers =  $340\text{ kg}$

upthrust when the envelope is full =  $33\,000\text{ N}$

(6)

$$\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$$

$$pV = \frac{1}{3} Nm \langle c^2 \rangle$$

$$pV = NkT$$

$$F = 6\pi \eta r v$$

$$\rho = \frac{m}{V}$$



$$7063.2N$$

+

$$1.2 = \frac{m}{2800}$$

$$\times 2800 \quad \times 2800$$

$$m = 3360 \text{ kg} = \text{mass of air}$$

$$3360 \times 9.81 = 32961.6 \text{ N}$$

$$\begin{aligned} \text{Force down} &= (380 + 340) \times 9.81 \\ &= 7063.2 \text{ N} \end{aligned}$$

density of air at 10:

$$32961.6 + 7063.2 = 40024.8 \text{ N}$$

$$40024.8 \text{ N} > 33000 \text{ N}$$

Therefore the balloon cannot take off yet

$$\Delta T = 100 \text{ K}$$



**ResultsPlus**  
Examiner Comments

This response scores MP3 for calculating the mass of air and MP5 for use of  $W = mg$ .

## Question 17 (b)(i)

This short 1 mark question was reasonably well answered by around half of all candidates. Frequently seen correct responses related to the random motion of particles or to the collisions being elastic. Incorrect responses often referred to the kinetic energy of all of the particles being the same.

This scored MP9, that particles move with random motion.

(b) (i) State one assumption of the kinetic theory of gases.

(1)

The <sup>particles</sup> particles move in random in all directions



See above.

(b) (i) State one assumption of the kinetic theory of gases.

(1)

All molecules travel at exactly the same ~~velocity~~ speed



This scored 0, as this is not one of the assumptions of an ideal gas and in reality there will be a range of speeds.

(b) (i) State one assumption of the kinetic theory of gases.

(1)

• The gas is ideal and thus all particles have same mass and move at the same speed



The gas being ideal was a fairly common incorrect response.

### Question 17 (b)(ii)

This question was generally well answered, with the vast majority of responses scoring at least 1 if not 2 marks. MP1 was most frequently not awarded due to not writing both formulae out in full and simply equating them directly. MP2 was very frequently awarded due to the use of suitable algebra to derive the necessary equation.

This response scored full marks. Both equations have been written out in full with correct use of brackets, which scored MP1. Going on to equate both equations and suitable use of algebra scored MP2.

(ii) Derive an equation to show that, for a gas at temperature  $T$ ,

the mean kinetic energy of the molecules =  $\frac{3}{2} kT$

$$PV = NkT$$

$$NkT = \frac{1}{3} Nm \langle c^2 \rangle$$

$$\frac{1}{2} m \langle c^2 \rangle = m \langle \text{KE} \rangle \quad (2)$$

$$PV = \frac{1}{3} Nm \langle c^2 \rangle$$

$$kT = \frac{1}{3} m \langle c^2 \rangle$$

$$3kT = m \langle c^2 \rangle$$

$$\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$$



**ResultsPlus**  
Examiner Comments

See above.

(ii) Derive an equation to show that, for a gas at temperature  $T$ ,

$$\text{the mean kinetic energy of the molecules} = \frac{3}{2} kT \quad (2)$$

$$NkT = \frac{1}{3} Nm \langle c^2 \rangle$$

$\frac{1}{2} m \langle c^2 \rangle = \text{mean kinetic energy}$

$$kT = \frac{1}{3} m \langle c^2 \rangle$$

$$\therefore \frac{3}{2} kT = \text{mean } E_k$$

$$3kT = m \langle c^2 \rangle$$

$$\frac{3}{2} kT = \frac{1}{2} m \langle c^2 \rangle$$



This response did not score MP1 as the candidate has directly equated both equations. However, there is correct use of algebra leading to the required expression, scoring MP2.

(ii) Derive an equation to show that, for a gas at temperature  $T$ ,

$$\text{the mean kinetic energy of the molecules} = \frac{3}{2} kT \quad (2)$$

$$\frac{1}{3} Nm \langle c^2 \rangle = NkT$$

$$\frac{1}{3} m \langle c^2 \rangle = kT$$

$$E_k = \frac{1}{2} mv^2 \quad \frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$$

( $\times 3$ ,  $\div 2$ )



This also scored 1 mark, for the same reasons stated above.

### Question 17 (b)(iii)

This question was very well answered with the majority of candidates scoring at least 2 out of the 3 available marks. MP1 was very commonly scored, with barely no instances of MP1 being lost for using the mass of a proton instead of the mass of 1u, which is given in the data booklet as  $1.66 \times 10^{-27}$  kg. MP2 was also awarded frequently as most candidates were aware of the need to convert T to K. MP3 was most frequently not awarded when candidates had not calculated the square root of the velocity.

(iii) Calculate the root-mean-square speed of nitrogen molecules at a temperature of  $120^\circ\text{C}$ .

mass of nitrogen molecule = 28 u

$$\frac{3}{2} kT = \frac{1}{2} m \langle c^2 \rangle \quad (3)$$

$$\langle c^2 \rangle = \frac{3kT}{m}$$

$$\langle c \rangle = \sqrt{\frac{3kT}{m}}$$

$$\langle c \rangle = \sqrt{\frac{3 \times (120 + 273) \times 1.38 \times 10^{-23}}{28 \times 1.66 \times 10^{-27}}}$$

$$\langle c \rangle = 591.6 \text{ ms}^{-1}$$

Root-mean-square speed =  $592 \text{ ms}^{-1}$  (3sf)



**ResultsPlus**  
Examiner Comments

This response scored all 3 marks. The mass was correctly calculated using the correct value for u and T has been converted to K.

- (iii) Calculate the root-mean-square speed of nitrogen molecules at a temperature of 120°C.

mass of nitrogen molecule = 28 u

$$\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} k T \quad \rightarrow \text{kelvin.} \quad (3)$$

120 + 273 = 393 K

$$\sqrt{\frac{1}{2} \langle c^2 \rangle} = \sqrt{\frac{\frac{3}{2} k T}{\frac{1}{2} m}} = \sqrt{\frac{3 (1.38 \times 10^{-23}) (393)}{28 \times 1.66 \times 10^{-27}}}$$

$$= 602.6392844 \text{ m s}^{-1}$$

Root-mean-square speed = 602.639 m s<sup>-1</sup>



**ResultsPlus**  
Examiner Comments

Here MP1 and MP2 have been scored, as the correct values have been effectively substituted into the correct equation, with temperature in K. However, due to a calculator error, the final answer is incorrect and therefore MP3 was not awarded.

- (iii) Calculate the root-mean-square speed of nitrogen molecules at a temperature of 120°C.

mass of nitrogen molecule = 28 u

(3)

$$\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} k T \quad \frac{3 k T}{m} = \langle c^2 \rangle$$

$$\frac{3(1.38 \times 10^{-23})(120)}{28(1.66 \times 10^{-27})} = 106884.68$$

Root-mean-square speed = ~~4060~~ 107000



**ResultsPlus**  
Examiner Comments

MP1 for correct calculation of the mass was awarded. MP2 and 3 were not awarded as temperature was not in K.

## Question 18 (a)

This was the linkage question. A wide spread of marks was awarded to candidates' responses. A significant number of responses scored all 6 marks, showing that all of the indicative content (IC) marks were accessible. The majority of responses scored at least 3 marks. The most commonly scored mark was IC1, which was for using the term energy levels in relation to electrons or atoms. IC2 was generally also well scored and where it wasn't credited, it was because candidates had not expressed that the photon is absorbed by the electron.

IC3 was generally well scored, for stating that photon energy =  $hf$ . A fairly common reason for IC5 and 6 not to be scored was when candidates said that electrons de-excite and emit a photon. In this case candidates were talking about emission spectrum, which was not what was required by the question. They needed to talk about the corresponding wavelength/frequency of the absorbed photon to be able to access MP5 and 6.

18 In 1864, William Huggins and William Miller used dark lines in the spectrum of the Sun to identify elements in the Sun's atmosphere. absorption spectrum

\*(a) Explain how gases in the Sun's atmosphere cause dark lines in the spectrum corresponding to different elements.

(6)

• atoms exist in discrete energy levels.

There are many different elements in the Sun's atmosphere, all possessing different discrete energy levels. When the electrons in these atoms absorb a specific photon, with energy equal to the difference in energy levels, the electron is excited to a higher energy level. It then de-excites emitting a photon with wavelength energy equal to the difference in energy levels ( $hf = E_2 - E_1$ ).

• due to  $E = hf = \frac{hc}{\lambda}$ , if these elements can only absorb specific energies of photon, then they can only absorb specific wavelengths of light (photons).

• the wavelengths of light absorbed are represented by the dark lines in the emission spectrum.

• the different elements in the Sun's atmosphere (such as hydrogen and helium created through fusion) ~~are~~ have different discrete energy levels and therefore will absorb specific wavelengths of light that will be different, causing lots of dark lines in the spectrum.



This scored 6 marks. IC1 was scored in line 1. IC5 is scored in lines 2 and 3. Lines 4 to 7 score IC2 and IC4. IC3 is scored on the last printed line and the candidate then goes on to score IC6 in the section written below.

**18** In 1864, William Huggins and William Miller used dark lines in the spectrum of the Sun to identify elements in the Sun's atmosphere.

**\*(a)** Explain how gases in the Sun's atmosphere cause dark lines in the spectrum corresponding to different elements.

(6)

Electrons have certain energy level for ~~spec~~ that specific elements.

At sun's atmosphere, electrons in atom get excited to higher energy level absorbing photon.

Energy of absorbing photon is the difference between the ~~two~~ energy level which differ in different elements.

This ~~course~~ absorption of energy cause dark line in the spectrum corresponding to different element.



IC1 and just enough for IC5 is scored in the first line. IC2 is awarded in lines 3 to 5. IC4 is scored in lines 6 and 7.

18 In 1864, William Huggins and William Miller used dark lines in the spectrum of the Sun to identify elements in the Sun's atmosphere.

\* (a) Explain how gases in the Sun's atmosphere cause dark lines in the spectrum corresponding to different elements.

$e^-$  excitation after absorbing the photon.

exists in a way to replace  $e^-$  except its original  $e^-$ .

The gases in the Sun's atmosphere have electrons. These electrons can absorb the energy of photons promoting the  $e^-$  to higher energy levels. This is called excitation of  $e^-$ . When the  $e^-$  'relaxes' it de-excites, releasing the absorbed energy in different amounts and in all forms of wavelengths except its original wavelength causing the dark lines in the emission spectrum.

Different elements have different amounts of electrons. This means different amounts of dark lines in the spectrum. Judging the number of dark lines can help scientists judge the different elements in the Sun's atmosphere.



This response scored IC1 and IC2 in lines 2 and 3. The candidate then went on to talk about emission and scored no further marks.

## Question 18 (b)

This was one of the more challenging calculation questions on the paper. However, it was generally well answered, with the majority of candidates scoring 3 or 4 marks. A very common reason to not score MP4 after having successfully scored MP1, 2 and 3 was to state the transition is from  $n = 3$  to  $n = 2$ . This could have followed on from candidates referring to an emission spectrum in the previous question.

(b) The diagram shows some energy levels of a hydrogen atom.

$$n = 5 \quad \text{_____} \quad -0.54 \text{ eV}$$

$$n = 4 \quad \text{_____} \quad -0.85 \text{ eV}$$

$$n = 3 \quad \text{_____} \quad -1.51 \text{ eV}$$

Not to scale

$$n = 2 \quad \text{_____} \quad -3.40 \text{ eV}$$

$$n = 1 \quad \text{_____} \quad -13.6 \text{ eV}$$

The absorption spectrum for hydrogen includes a set of lines that all derive from transitions involving the  $n = 2$  energy level. One of these lines is known as the hydrogen-alpha line.

Deduce the transition involved in the formation of the hydrogen-alpha line.

wavelength of hydrogen-alpha line = 656.46 nm

(4)

$$3 \times 10^8 = f \times 656.46 \times 10^{-9}$$

$$\therefore f = 4.6 \times 10^{14}$$

$$E = hf$$

$$= 6.63 \times 10^{-34} \times 4.6 \times 10^{14}$$

$$= 3.029 \times 10^{-19} \text{ J}$$

$$E \text{ in eV} = \frac{3.029 \times 10^{-19}}{1.6 \times 10^{-19}} = 1.89 \text{ eV}$$

From  $n = 2$  to

$n = 3$

-3.40 to -1.51

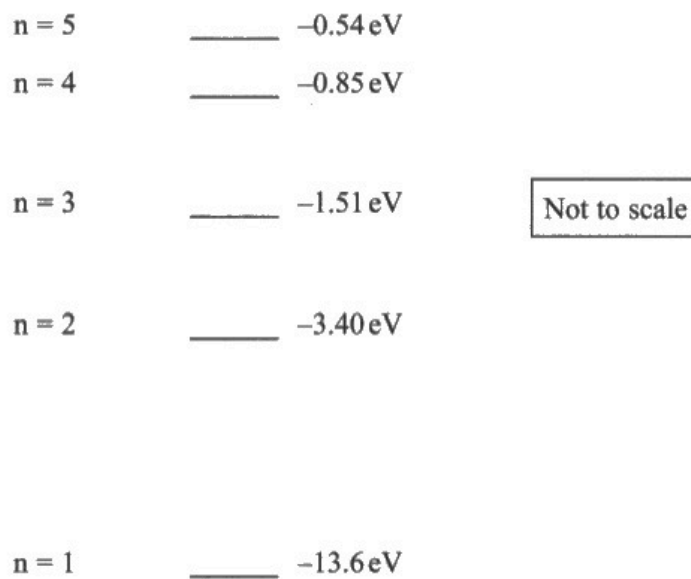
1.89 eV



**ResultsPlus**  
Examiner Comments

This response scores full marks. MP1, 2 and 3 for the calculations and MP4 for the valid conclusion from  $n = 2$  to  $n = 3$ .

(b) The diagram shows some energy levels of a hydrogen atom.



The absorption spectrum for hydrogen includes a set of lines that all derive from transitions involving the  $n = 2$  energy level. One of these lines is known as the hydrogen-alpha line.

Deduce the transition involved in the formation of the hydrogen-alpha line.

wavelength of hydrogen-alpha line = 656.46 nm

(4)

$$1H \rightarrow 4\alpha \quad E = hf$$

$$6.63 \times 10^{-34} \times 4.56 \times 10^{14} = \frac{3.029 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$= 1.89 \text{ eV}$$

$$E = mc^2$$

$$\frac{c}{\lambda} = f \quad \frac{3 \times 10^8}{656.46 \times 10^{-9}} = 4.5699 \times 10^{14}$$

from  $n = 3$  to  $n = 2$

$$\cancel{-3} \rightarrow \cancel{4} \rightarrow 1S \rightarrow 2S \quad -1.51 - -3.4 = +1.89 \text{ eV}$$



This scores MP1, 2 and 3 for the calculations. MP4 is not awarded as the conclusion states from  $n = 3$  to  $n = 2$ .

## Question 18 (c)(i)

This was one of the more challenging questions and the majority of candidates scored either 0 or 1 mark. However, a significant number of candidates were able to score all 3 marks for a valid conclusion which explained how change in wavelength can be used to find the speed and direction. MP1 was commonly scored for recognising that wavelength will increase if an object is moving away from Earth, or the converse that it will decrease if the object is moving towards Earth. Where MP1 was not awarded it was because candidates talked about red/blueshift rather than increase/ decrease in wavelength. MP2 was quite frequently scored for correctly rearranging the redshift of electromagnetic radiation equation.

- (c) In 1868, William Huggins analysed light from the star Sirius A. The wavelength of the hydrogen-alpha line for light from Sirius A was slightly different from the hydrogen-alpha line observed from a source in a laboratory.

Huggins suggested that this difference could be explained using the Doppler effect and could be used to determine the speed and direction of the star's motion relative to the Earth.

- (i) Assess Huggins's suggestion.

(3)

His suggestion is true because as an object moves closer to earth wavelength decreases and as it moves away it increases. ~~The~~ As  $\frac{v}{c} = \frac{\Delta\lambda}{\lambda}$  the velocity is proportional to the change in wavelength so so both direction and speed could be determined.



All 3 marks have been awarded to this response. MP1 for the decrease in wavelength if an object is moving towards Earth. MP2 was awarded for stating the velocity is proportional to the change in wavelength. MP3 was awarded for 'his suggestion is true', which is a valid conclusion.



When being asked to assess a suggestion you must always give a valid conclusion.

- (c) In 1868, William Huggins analysed light from the star Sirius A. The wavelength of the hydrogen-alpha line for light from Sirius A was slightly different from the hydrogen-alpha line observed from a source in a laboratory.

Huggins suggested that this difference could be explained using the Doppler effect and could be used to determine the speed and direction of the star's motion relative to the Earth.

- (i) Assess Huggins's suggestion.

(3)

The Doppler effect shows how celestial bodies can be red-shifted as they are moving away from us so their wavelength increases.



**ResultsPlus**  
Examiner Comments

This response scores MP1 only, for the idea that wavelength increases when an object is moving away from Earth.

- (c) In 1868, William Huggins analysed light from the star Sirius A. The wavelength of the hydrogen-alpha line for light from Sirius A was slightly different from the hydrogen-alpha line observed from a source in a laboratory.

Huggins suggested that this difference could be explained using the Doppler effect and could be used to determine the speed and direction of the star's motion relative to the Earth.

- (i) Assess Huggins's suggestion.

(3)

the direction of motion can be worked out ~~by~~ if the wavelength has been stretched or compressed ~~to~~ due to red/blue shift. The speed can be worked out by how much ~~the~~ the wavelength has been altered.



See below.



This response scored 0 marks. The candidate has the idea that there is a change in wavelength caused by the relative motion of the star; however they have not provided enough information to score MP1. 'Stretched' or 'compressed' is not sufficient for increased/decreased wavelength and red/blueshift would have needed this information for further clarification to score MP1.

### Question 18 (c)(ii)

A generally well answered question, the vast majority of candidates being able to score MP1 for correct use of the redshift of electromagnetic radiation equation. A significant proportion of candidates then went on to add the change in wavelength to the laboratory value, scoring MP2. Where MP2 was not awarded, it was generally because the change in wavelength was subtracted from the laboratory value, or no further calculations were done.

(ii) Sirius A has a component of velocity away from the Earth of  $5.5 \text{ km s}^{-1}$ .

The wavelength of the hydrogen-alpha line observed from a source in the laboratory is  $656.46 \text{ nm}$ .

Calculate the wavelength of the hydrogen-alpha line as seen in the spectrum of Sirius A.

(2)

$$\lambda = 656.46 \times 10^{-9} \text{ m}$$

$$v = 5.5 \times 10^3 \text{ m s}^{-1}$$

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$

$$\Delta\lambda = \frac{v}{c} \times \lambda$$

$$= 1.20351 \times 10^{-11} \text{ m}$$

$$656.46 \times 10^{-9} + 1.2 \times 10^{-11} = 6.56 \times 10^{-7} \text{ m}$$

$$\text{Wavelength} = 6.56 \times 10^{-7} \text{ m}$$



**ResultsPlus**  
Examiner Comments

MP1 has been awarded for correct calculation of  $\Delta\lambda$  and MP2 has been scored for adding this to  $\lambda$  as measured in the laboratory.

- (ii) Sirius A has a component of velocity away from the Earth of  $5.5 \text{ km s}^{-1}$ .

The wavelength of the hydrogen-alpha line observed from a source in the laboratory is  $656.46 \text{ nm}$ .

Calculate the wavelength of the hydrogen-alpha line as seen in the spectrum of Sirius A.

(2)

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$$
$$\Delta\lambda = \frac{v\lambda}{c}$$
$$= \frac{(5.5 \times 10^3)(656.46 \times 10^{-9})}{(3 \times 10^8)}$$
$$= 1.2 \times 10^{-9} \text{ m}$$

Wavelength =  $1.2 \times 10^{-9} \text{ m}$



**ResultsPlus**  
Examiner Comments

MP1 has been scored here for correct use of the redshift of electromagnetic radiation equation. This value needed to be added onto the wavelength of the line in the laboratory to score MP2. So this response scores 1 mark.

(ii) Sirius A has a component of velocity away from the Earth of  $5.5 \text{ km s}^{-1}$ . *help with doppler eqn*

The wavelength of the hydrogen-alpha line observed from a source in the laboratory is  $656.46 \text{ nm}$ .

Calculate the wavelength of the hydrogen-alpha line as seen in the spectrum of Sirius A.

$5.5 \times 1000000 = 5500000$  *= 1000*  
 $5.5 \times 656460000 = 3610200000$  *= 1000* (2)

$5.5 \times 10 \times 6.564 \times 10^4 = 361020$

Wavelength =  $361020$



This response scored 0 marks. The full version of the redshift formula has not been used.

## Question 19 (a)(i)

This question required recall of the definitions of 'random' and 'spontaneous'. However, the majority of responses scored 0 or 1 mark only. MP1 was often awarded for saying it is not affected by external conditions. MP2 was also awarded in many cases. However, there were several responses which were approaching being creditworthy but did not score MP2. This was usually by saying "it" cannot be predicted, but not clarifying what "it" was, eg when the next nuclei will decay.

**19** Nuclear decay is described as being spontaneous and random.

(a) (i) State what is meant by spontaneous and random in this context.

(2)

Spontaneous means that it occurs with no external stimulus / no external forces. Random means that we cannot predict which nucleus will decay and when.



This response scores MP1 for saying that spontaneous occurs with external stimuli and MP2 for saying which nucleus will decay and when.

**19** Nuclear decay is described as being spontaneous and random.

(a) (i) State what is meant by spontaneous and random in this context.

(2)

Spontaneous → ~~is~~ decays without external stimuli.  
Random → No pattern to decay of isotope.



MP1 was scored for decays without external stimuli. MP2 was not awarded as 'no pattern' is too vague.

19 Nuclear decay is described as being spontaneous and random.

(a) (i) State what is meant by spontaneous and random in this context.

(2)

Spontaneous and random means it can't be controlled and it can happen at anytime. ~~Nuclear decay can't be~~ <sup>Only the half-life can</sup> be measured from this.



'Can't be controlled' is too vague to award MP1. 'It can happen at anytime' is not specific enough to which nuclei decays and why it cannot be predicted; therefore MP2 was not awarded.

## Question 19 (a)(ii)

This was a demanding question, which in general was not answered well. The majority of candidates did not score any marks. However, there were a significant number of responses which scored full marks. This showed that the mark scheme was accessible. MP2 was the most commonly scored mark for the idea that a large number of nuclei are involved.

(ii) Explain why the decay constant of an isotope can be determined even though nuclear decay is random.

(2)

The probability of each nucleus decaying per unit time, and can be calculated  $\rightarrow$  if the number of nuclei decaying is large so we can look at the average time for nuclei to decay.



This scored both MP1 and MP2 – – the idea that the probability can be determined and that a large number of nuclei are involved scores both marks.

- (ii) Explain why the decay constant of an isotope can be determined even though nuclear decay is random.

(2)

~~Large Activity~~ Half life observed for a large number of nuclei. Decay pattern is predictable for a large number of nuclei

$$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$$



**ResultsPlus**  
Examiners Comments

This response scored MP2, for the idea of a large number of nuclei.

(ii) Explain why the decay constant of an isotope can be determined even though nuclear decay is random.

(2)

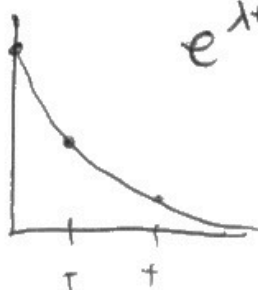
$$\lambda = \frac{\ln(2)}{t_{1/2}}$$

As the number of isotopes always

~~have~~ half at set times, it creates an exponential relationship.  $e^{\lambda t_{1/2}} = 2$

$$\lambda t_{1/2} = \ln 2$$

$$e^{\lambda t_{1/2}} = 2$$



~~$t_{1/2} = \frac{\ln 2}{\lambda}$~~   
 ~~$t_{1/2} = \frac{\ln 2}{\lambda}$~~



**ResultsPlus**  
Examiner Comments

This candidate has demonstrated an understanding of exponential decay, but has not explained how the probability can be determined, or that a large number of nuclei are involved.

## Question 19 (b)

This question proved to be particularly challenging to most candidates. Many responses required the use of additional paper and it should be noted that in this case, it is important that the candidate indicates the location of any additional information. MP1 was commonly not scored due to omission of the words 'measure' and/or 'count'. Phrases such as "the student should measure the background radiation" were insufficient as there was no mention of count rate. As this error was only penalised once, most students were able to be awarded MP2 for measuring the count rate from the source. MP3 was frequently scored for using paper to absorb alpha. Many responses suggested moving the source further away from the GM tube, so alpha would not be detected. This was not creditworthy as it would also give an incorrect beta reading. MP4 was the least frequently awarded marking point, as it required count rate of beta/ total count rate x 100 to give the % of beta radiation. Incorrect methods to obtain the beta count and omission of x 100 to give % were common reasons for not awarding MP4.

(b) A radioactive source used in a school laboratory emits alpha and beta radiation.

Describe how the percentage of the activity due to beta radiation may be determined using a Geiger-Müller tube and ratemeter.

(4)

Record the background radiation count various times to get a mean.  
Record count rate with ~~nothing~~ nothing blocking the ~~10~~ source from the counter, count rate for both types of radiation  
Record count rate with a piece of paper blocking the ~~10~~ source from the GM tube and ratemeter, count rate for beta radiation  
Subtract the background count from the two count rates measured  
$$\% \text{ activity of beta} = \frac{\text{count rate of beta radiation}}{\text{count rate of both types radiation}} \times 100$$



This response scored all 4 marks. Record the background count was sufficient for MP1. MP2 is scored in lines 2 and 3. MP3 was awarded for the use of paper and MP4 was awarded for a correct method to determine the % of beta emitted.

(b) A radioactive source used in a school laboratory emits alpha and beta radiation.

Describe how the percentage of the activity due to beta radiation may be determined using a Geiger-Müller tube and ratemeter.

(4)

By using the Geiger-Müller tube, the total count of the source can be measured. Background counts should also be measured and subtracted.

Because of the low penetrating ability of ~~the~~ alpha particles, by putting a <sup>piece of</sup> paper in front of the ratemeter, the beta radiation count/activity can also be measured.

By dividing the beta radiation count over the total count, the percentage of the activity can be determined.



**ResultsPlus**  
Examiner Comments

MP1, 2 and 3 have been awarded to this response. MP4 was not awarded as the candidate did not state to multiply by 100 to calculate the percentage.



**ResultsPlus**  
Examiner Tip

If you have been asked to determine a percentage, make sure to say how you will perform the percentage calculation.

(b) A radioactive source used in a school laboratory emits alpha and beta radiation.

Describe how the percentage of the activity due to beta radiation may be determined using a Geiger-Müller tube and ratemeter.

(4)

Alpha radiation only travels a short distance in air compared to beta radiation. Connect two Geiger-Müller tubes (GM tube) and ratemeter. Place the GM tube against the source and ~~measure~~<sup>record</sup> the average counts over an appropriate time for that source. Move the GM tube <sup>15 cm</sup> ~~10 cm~~ from the source and record the average count over the same period of time. Divide the second attained value by the first and multiply by the first to get the percentage activity due to beta radiation  $\frac{\text{counts}}{\text{counts}} \times 100 = \% \text{ beta activity}$ .



**ResultsPlus**  
Examiner Comments

This scored MP2 only for recording the counts from the source. The candidate then went on to talk about moving the source further away, which would give an incorrect beta count, and so MP3 and 4 could not be awarded. There is no mention of measuring background count, so MP1 was not awarded.

### Question 19 (c)(i)-(ii)

Part (i) was well answered with the majority of candidates scoring all 3 marks.

Part (ii) was more demanding and the majority of candidates scored 0 or 1 mark only. MP1 was not commonly scored as candidates needed to state which decay chains would emit beta, or those that would only emit alpha. MP2 was the most commonly scoring marking point for the idea that Neptunium has a very long half-life. Where candidates quoted the numerical value of this, MP2 could not be scored, as this information had been provided in the table. MP3 could only be awarded if the candidate had referred to only a small proportion/amount of proactinium being present and a valid conclusion.

- (c) Americium-241 is used in schools as a source of alpha radiation.  
A pure americium-241 source was bought 34 years ago by a school.

*atypical. U  
Do it for some time*

- (i) Determine the percentage of the initial activity that would be expected today for the americium-241 source.

half-life of americium-241 = 432 years

(3)

$$\lambda = \frac{\ln(2)}{432} = 1.6 \times 10^{-3} \text{ y}^{-1}$$

$$A = A_0 e^{-\lambda t} = A_0 e^{-1.6 \times 10^{-3} \times 34} = 0.947$$

~~(A/P)~~

$$\therefore A = 0.947 A_0 \therefore 95\%$$

Expected percentage of initial activity = 95%

- (ii) The decay products of americium are unstable and undergo a series of further decays.

The table shows the first three decays in this sequence.

Isotope	Decay product	Emission	Half-life
americium-241	neptunium-237	alpha	432 years
neptunium-237	protactinium-233	alpha	2 100 000 years
protactinium-233	uranium-233	beta	27 days

A student states, "Protactinium-233 emits beta particles when it decays, so by now the americium-241 source bought 34 years ago will be emitting a significant amount of beta radiation."

Discuss the student's statement.

(3)  
Americium decays into neptunium. Americium has quite a long half-life, so not a lot of the radioactive Americium atoms would have decayed by 34 years. Neptunium would need to decay into protactinium. However, neptunium has a very large half-life, many in 34 years, so close to none of the neptunium would have decayed in only 34 years. Therefore, as both

(Total for Question 19 = 14 marks)

Americium and neptunium only provide alpha decay, basically none of the decay measured will be beta. However, protactinium does have short half life, so any neptunium decaying into protactinium would have high chance of decaying to provide a beta decay. But barely any protactinium decaying, so significant amount is alpha, so student is wrong.

TOTAL FOR PAPER = 90 MARKS

Part (i) scored all 3 marks for correct calculations, leading to a correct percentage.

Part (ii) also scored all 3 marks.

Scores MP2 in line 4. MP1 is scored just below the printed line. Barely any proactinium and student is wrong scores MP3.

(c) Americium-241 is used in schools as a source of alpha radiation.

A pure americium-241 source was bought 34 years ago by a school.

(i) Determine the percentage of the initial activity that would be expected today for the americium-241 source.

half-life of americium-241 = 432 years

$$\frac{A}{A_0} = e^{-\lambda t} \quad t = 34 \text{ yrs} = 1.072 \times 10^9 \text{ secs} \quad (3)$$

$$\lambda = \frac{\ln 2}{1.362 \times 10^{10}} = 5.088 \times 10^{-11}$$

$$\therefore \frac{A}{A_0} = e^{-5.088 \times 10^{-11} \times 1.072 \times 10^9}$$

$$= e^{-0.0545}$$

$$\frac{A}{A_0} = \underline{0.947} = \underline{94.7\%} \text{ left}$$

Expected percentage of initial activity = 94.7%

- (ii) The decay products of americium are unstable and undergo a series of further decays.

The table shows the first three decays in this sequence.

Isotope	Decay product	Emission	Half-life
americium-241	neptunium-237	alpha	432 years
neptunium-237	protactinium-233	alpha	2 100 000 years
protactinium-233	uranium-233	beta	27 days

A student states, "Protactinium-233 emits beta particles when it decays, so by now the americium-241 source bought 34 years ago will be emitting a significant amount of beta radiation."

Discuss the student's statement.

(3)

The statement is incorrect because the student has forgotten that americium-241 must decay into neptunium-237 before it can then decay into protactinium-233. Since neptunium-237 has a half life of 2.1 million years, it's very unlikely that there will be significant beta radiation after only 34 years.



Part (i) scores all 3 marks.

Part (ii) scores 0 marks. There is no mention of which decay produces alpha or beta for MP1 and the half life of Neptunium has not been identified as very long for MP2.

(c) Americium-241 is used in schools as a source of alpha radiation. discuss due to  $\beta$ .  
 A pure americium-241 source was bought 34 years ago by a school.

- (i) Determine the percentage of the initial activity that would be expected today for the americium-241 source.

half-life of americium-241 = 432 years

(3)

$$\lambda = \frac{\ln 2}{432 \times 365 \times 24 \times 3600} = 5.08765 \times 10^{-11} \text{ s}^{-1}$$

$$A = A_0 e^{-\lambda t} \quad \frac{A}{A_0} = e^{-\lambda t} = e^{-5.08765 \times 10^{-11} \times 432 \times 365 \times 24 \times 3600}$$

$$\frac{A}{A_0} = 0.94 = 94.6\%$$

Expected percentage of initial activity = 95%

- (ii) The decay products of americium are unstable and undergo a series of further decays.

The table shows the first three decays in this sequence.

Isotope	Decay product	Emission	Half-life
americium-241	neptunium-237	alpha	432 years
neptunium-237	protactinium-233	alpha	2 100 000 years
protactinium-233	uranium-233	beta	27 days

A student states, "Protactinium-233 emits beta particles when it decays, so by now the americium-241 source bought 34 years ago will be emitting a significant amount of beta radiation."

Discuss the student's statement.

(3)

- The student is wrong, this is because the half life of Americium is 432 years, so it has a very small decay constant, and is not very active. So only 5% of the source has decayed. Now that 5% ~~of neptunium~~ of neptunium has a half life of 2,100,000 years, which has a very small activity. ∴ for the student

(Total for Question 19 = 14 marks)

to say now will be a significant amount of beta radiation would be incorrect. As this is extremely unlikely and not possible.

TOTAL FOR PAPER = 90 MARKS



The candidate had converted the half lives to seconds, which was unnecessary; this response still scores 3 marks as this is a valid method.

Part (ii) scores 0. MP1 was not awarded as there is no mention of which decays will lead to beta being emitted. MP2 was not awarded as the candidate has not identified the half-life of Neptunium as being very long. MP3 was not awarded although there was some potentially creditworthy information, in that only 5% would have decayed and the student is wrong. However, this required clarification that only 5% of Americium had decayed, so the proportion of proactinium would be small.

## Paper Summary

Based on their performance in this paper, candidates should:

- Check which mode their calculator should be in, depending on if they are dealing with degrees or radians.
- Check that numerical answers to calculations represent sensible values and go back and check the calculation when they do not.
- Remember that physical quantities have a magnitude and a unit and both must be given in answers to numerical questions.
- Note that if you are given a value of the radius, then doubling it will lead to an invalid area calculation; the diameter needs to be halved in an area calculation.
- Be sure to convert all values to the same SI units in questions with mixed quantities. For example use m instead of cm in the lens formula.
- Learn standard descriptions such as threshold frequency and the definition of a photon.
- Know that in calculations which involve ideal gases, temperature must be converted to K.
- Remember when calculating a value to the power of  $x$ , not to miss off the power.
- When the question is an assess or discuss question, remember to provide a valid conclusion.

## **Grade boundaries**

Grade boundaries for this, and all other papers, can be found on the website on this link:

<https://qualifications.pearson.com/en/support/support-topics/results-certification/grade-boundaries.html>

