Example Candidate Responses

Cambridge International Level 3
Pre-U Certificate in
PHYSICS (9792)

UNIVERSITY of CAMBRIDGE
International Examinations

Example Candidate Responses

Physics (9792)

Cambridge International Level 3
Pre-U Certificate in Physics (Principal)

Cambridge International Level 3 Pre-U Certificate

Physics

9792

Contents

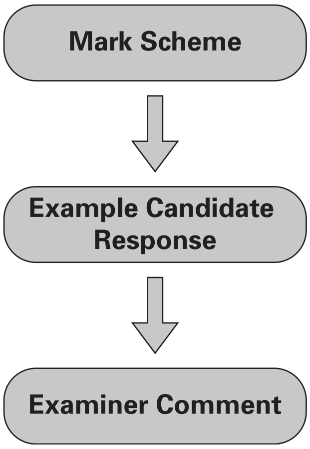
Introduction

The main aim of this booklet is to exemplify standards for those teaching Cambridge Pre-U, and to show how different levels of candidates' performance relate to the subject's curriculum and assessment objectives.

Cambridge Pre-U is reported in three bands (Distinction, Merit and Pass) each divided into three grades (D1, D2, D3; M1, M2, M3; P1, P2, P3).

In this booklet a selection of candidate responses has been chosen to illustrate as far as possible each band (Distinction, Merit and Pass).

For ease of reference the following format for Papers 2 and 3 has been adopted:



The mark scheme used by Examiners is followed by examples of marked candidate responses, each with an examiner comment on performance. Comments are given to indicate where and why marks were awarded, and how additional marks could have been obtained. In this way, it is possible to understand what candidates have done to gain their marks and what they still have to do to improve their grades.

Please note that all of the comments on the extracts and the complete Personal Investigation in Paper 4 are the annotations of the teachers who marked them in their school. The typed comments are those of the moderator.

Teachers are reminded that a full syllabus and other teacher support materials are available on www.cie.org.uk. For past papers and Examiner Reports please contact University of Cambridge International Examinations on international@cie.org.uk.

Components at a Glance

Component	Component Name	Duration	Weighting (%)	Type of Assessment
1	Part A Multiple Choice	1 hour 15 minutes	20	Multiple choice paper, externally set and marked
2	Part A Written Paper	2 hours	30	Written paper, externally set and marked
3	Part B Written Paper	3 hours	35	Written paper, externally set and marked
4	Personal Investigation	(20 hours)	15	Project report, internally marked and externally moderated

This booklet contains a selection of example candidate responses and Examiner comments for Part A Written Paper, Part B Written Paper and Personal Investigation.

Paper 2 Part A Written Paper

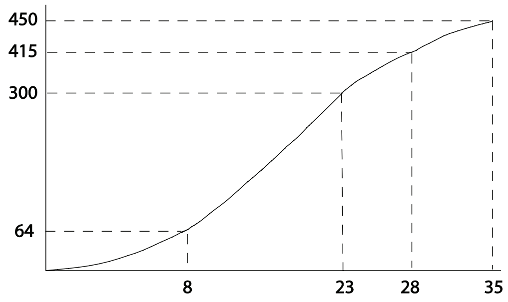
Question 1 Mark Scheme

(a) **(i)** area under graph (award in either **(i)** or **(ii)**) (1)
½ × 8 × 16 = 64 (m) (1) [2]

(ii) ½ × 7 × 10 = 35 (m) [1]

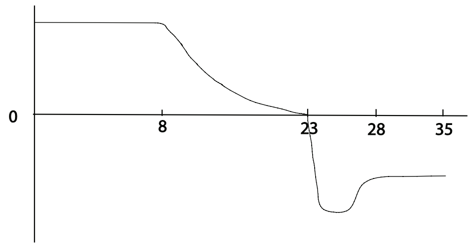
(b) estimates area of central section (1)
e.g. 700 ± 20 small squares **or** 15 × ~18.5 **and** 5 × ~15 (1)
equivalent to 350 m + 99 m = 450 ± 10 (m) (1) [3]

(c) **(i)**



curve with gradient increasing to 23 s (1)
distance increasing to 35 s and **candidate's** 450 m (1)
with gradient decreasing (1) [3]
Penalise: sudden change of gradient / more than one line

(ii)



horizontal to 8 s (1)
falling to zero at 23 s (1)
negative then rises to negative horizontal to 35 s (1) [3]

(d) at equal intervals along route (1)
position (student) with a stopwatch (at each point) (1)
some mechanism for starting together (1) max 3
record time as bus passes (1)

same point on bus (used for measurements) (1) [4]

[Total: 16]

Example Candidate Response – Distinction

1 Fig. 1.1 shows a velocity-time graph for a bus travelling along a straight road between two bus stops. It is divided into four parts.

a constant acceleration
a further increase in velocity to 20 m s^{-1}
a decrease in velocity to 10 m s^{-1}
a constant deceleration to rest

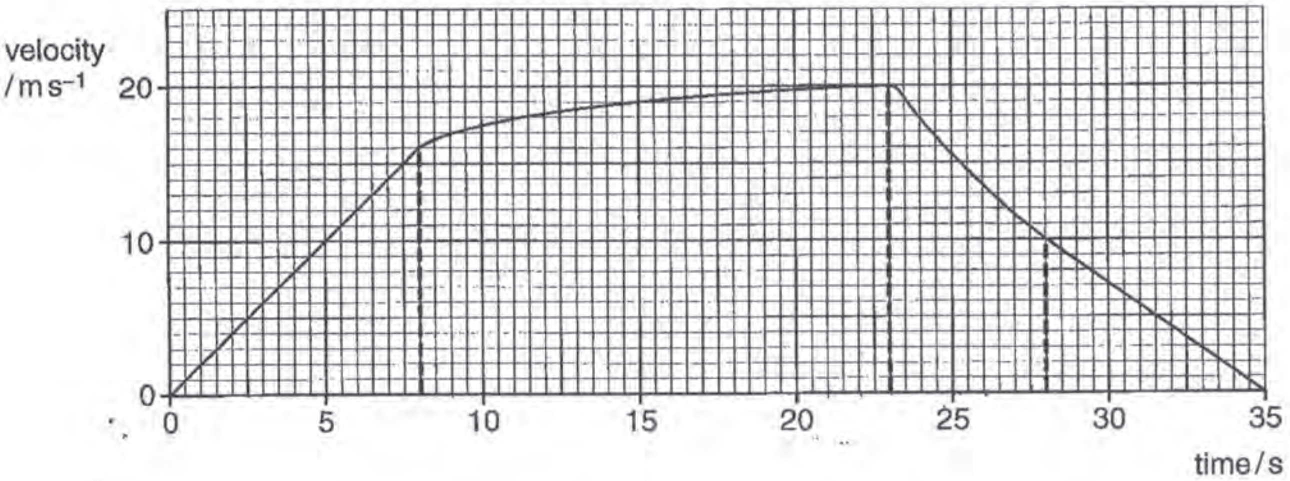


Fig. 1.1

(a) Calculate the distance travelled during

(i) the first 8 seconds,

$\frac{1}{2} \times 8 \times 16 = 64$ m

✓✓

distance = 64.0 m [2]

(ii) the last 7 seconds.

$\frac{1}{2} \times 7 \times 10 = 35$ m

✓

distance = 35.0 m [1]

3

(b) Estimate the total distance travelled.

$$64 + 35 + 15 \times 16 + \tfrac{1}{2} \times 15 \times 4 + \tfrac{5}{2} \times (10 + 20)$$

$$= 99 + 240 + 30 + 75$$

$$= 444 \text{ m}$$

✓✓✓

distance = [illegible] 444 m [3]

3

(c) **(i)** On Fig.1.2, sketch the corresponding distance-time graph for the bus.

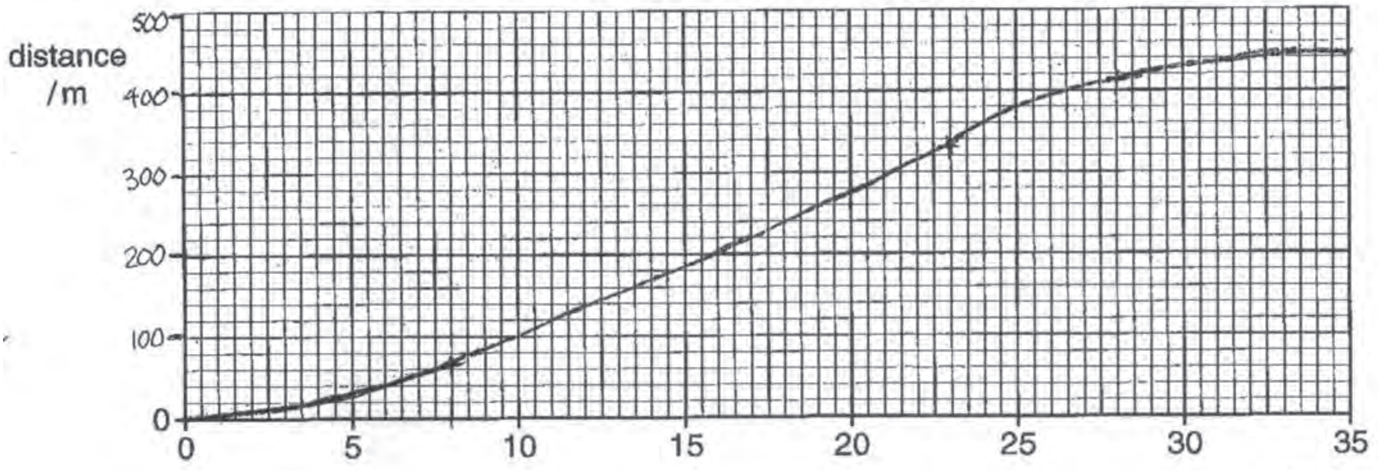
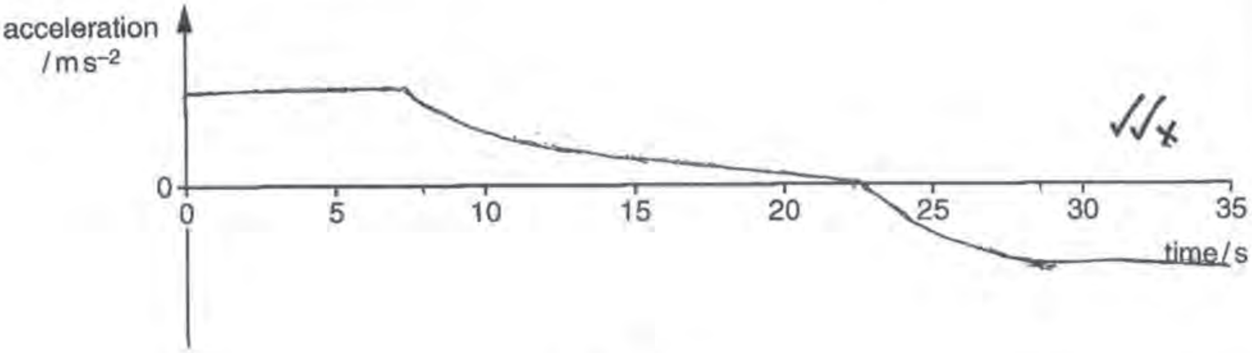


Fig. 1.2

✓✓✓

[3]

(ii) On Fig. 1.3, sketch the shape of the corresponding acceleration-time graph for the bus.



✓✓✗

Fig. 1.3

[3]

5

(d) For a group of about 10 students, each with a stopwatch and a 50 m tape measure, write an instruction sheet for them to enable them to carry out an exercise to obtain data to plot a distance-time graph for such a journey.

Space students out at 50 m intervals along the path of the bus. Every ✓ student must start their stopwatch at ✓ the instant the bus starts to move. They must stop their own stopwatch as the ✓ bus passes their 50 m point. The collected data will show ~~at~~ the time since the start that the bus has taken to travel each 50 m section. These data can then be plotted as ✗ points on a distance/time graph.

[4] 3

Examiner Comment

(a) Both parts are correctly answered with the correct working shown.

(b) The candidate estimates the area of the central section correctly and adds on the two previous answers; the final answer is within the allowable range.

(c) **(i)** This graph has the correct shape and although the curve is untidy towards the end, no marks are forfeited.

(ii) This graph scores the first 2 marks but is does not rise to a negative horizontal value just after 23 s; the gradual increase in the size of the deceleration does not correspond to the gradient in Fig. 1.1.

(d) The candidate makes three of the first four points in the mark scheme and this is sufficient to score a maximum of 3 marks but there is no reference to using a specified part of the bus to act as a reference point. The bus is a large object.

Example Candidate Response – Merit

1 Fig. 1.1 shows a velocity-time graph for a bus travelling along a straight road between two bus stops. It is divided into four parts.

a constant acceleration
a further increase in velocity to 20 m s^{-1}
a decrease in velocity to 10 m s^{-1}
a constant deceleration to rest

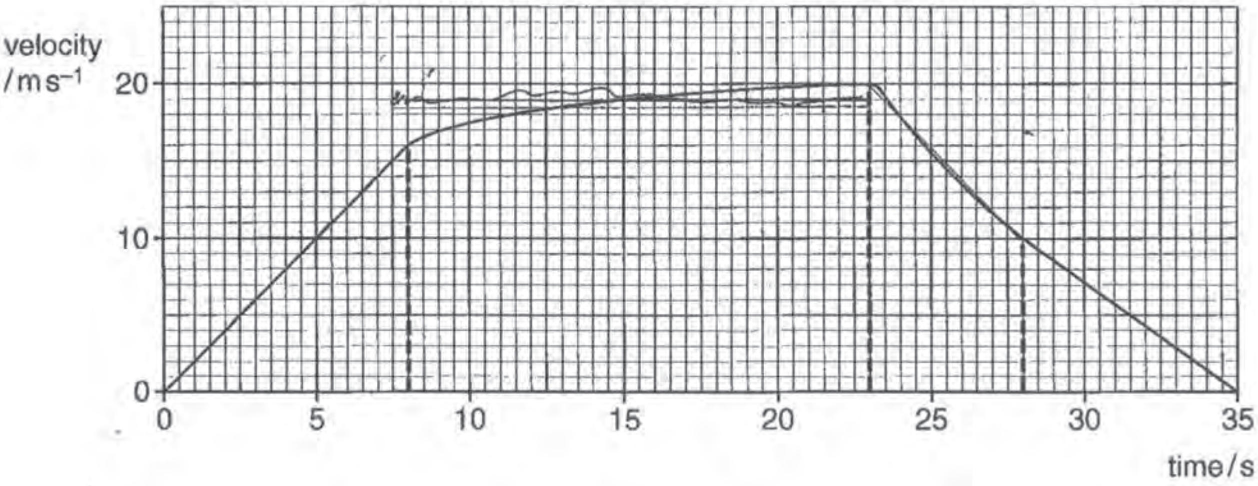


Fig. 1.1

(a) Calculate the distance travelled during

(i) the first 8 seconds,

$\frac{16 \times 8}{2} = 64$ m

distance = ...64........ m [2] ✓✓

(ii) the last 7 seconds.

$\frac{10 \times 7}{2} = 35$m

distance = ...35........ m [1] ✓

3

(b) Estimate the total distance travelled.

$64 + \frac{18.5 \times 15}{\textcircled{2}} + 10 \times 5 + \frac{10 \times 5}{2} + 35$

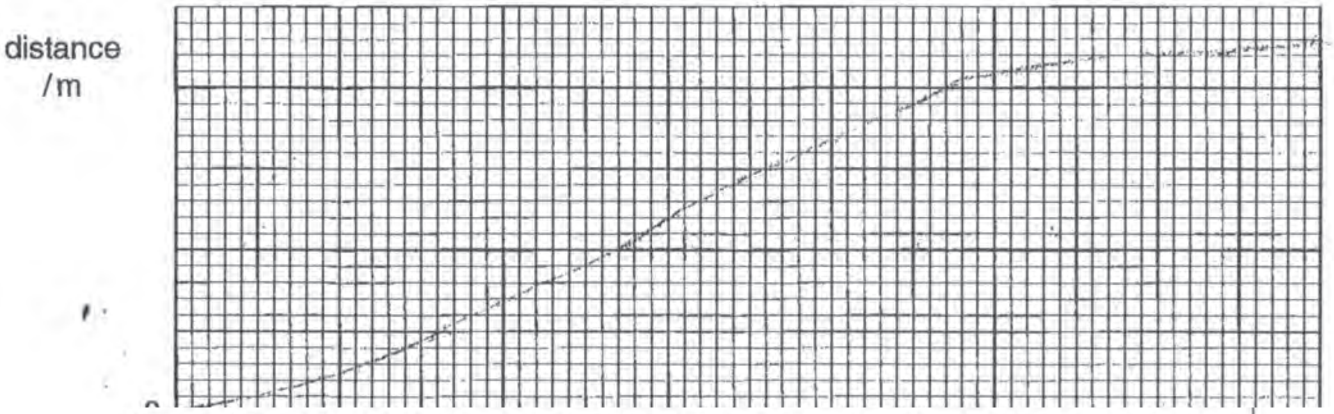
$\simeq 318$ m

✓××

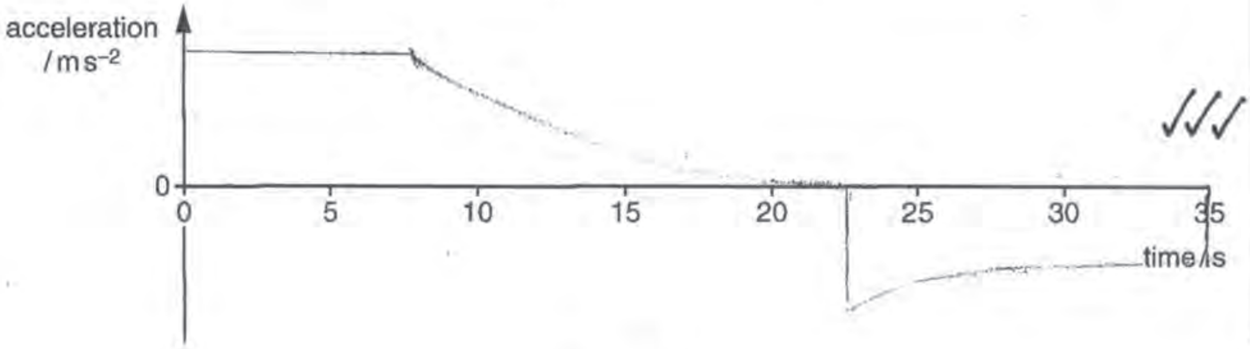
1

distance = ...313........ m [3]

(c) **(i)** On Fig.1.2, sketch the corresponding distance-time graph for the bus.



(ii) On Fig. 1.3, sketch the shape of the corresponding acceleration-time graph for the bus.



✓✓✓

3

Fig. 1.3

[3]

(d) For a group of about 10 students, each with a stopwatch and a 50 m tape measure, write an instruction sheet for them to enable them to carry out an exercise to obtain data to plot a distance-time graph for such a journey.

Place the tape measures end to end along the side of the road therefore measuring a distance of roughly 500m. Each student should stand at the end of their ✓✓✓ measuring tape that is furthest from the bus ~~which~~ whose ~~is at the beginning~~ front end is aligned with the end of the first measuring tape. At a given time all the students should start their stop watches and the bus should start moving on the students should stop their stopwatches when the front ✓ of the bus is level with them. ~~This will the difference between the time~~ [4] on ~~every students sensor~~ This data can then be used to plot a distance time graph.

4

Examiner Comment

(a) Both parts are correctly answered with the correct working shown.

(b) The candidate makes an error in estimating the area between 8 and 23 s. The answer given, multiplies the average height by the width but then divides by 2. This inevitably generates a wrong answer.

(c) **(i)** Although at first glance this graph suggests that the candidate has some idea of what is happening, it has been plotted carelessly and it does not score any marks. There are two regions before 23 s where the candidate's graph has a constant gradient and between them the gradient is decreasing. No scale is added to the vertical axis and so it is not clear that the graph reaches 313 m (candidate's value). After 23 s, the candidate's graph does not show a uniformly decreasing gradient.

(ii) This answer is correct and the graph shows a rise to a negative horizontal value just after 23 s.

(d) The candidate does not describe a mechanism for starting the stopwatches together but does make the other three points and so scores the first 3 marks. The candidate specifies the use of the front of the bus as a timings marker and so also scores the fourth mark.

Example Candidate Response – Pass

1 Fig. 1.1 shows a velocity-time graph for a bus travelling along a straight road between two bus stops. It is divided into four parts.

A a constant acceleration
B a further increase in velocity to 20 m s^{-1}
C a decrease in velocity to 10 m s^{-1}
D a constant deceleration to rest

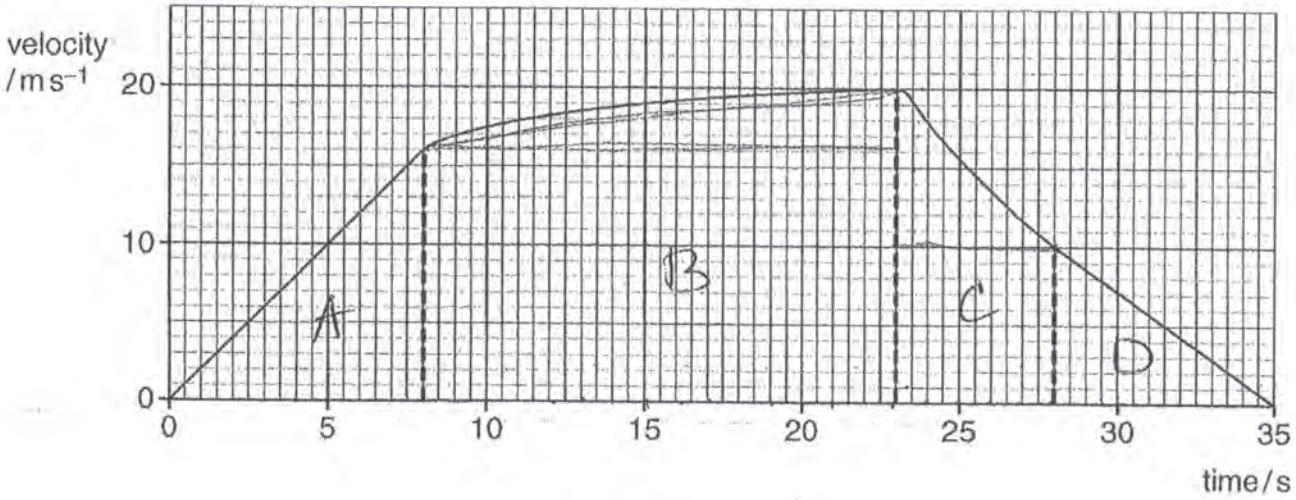


Fig. 1.1

(a) Calculate the distance travelled during

(i) the first 8 seconds,

$S = \left(\frac{u+v}{2}\right)t = \frac{16}{2} \times 8 = 8 \times 8 = 64$ m

✓✓

distance = ...64......... m [2]

(ii) the last 7 seconds.

area under that section.

$\frac{1}{2} \times 7 \times 10 = 35$

✓

distance = ...35......... m [1]

3

(b) Estimate the total distance travelled.

Total S = Total Area $= A + B + C + D$

$A = 64\text{m}$

$B \approx 16 \times 15 + \frac{1}{2} 15 \times 4 = 240$ ~~4~~ $+ 30 = 270\text{m}$

$C \approx 5 \times 10 + \frac{1}{2} 5 \times 10 = 50 + 25 = 75\text{ m}.$

$D = 35\text{m}.$

⇓

Total distance ≈ 444m.

or (450).

✓✓✓ 3

distance = 444m (450) m [3]

(c) (i) On Fig.1.2, sketch the corresponding distance-time graph for the bus.

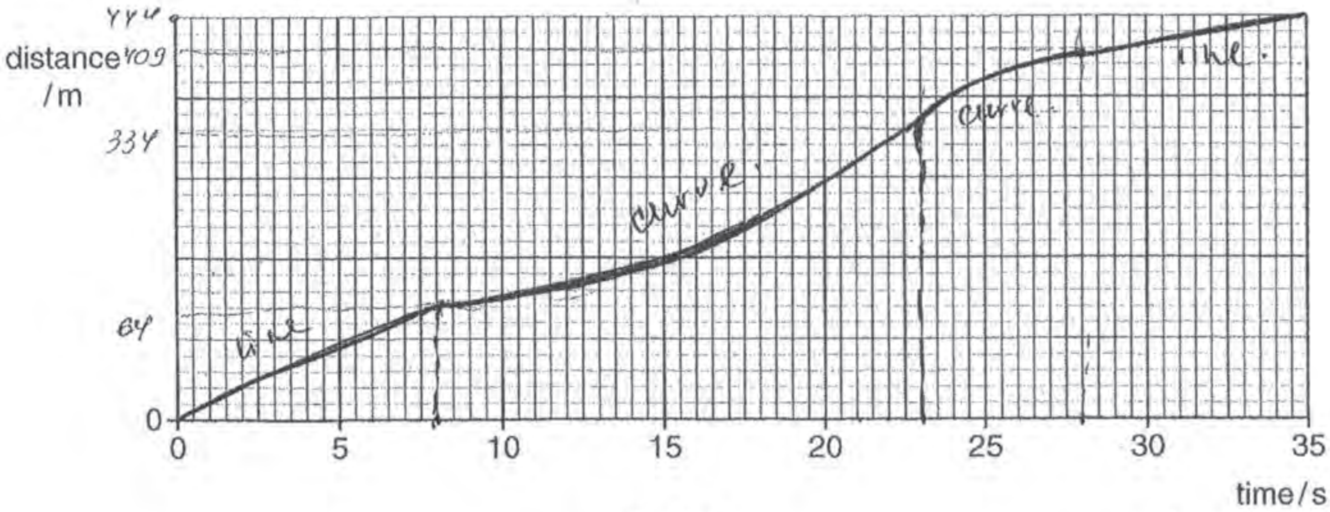
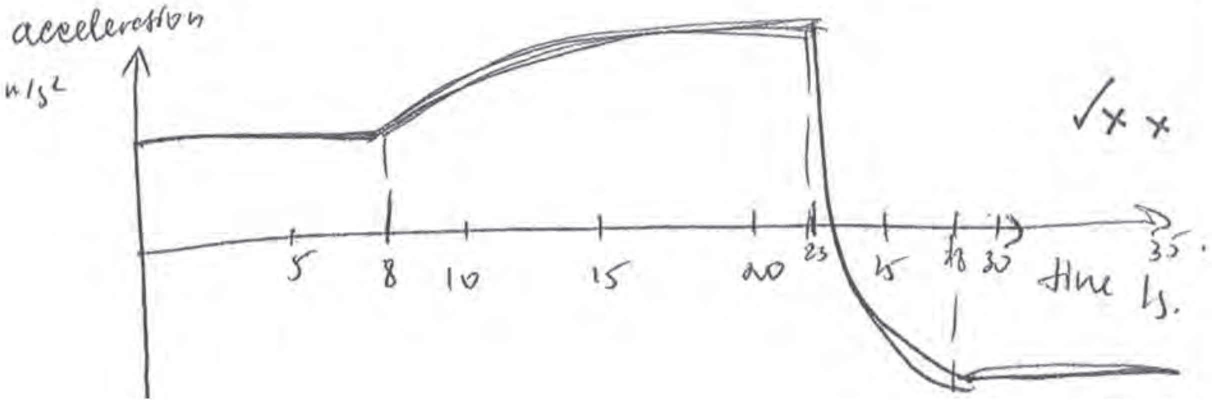


Fig. 1.2

× ✓ × [3]

Fig. 1.3

[3]



✓ × ×

1

(d) For a group of about 10 students, each with a stopwatch and a 50 m tape measure, write an instruction sheet for them to enable them to carry out an exercise to obtain data to plot a distance-time graph for such a journey.

Measure the length of the bus. Say it is 50 meters. Now when the bus starts moving ✓ students should start the watch.' Each ✓ time the bus pases its own length' they should take masurment of the watch.

Then they can plot a graph.
they wont have any curcved lines.
but it will be a good estimate. ✗

✗

2

[4]

take masurmets each 'bus length'.

Examiner Comment

(a) Both parts are correctly answered with the correct working shown.

(b) The candidate estimates the area of the central section correctly and adds on the two previous answers; the final answer is within the allowable range.

(c) **(i)** This line is drawn in a careless manner which, in terms of the basic mark scheme, would still score 1 mark. That mark, however, is cancelled because there are sudden changes of gradient and in places, more than one line.

(ii) This first mark was awarded as the candidate probably intended this initial section to be horizontal.

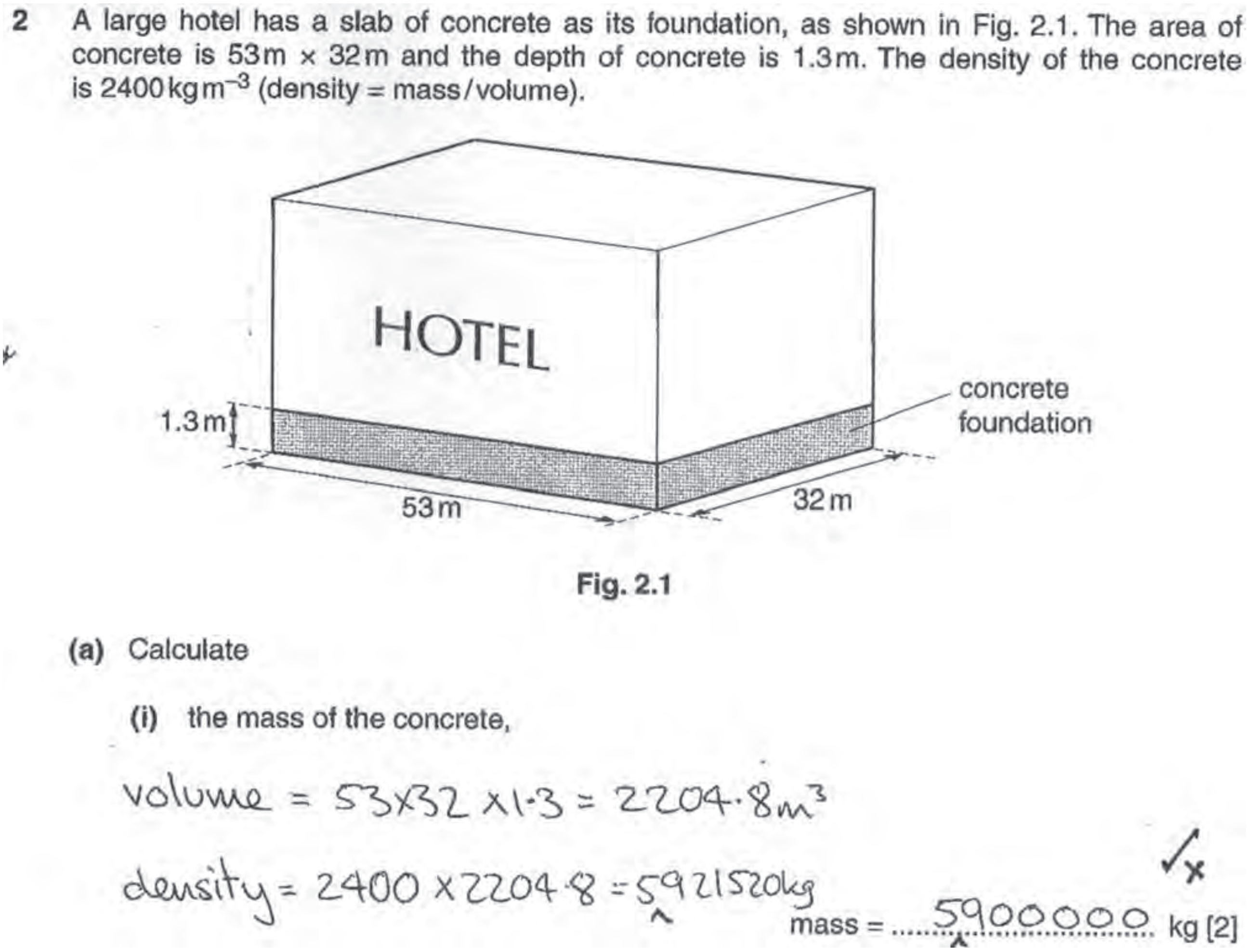
(d) One mark has been awarded for a mechanism for starting the stopwatches together and the diagram seems to suggest that the watches are stopped every time the bus travels 50 m.

Question 2 Mark Scheme

(a)	**(i)**	volume = 53 × 32 × 1.3 = (2205 m^3)	(1)	
		mass = 2205 × 2400 = 5.29 × 10^6 (kg)	(1)	[2]
	(ii)	weight = 5.29 × 10^6 × 9.81 = 5.19 × 10^7 (N)		[1]
	(iii)	pressure = weight / area	(1)	
		5.19 × 10^7 / 53 × 32 = 30 600 (N m^{-2})	(1)	[2]
(b)		building provides (70 – 30.6) = 39.4 (kN m^{-2})	(1)	
		mass of building is 39.4 × 5.29 × 10^6 / 30.6 = 6.81 × 10^6 (kg) (or the long way)	(1)	[2]

[Total: 7]

Example Candidate Response – Distinction



2 A large hotel has a slab of concrete as its foundation, as shown in Fig. 2.1. The area of concrete is 53 m × 32 m and the depth of concrete is 1.3 m. The density of the concrete is 2400 kg m^{-3} (density = mass / volume).

Fig. 2.1

(a) Calculate

(i) the mass of the concrete,

volume = 53x32 x1·3 = 2204·8m^3

density = 2400 x2204·8 = 5921520kg

✓x

mass = 5900000 kg [2]

(ii) the weight of the concrete,

$5921520\,\text{kg} \times 9.8\,\text{Nkg}^{-1}$

$= 51856896\,\text{N}$ ✓

weight = 5.2×10^7 N [1]

(iii) the pressure the foundations exert on the ground beneath them before the hotel itself is built.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = \frac{51856896}{53 \times 32} = 30576\,\text{Nm}^{-2}$$

✓✓

pressure = 31000 Nm^{-2} [2] ~~5~~ 4

(b) Building regulations state that the maximum pressure allowed on the ground under the foundations beneath the hotel is $70\,\text{kN}\,\text{m}^{-2}$. Deduce the maximum mass of the building and contents that can be allowed on top of the foundations.

$70000 - 30576\,\text{Nm}^{-2} = 39424\,\text{Nm}^{-2}$ exerted by hotel

$39424 \times (32 \times 53) = 66863104\,\text{N}$

$$\frac{66863104\,\text{N}}{9.8} = 6822766\,\text{kg}$$

✓✓

mass = 6800000 kg [2] 2

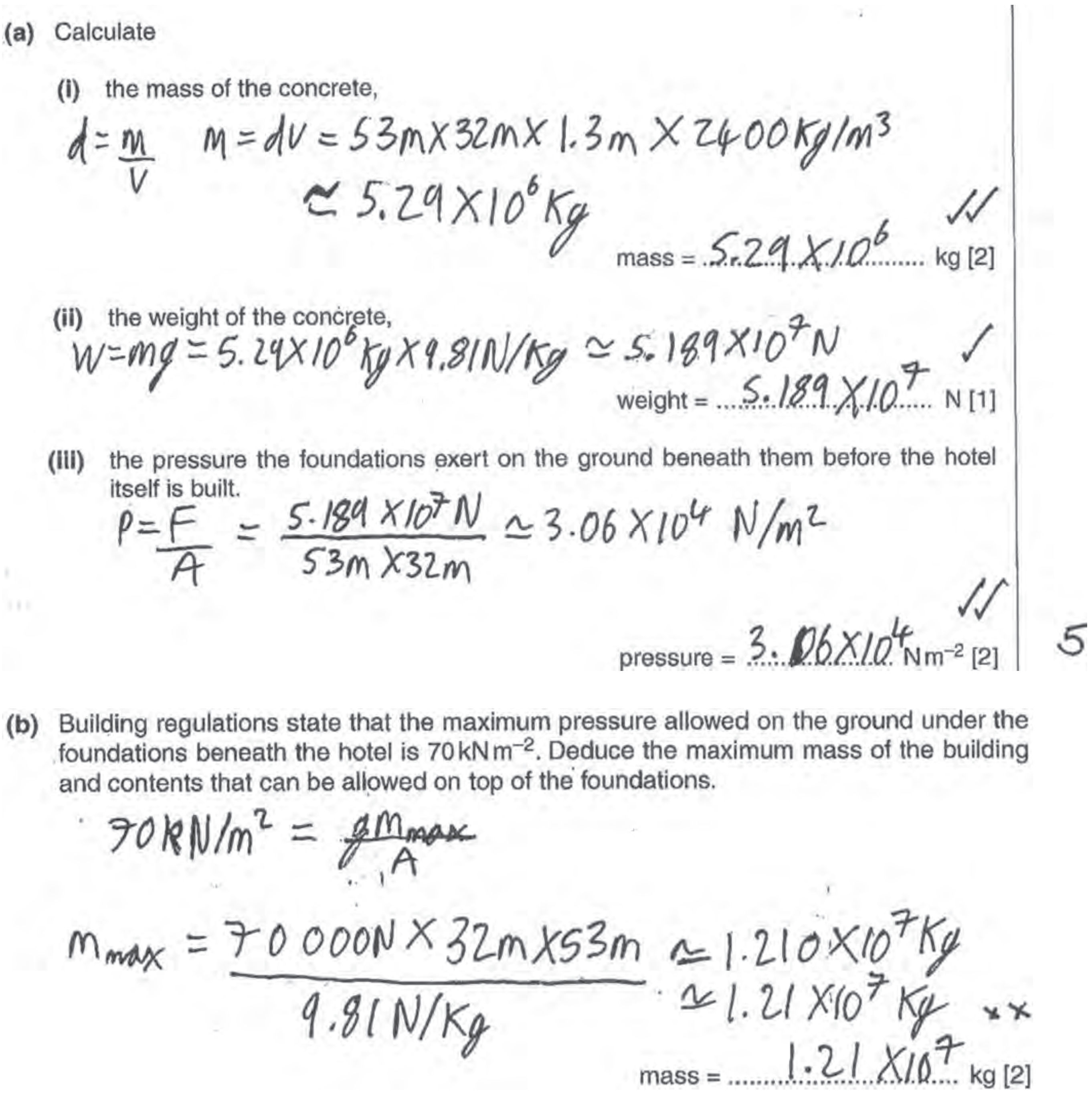
Examiner Comment

(a) **(i)** The candidate tackles the question correctly but writes down 5 921 520 instead of 5 291 520. This is then rounded off to two significant figures to give 5 900 000. The error results in a lost mark.

(ii) Although the candidate writes down 5 921 520 x 9.8, the calculation uses 5 291 520 and so the correct answer is obtained. Had the candidate correctly used 5 291 520, there would, in any case, have been no further penalty; the error would have been carried forward. There is no penalty for the use of 9.8 rather than the 9.81 given in the data.

(iii) The candidate now uses the correct answer to **(ii)** and from here on the correct answers are obtained and full marks awarded.

Example Candidate Response – Merit



(a) Calculate

(i) the mass of the concrete,

$d = \frac{m}{V}$ $m = dV = 53m \times 32m \times 1.3m \times 2400 kg/m^3$

$\simeq 5.29 \times 10^6 Kg$ ✓✓

mass = 5.29×10^6 kg [2]

(ii) the weight of the concrete,

$W = mg = 5.29 \times 10^6 Kg \times 9.81 N/Kg \simeq 5.189 \times 10^7 N$ ✓

weight = 5.189×10^7 N [1]

(iii) the pressure the foundations exert on the ground beneath them before the hotel itself is built.

$P = \frac{F}{A} = \frac{5.189 \times 10^7 N}{53m \times 32m} \simeq 3.06 \times 10^4 N/m^2$

✓✓

pressure = 3.06×10^4 N m^{-2} [2]

5

(b) Building regulations state that the maximum pressure allowed on the ground under the foundations beneath the hotel is 70 kN m^{-2}. Deduce the maximum mass of the building and contents that can be allowed on top of the foundations.

$70 kN/m^2 = \frac{g m_{max}}{A}$

$m_{max} = \frac{70\,000N \times 32m \times 53m}{9.81 N/Kg} \simeq 1.210 \times 10^7 Kg$

$\simeq 1.21 \times 10^7 Kg$ ××

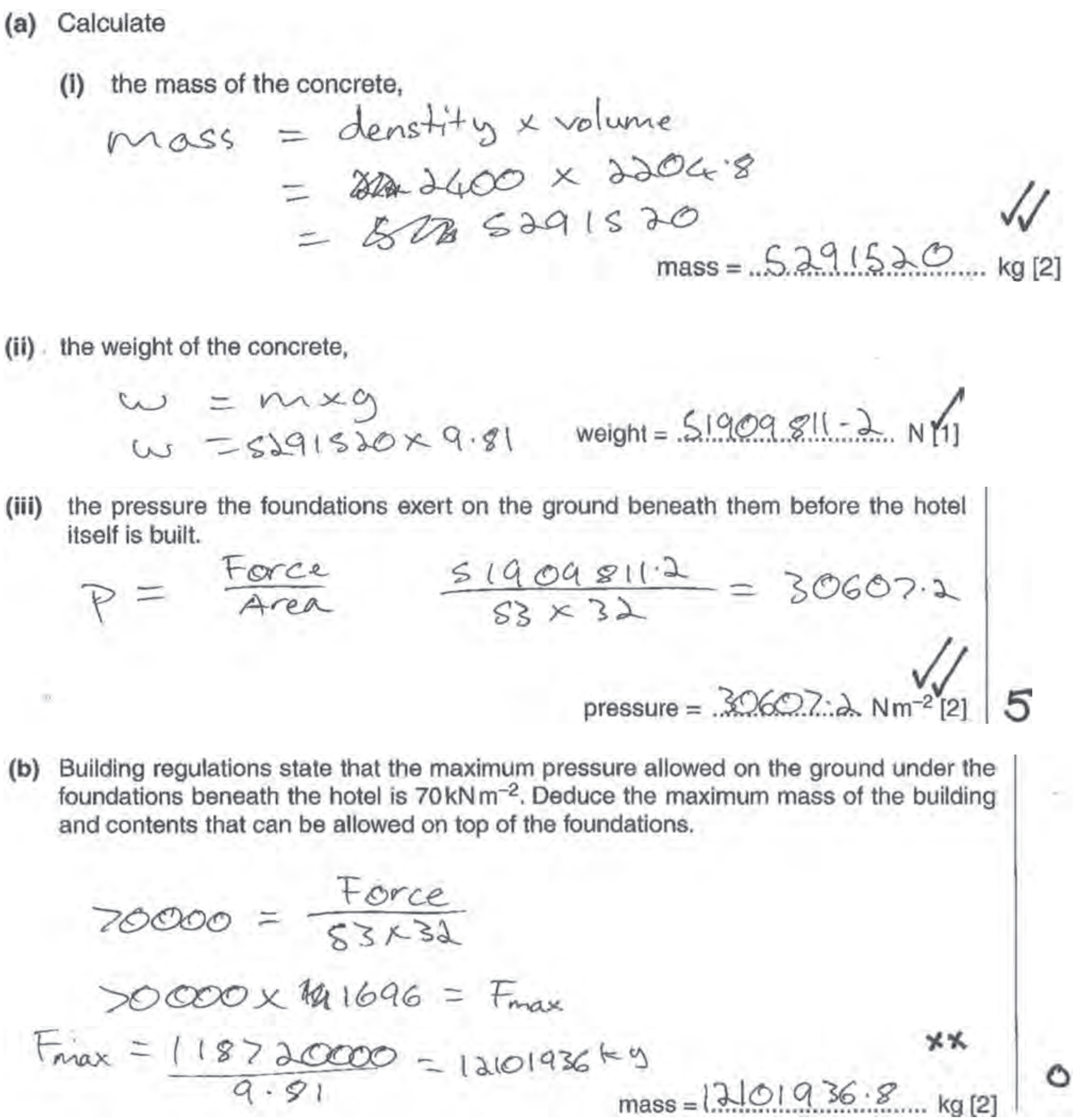
mass = 1.21×10^7 kg [2]

Examiner Comment

(a) This part of the question is correctly answered and full marks are given. No penalty was applied for four significant figures in **(ii)** even though the lengths in the question are only given to two significant figures.

(b) Although the candidate calculates the total mass resting on the ground, there is no subtraction of the mass of the foundations or any subtraction performed with the weights or pressures.

Example Candidate Response – Pass



(a) Calculate

(i) the mass of the concrete,

mass = density × volume

= 2400 × 2204·8

= 5291520

✓✓

mass = 5291520 kg [2]

(ii) the weight of the concrete,

w = m × g

w = 5291520 × 9·81

weight = 51909811·2 N ✓[1]

(iii) the pressure the foundations exert on the ground beneath them before the hotel itself is built.

$$P = \frac{\text{Force}}{\text{Area}} \qquad \frac{51909811{\cdot}2}{53 \times 32} = 30607{\cdot}2$$

✓✓

pressure = 30607·2 Nm^{-2} [2]

5

(b) Building regulations state that the maximum pressure allowed on the ground under the foundations beneath the hotel is 70 kN m^{-2}. Deduce the maximum mass of the building and contents that can be allowed on top of the foundations.

$$70000 = \frac{\text{Force}}{53 \times 32}$$

$$70000 \times 1696 = F_{max}$$

$$F_{max} = \frac{118720000}{9{\cdot}81} = 12101936 \text{ kg}$$

××

mass = 12101936·8 kg [2]

0

Examiner Comment

(a) (i) The candidate answers this section correctly, using the correct figures and showing the formulae used.

(ii)–(iii) The answers are presented as strings of numbers and to an unjustified number of significant figures. Nevertheless, no penalty was applied. In general however, it is expected that candidates will quote their final answers in a way appropriate to the data used (although the retention of more figures in intermediate steps is encouraged, to prevent rounding errors).

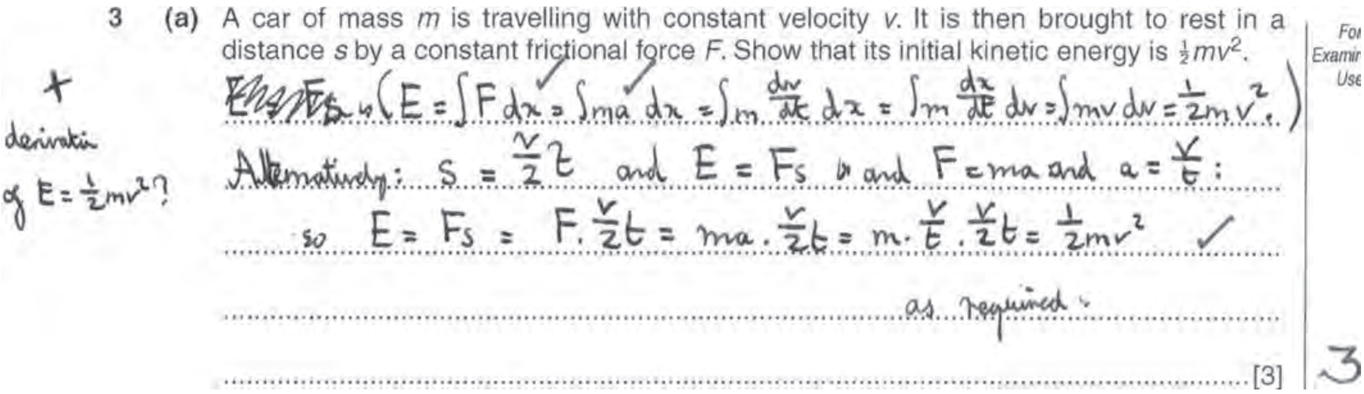
(b) The total mass of the hotel and foundations is calculated, but no subtraction is carried out at any stage and so the candidate did not score any marks.

Question 3 Mark Scheme

(a)	acceleration of body (= *a*) = (–)*F/m*	(1)	
	use of $v^2 = u^2 + 2as$ (condone use of signs wrongly and using u = v)	(1)	
	Fs = work done = k.e. **and** substitution to get *mas* = $msv^2 / 2s = ½mv^2$ (integration methods acceptable)	(1)	[3]
(b) (i)	½ × 1800 × 85002 = 6.5 × 1010 (J)		[1]
(ii)	6.5 × 1010 = 1800 × 5300 × Δθ	(1)	
	Δθ = 6820 (K)	(1)	[2]
(iii)	(gravitational) **potential** (energy must be lost as well)	[1]	
(iv)	heat/energy lost from spacecraft	(1)	
	by conduction **to air** **or** heat due to/WD against **air** resistance/atmosphere **or** by radiation	(1)	
	less (net) energy gain leads to (less temperature rise) **or** net energy gain is less than actual energy gain	(1)	[3]

[Total: 10]

Example Candidate Response – Distinction (D1)



3 (a) A car of mass *m* is travelling with constant velocity *v*. It is then brought to rest in a distance *s* by a constant frictional force *F*. Show that its initial kinetic energy is $\frac{1}{2}mv^2$.

$(E = \int F\,dx = \int ma\,dx = \int m\frac{dv}{dt}\,dx = \int m\frac{dx}{dt}\,dv = \int mv\,dv = \frac{1}{2}mv^2.)$ ✓ ✓

Alternatively: $s = \frac{v}{2}t$ and $E = Fs$ and $F = ma$ and $a = \frac{v}{t}$:

so $E = Fs = F.\frac{v}{2}t = ma.\frac{v}{2}t = m.\frac{v}{t}.\frac{v}{2}t = \frac{1}{2}mv^2$ ✓

as required.

[3]

+ derivation of $E = \frac{1}{2}mv^2$?

Fo Examir Use

3

(b) A spacecraft of mass 1800 kg, far out in space, is travelling towards the Earth with velocity 8500 m s^{-1}.

(i) Calculate its kinetic energy.

$= \frac{1}{2}mv^2 = \frac{1}{2} \times 1800 \times 8500^2$ ✓

kinetic energy = 6.5×10^{10} J [1]

(ii) The average specific heat capacity of the spacecraft is 5300 J kg^{-1} K^{-1}. Calculate the rise in the temperature of the spacecraft should all its kinetic energy be used in raising its temperature.

$E = mc\Delta T \Rightarrow \Delta T = \frac{E}{mc} = \frac{6.5 \times 10^{10}}{1800 \times 5300} = 6800$

✓✓

(2s.f.)

rise in temperature = 6800 K [2]

(iii) Kinetic energy is transformed to thermal energy as the spacecraft moves closer to the Earth. State the other form of energy that is transformed between the time when it was far out in space and landing.

Gravitational potential energy. ✓

[1]

(iv) Describe why, in practice, the spacecraft does not experience the rise in temperature calculated in **(ii)**.

Heat energy is lost by radiation (electromagnetic)

Heat energy is lost by conduction once in atmosphere ✓✓✗

Spacecraft is also slowed by air resistance

Heat capacity is a function of temperature, so is not constant.

[3]

6

Examiner Comment

(a) This candidate uses integral calculus to obtain the work done by the decelerating car. This is done accurately even though no limits are used for the integration. Crucially the candidate makes it clear that the energy of the car is the work that it can do.

(b) **(i)–(iii)** The first three parts are completely correct.

(iv) The candidate clearly states that energy is lost from the spacecraft by radiation but does not relate this to the lesser rise in temperature.

Example Candidate Response – Distinction

For Examin Use

3 **(a)** A car of mass *m* is travelling with constant velocity *v*. It is then brought to rest in a distance *s* by a constant frictional force *F*. Show that its initial kinetic energy is $\frac{1}{2}mv^2$.

s a
u v

Work done on the car by friction = Fs = initial K.E. ✓

during deceleration ~~its~~ acceleration = $-\frac{F}{m}$

$u^2 = u^2 + 2as \Rightarrow 0 = v^2 - 2\frac{F}{m}s$ ✓

$\frac{2Fs}{m} = v^2 \Rightarrow$ ~~4~~ $Fs = \frac{1}{2}mv^2$

but Fs is ~~the work done~~ Initial K.E. [3]

∴ Initial K.E. = $\frac{1}{2}mv^2$

3

(b) A spacecraft of mass 1800 kg, far out in space, is travelling towards the Earth with velocity 8500 m s^{-1}.

(i) Calculate its kinetic energy.

$\frac{1}{2} \times 1800 \times 8500^2 = 6.50 \times 10^{10}$ J

2 s.f. ✓

kinetic energy = 6.5×10^{10} ✓ J [1]

(ii) The average specific heat capacity of the spacecraft is 5300 J kg^{-1} K^{-1}. Calculate the rise in the temperature of the spacecraft should all its kinetic energy be used in raising its temperature.

$\frac{6.5 \times 10^{10}}{1800 \times 5300} = 6813$ K

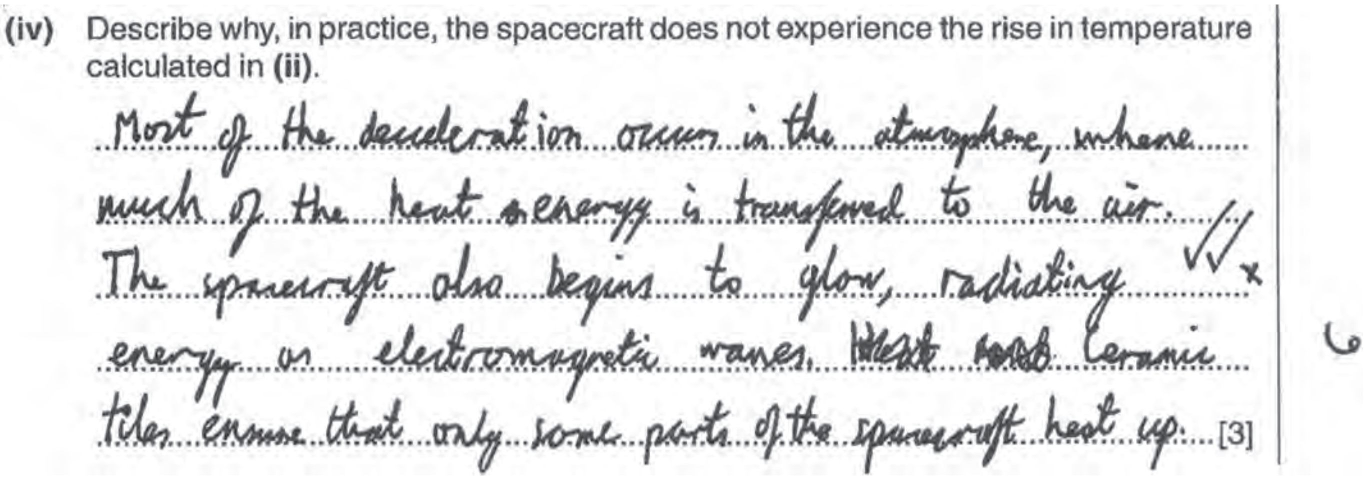
✓✓ 2 s.f.

rise in temperature = 6800 K [2]

(iii) Kinetic energy is transformed to thermal energy as the spacecraft moves closer to the Earth. State the other form of energy that is transformed between the time when it was far out in space and landing.

Gravitational Potential energy ✓

[1]



(iv) Describe why, in practice, the spacecraft does not experience the rise in temperature calculated in **(ii)**.

Most of the deceleration occurs in the atmosphere, where much of the heat energy is transferred to the air. The spacecraft also begins to glow, radiating energy as electromagnetic waves. ~~Heat~~ ~~[illegible]~~ Ceramic tiles ensure that only some parts of the spacecraft heat up. [3]

✓✓✗

6

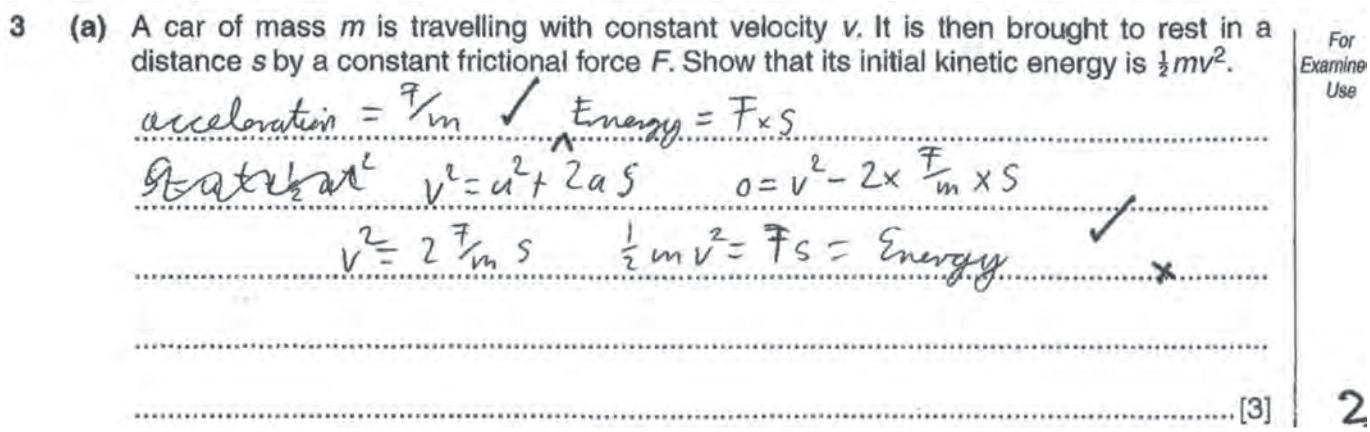
Examiner Comment

(a) The candidate tackles the question without calculus but makes all the essential points; the relationship between the work done and the initial kinetic energy is clear.

(b) (i)–(iii) The first three parts are completely correct.

(iv) This candidate is clear that energy is lost from the spacecraft but does not refer at all to the lesser temperature rise.

Example Candidate Response – Merit



3 (a) A car of mass *m* is travelling with constant velocity *v*. It is then brought to rest in a distance *s* by a constant frictional force *F*. Show that its initial kinetic energy is $\frac{1}{2}mv^2$.

For Examiner Use

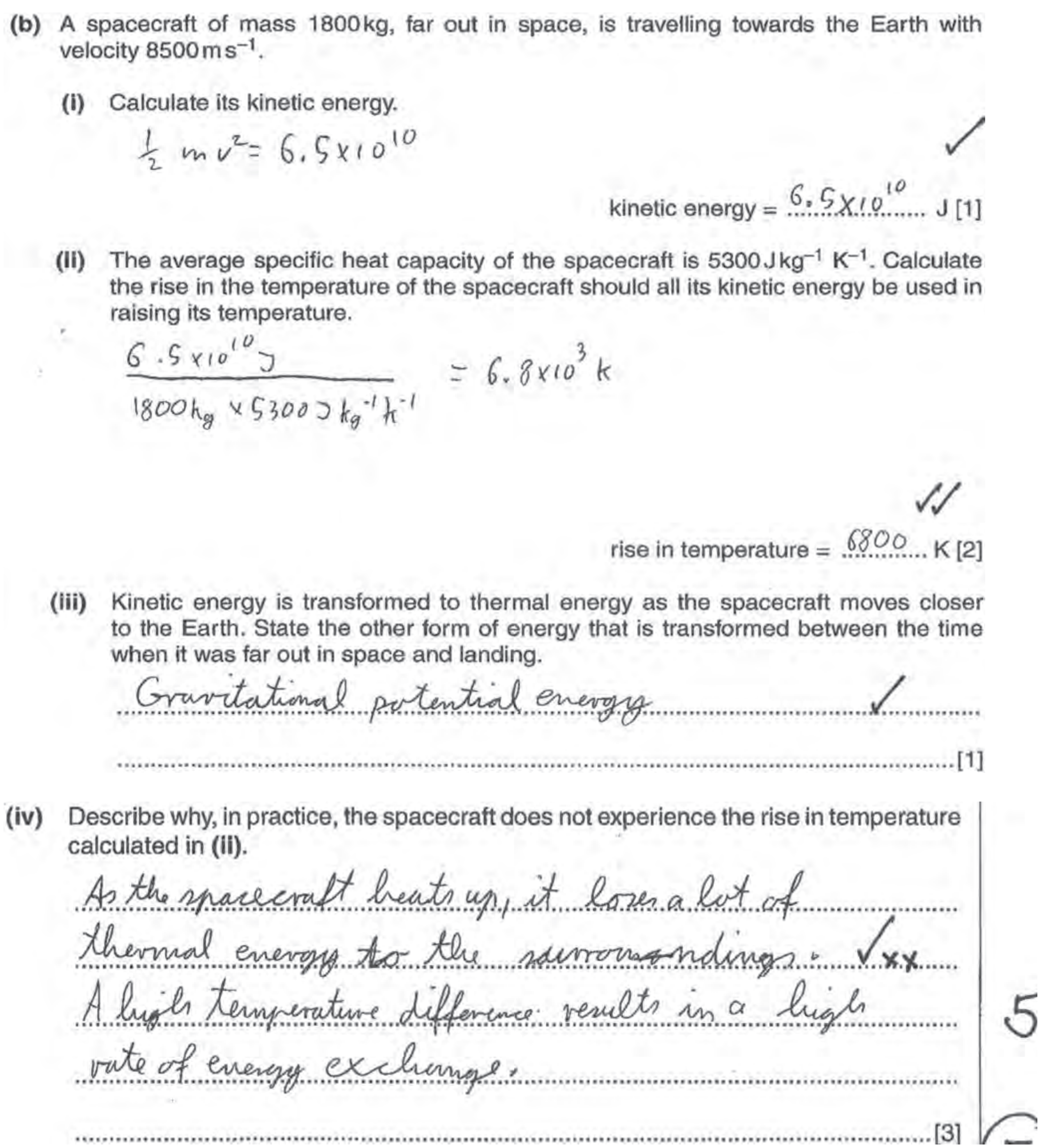
acceleration = F/m ✓ Energy = $F \times S$

~~$S = at + \frac{1}{2}at^2$~~ $v^2 = u^2 + 2aS$ $0 = v^2 - 2 \times \frac{F}{m} \times S$ ✓

$v^2 = 2\,F/m\,s$ $\frac{1}{2}mv^2 = Fs = $ Energy ✗

[3]

2



(b) A spacecraft of mass 1800 kg, far out in space, is travelling towards the Earth with velocity 8500 m s^{-1}.

(i) Calculate its kinetic energy.

$\frac{1}{2} m v^2 = 6.5 \times 10^{10}$ ✓

kinetic energy = 6.5×10^{10} J [1]

(ii) The average specific heat capacity of the spacecraft is 5300 J kg^{-1} K^{-1}. Calculate the rise in the temperature of the spacecraft should all its kinetic energy be used in raising its temperature.

$$\frac{6.5 \times 10^{10}\, J}{1800\, kg \times 5300\, J\, kg^{-1} k^{-1}} = 6.8 \times 10^{3}\, k$$

✓✓

rise in temperature = 6800 K [2]

(iii) Kinetic energy is transformed to thermal energy as the spacecraft moves closer to the Earth. State the other form of energy that is transformed between the time when it was far out in space and landing.

Gravitational potential energy ✓

[1]

(iv) Describe why, in practice, the spacecraft does not experience the rise in temperature calculated in **(ii)**.

As the spacecraft heats up, it loses a lot of thermal energy to the surroundings. ✓xx A high temperature difference results in a high rate of energy exchange.

[3]

5

Examiner Comment

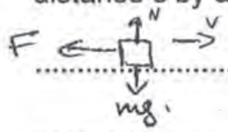
(a) The candidate correctly obtains ½mv² as the work done but simply refers to it as the energy without being clear why the initial kinetic energy equals the work done.

(b) (i)–(iii) The first three parts are completely correct.

(iv) The candidate correctly states that the spacecraft loses a lot of energy but does not offer a mechanism for this loss or relate this to the lesser temperature rise obtained.

Example Candidate Response – Pass

3 **(a)** A car of mass *m* is travelling with constant velocity *v*. It is then brought to rest in a distance *s* by a constant frictional force *F*. Show that its initial kinetic energy is $\frac{1}{2}mv^2$.



Work done on slowing down a cal = total energy. ✓××

$FS = \Delta KE + \cancel{\Delta GPE} + \cancel{\Delta EPE} = \frac{1}{2}mv^2$ ✓
(0) (0)
final speed 0 //

[3] 1

(b) A spacecraft of mass 1800 kg, far out in space, is travelling towards the Earth with velocity 8500 m s^{-1}.

(i) Calculate its kinetic energy.

$KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 1800 \times 8500^2 = 6.5 \times 10^{10}$ J ✓

kinetic energy = 6.5×10^{10} J [1]

(ii) The average specific heat capacity of the spacecraft is 5300 J kg^{-1} K^{-1}. Calculate the rise in the temperature of the spacecraft should all its kinetic energy be used in raising its temperature.

$c = 5300.$

$Q = cm\Delta t.$

if $Q = KE = 6.5 \times 10^{10}$ J.

$\Delta t = \frac{6.5 \times 10^{10}}{cm} = \frac{6.5 \times 10^{10}}{9540000} = \boxed{6813}\ °C.$

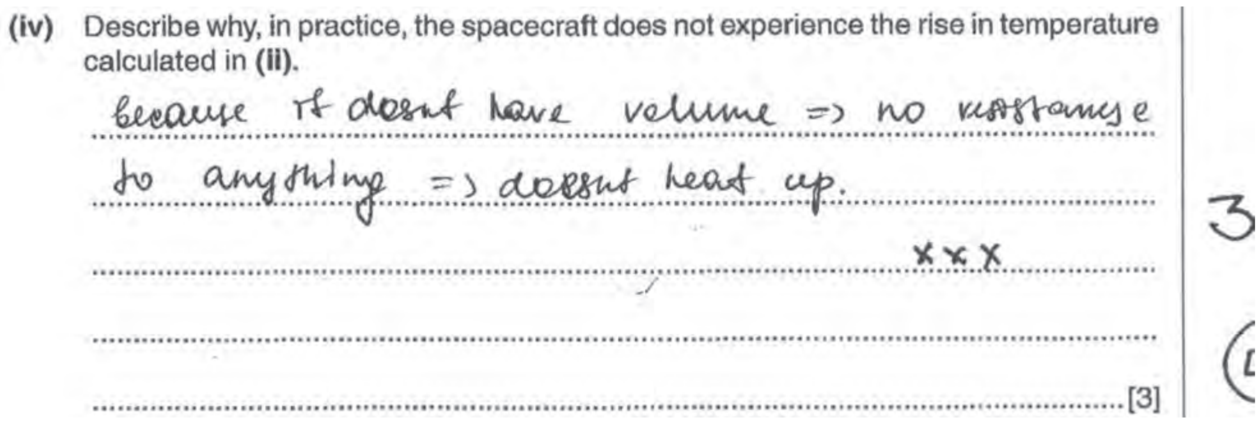
$6813°C = 7086$ K. ✓×

rise in temperature = 7086 K [2]

(iii) Kinetic energy is transformed to thermal energy as the spacecraft moves closer to the Earth. State the other form of energy that is transformed between the time when it was far out in space and landing.

potential energy. ✓

[1]



(iv) Describe why, in practice, the spacecraft does not experience the rise in temperature calculated in **(ii)**.

because it doesnt have volume => no resistance to anything => doesnt heat up.

x x X

[3]

3

Examiner Comment

(a) The candidate is clear that the work done as the car slows is the initial kinetic energy but there is no attempt to deduce the formula ½mv^2, it is simply stated and so these marks are not obtained.

(b) **(i)** The kinetic energy is calculated correctly.

(ii) The candidate obtains the correct answer but then adds on 273 to convert a temperature change in °C to K. This is an understandable error but a mark is forfeited as a result.

(iii) Correctly answered.

(iv) The candidate does not make any of the appropriate points and it is not clear what point the candidate is trying to make.

Question 4 Mark Scheme

I / A	P / W
3.0	0
2.4	2.9
2.0	4.0
1.5	**4.5**
1.2	**4.3(2)**
1.0	**4.0**
0.86	3.7
0.75	3.4
0.60	2.9
0.50	2.5

(a) **both** currents correct (1)
all three powers correct from values of current (1) [2]

(b) **(i)** suitable smooth curve [1]

(ii) maximum at $R = 2 \pm 0.2$ (Ω) [1]

(iii) all the power (is wasted as heat) in the internal resistance (1)
no power/energy to external resistor (as its value is zero so) (1) [2]

(iv) 1. total power supplied = 6 V × 1.5 A = 9.0 (W) (1)
efficiency = 4.5 / 9.0 = 0.5 (or 50%) (1) [2]

2. R for maximum fraction = 10 (Ω) [1]

[Total: 9]

Example Candidate Response – Distinction

4 A battery is connected to a variable resistor of resistance *R*, as shown in Fig. 4.1. The battery has an e.m.f. of 6.0 V and an internal resistance *r* of 2.0 Ω.

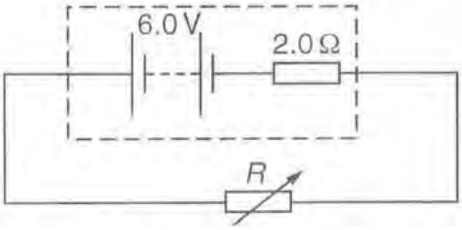


Fig. 4.1

Some values are given in Fig. 4.2 for total resistance (*R* + *r*), current *I* and power *P* dissipated in *R*.

$E = I(R+r)$

$I = \frac{E}{R+r}$

$P = I^2R$

R / Ω	(*R* + *r*) / Ω	*I* / A	*P* / W
0	2.0	3.0	0
0.5	2.5	2.4	2.9
1.0	3.0	2.0	4.0
2.0	4.0	1.5	4.5 [illegible]
3.0	5.0	1.2	~~3.6~~ 4.32
4.0	6.0	1.0	4.0
5.0	7.0	0.86	3.7
6.0	8.0	0.75	3.4
8.0	10.0	0.60	2.9
10.0	12.0	0.50	2.5

✓✓

Fig. 4.2

(a) Complete the table of Fig. 4.2. [2] 2

For Examiner's Use

(b) The graph of Fig. 4.3 shows how the power P dissipated in R varies as R changes.

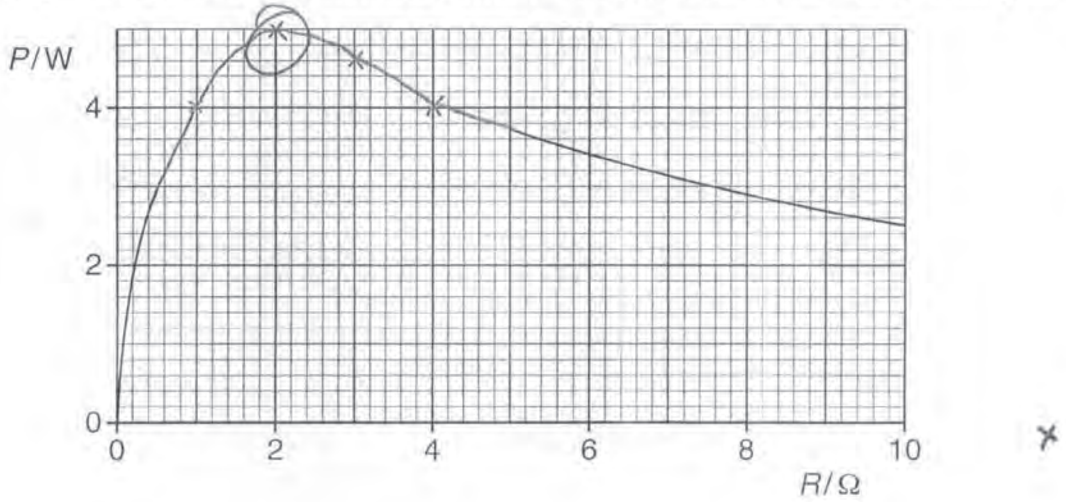


Fig. 4.3

(i) Complete the graph. [1]

(ii) State the value of R at which the power has its maximum value. ✓

resistance for maximum power = ...2........ Ω [1]

(iii) Explain what happens to the power supplied by the 6.0V battery when the current is 3.0A.

= IR = 3x2

- voltage drop across internal resistance = 6.0V,

ie. all power supplied is dissipated inside battery ✓

- no energy reaches R ∴ no power dissipated in R ✓ [2]

(iv) The efficiency of the circuit is defined by the equation

$$\text{efficiency} = \frac{\text{power dissipated in } R}{\text{power supplied by battery}}.$$

1. Determine the efficiency of the circuit when $R = 2.0\,\Omega$.

$$\text{efficiency} = \frac{4.5}{9} = 0.5$$ ✓✓

$$P_{\text{battery}} = 6 \times 1.5 = 9$$

efficiency = ...0.5............ [2]

2. State the value of R in the table that gives the greatest efficiency. ✓

value = ...10.................. Ω [1]

6

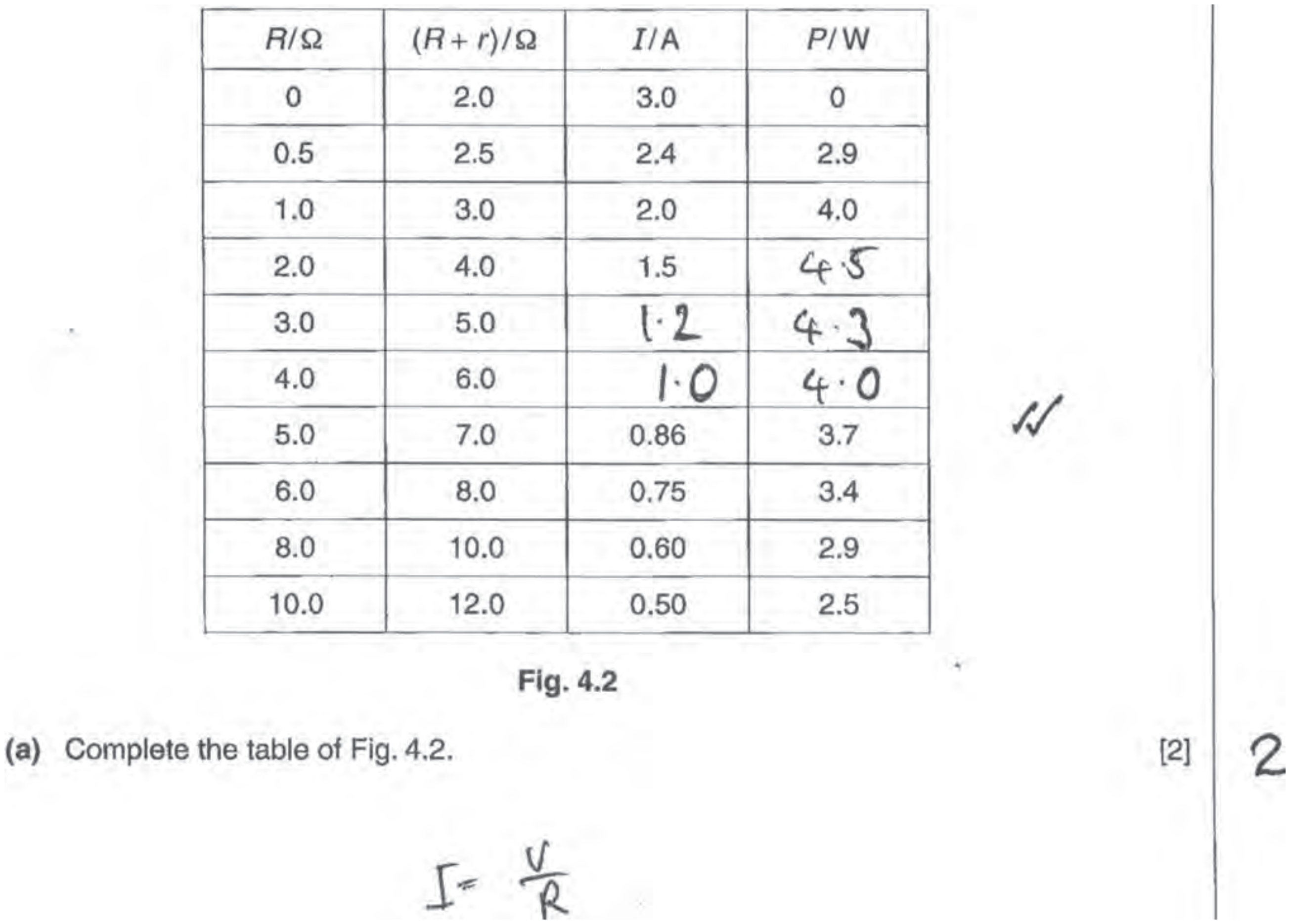
Examiner Comment

(a) The numbers added to the table are correct and the inconsistency that results from the three significant figures in 4.32 is ignored.

(b) **(i)** The candidate plots the value (2.0 V, 4.5 W) from the previous section at (2.0 V, 5.0 W).

(ii)–(iv) The remaining three parts are correctly answered and full marks are awarded.

Example Candidate Response – Merit



R/Ω	$(R+r)/\Omega$	I/A	P/W
0	2.0	3.0	0
0.5	2.5	2.4	2.9
1.0	3.0	2.0	4.0
2.0	4.0	1.5	4.5
3.0	5.0	1.2	4.3
4.0	6.0	1.0	4.0
5.0	7.0	0.86	3.7
6.0	8.0	0.75	3.4
8.0	10.0	0.60	2.9
10.0	12.0	0.50	2.5

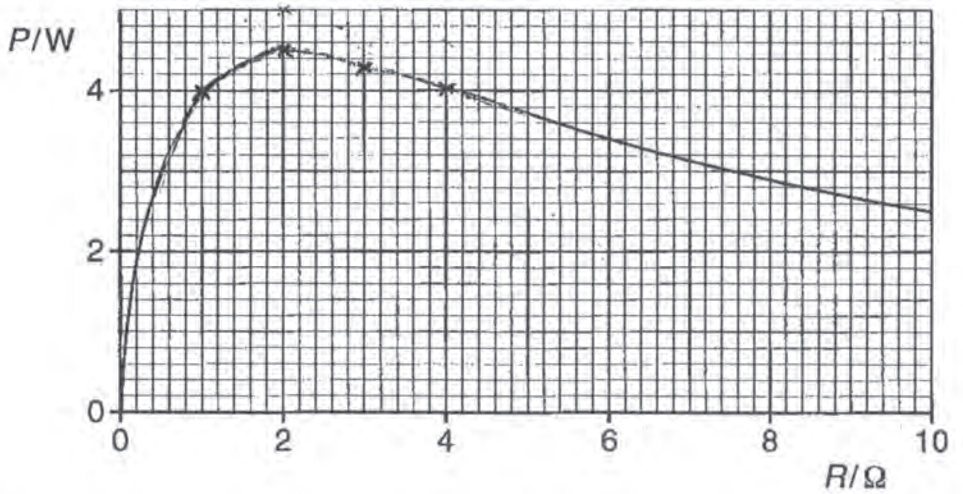
✓✓

Fig. 4.2

(a) Complete the table of Fig. 4.2. [2] 2

$I = \frac{V}{R}$

(b) The graph of Fig. 4.3 shows how the power *P* dissipated in *R* varies as *R* changes.



✗

Fig. 4.3

(i) Complete the graph. [1]

(ii) State the value of *R* at which the power has its maximum value.

✓

resistance for maximum power = 2·0 Ω [1]

(iii) Explain what happens to the power supplied by the 6.0V battery when the current is 3.0 A.

No power is supplied by the battery as it is all voltage ~~lost~~ is dropped across the internal resistance $V = IR = 3 \times 2 = 6{\cdot}0V$ [2]

✗✗

(iv) The efficiency of the circuit is defined by the equation

$$\text{efficiency} = \frac{\text{power dissipated in } R}{\text{power supplied by battery}}$$

1. Determine the efficiency of the circuit when *R* = 2.0 Ω.

$$\frac{4 \cdot 5}{6 \times 1 \cdot 5} \times 100\% = 50\%$$

efficiency = 50% ✓✓ [2]

2. State the value of *R* in the table that gives the greatest efficiency.

✓

value = 10·0 Ω [1]

4

Examiner Comment

(a) The candidate completes the table correctly.

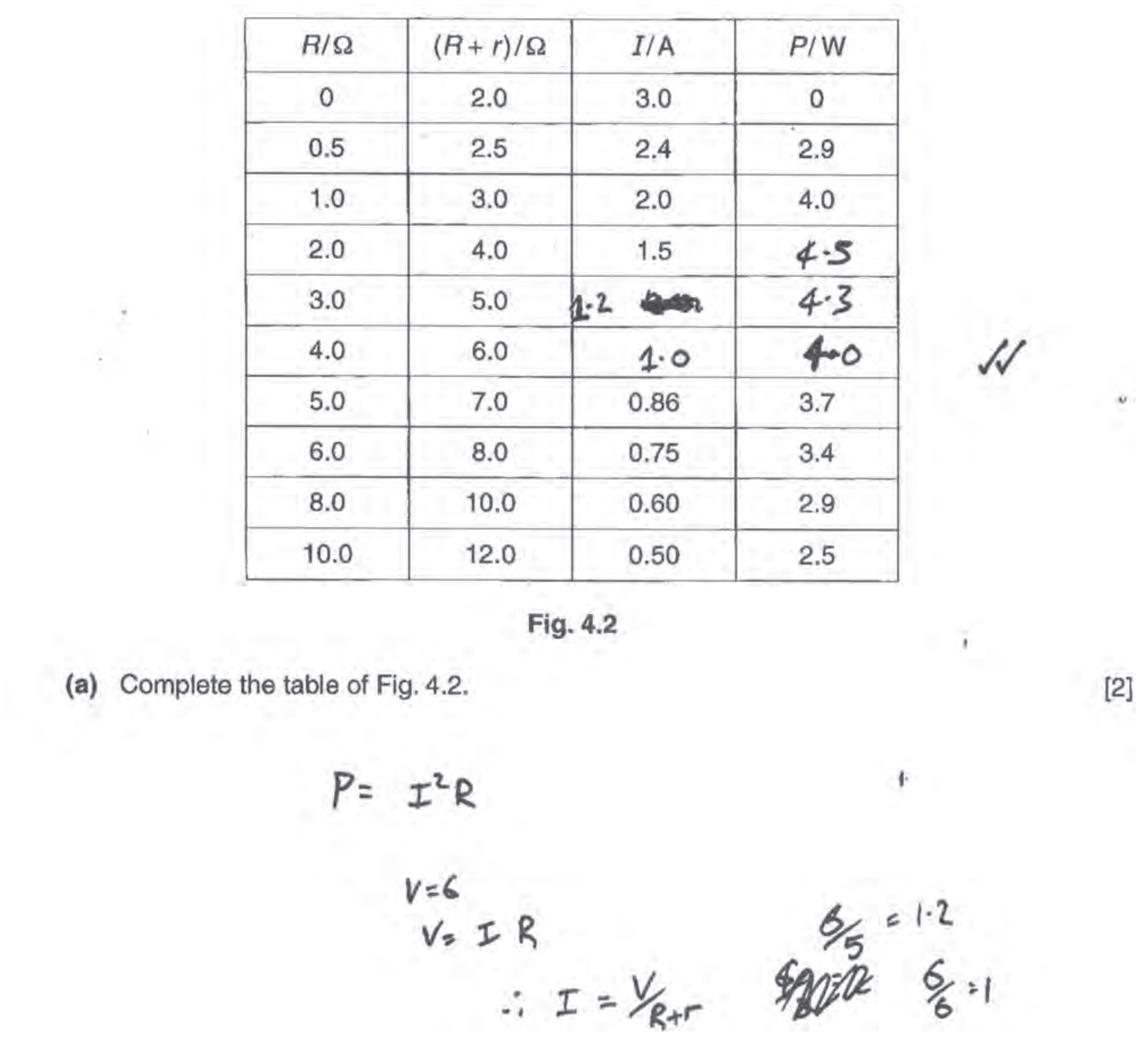
(b) **(i)** The points are plotted correctly but the curve that the candidate draws is not sufficiently smooth; in particular, the section between 1.0 Ω and 2.0 Ω is too close to being a straight line.

(ii) This answer is correct.

(iii) The initial statement that no power is supplied by the battery is wrong and neither point in the mark scheme is addressed.

(iv) Both answers are correct.

Example Candidate Response – Pass



R/Ω	$(R+r)/\Omega$	I/A	P/W
0	2.0	3.0	0
0.5	2.5	2.4	2.9
1.0	3.0	2.0	4.0
2.0	4.0	1.5	4.5
3.0	5.0	1.2 [illegible]	4.3
4.0	6.0	1.0	4.0
5.0	7.0	0.86	3.7
6.0	8.0	0.75	3.4
8.0	10.0	0.60	2.9
10.0	12.0	0.50	2.5

✓✓

Fig. 4.2

(a) Complete the table of Fig. 4.2. [2]

$P = I^2R$

$V = 6$

$V = IR$

$\therefore I = V/_{R+r}$

$6/5 = 1.2$

[illegible] $6/6 = 1$

(b) The graph of Fig. 4.3 shows how the power *P* dissipated in *R* varies as *R* changes.

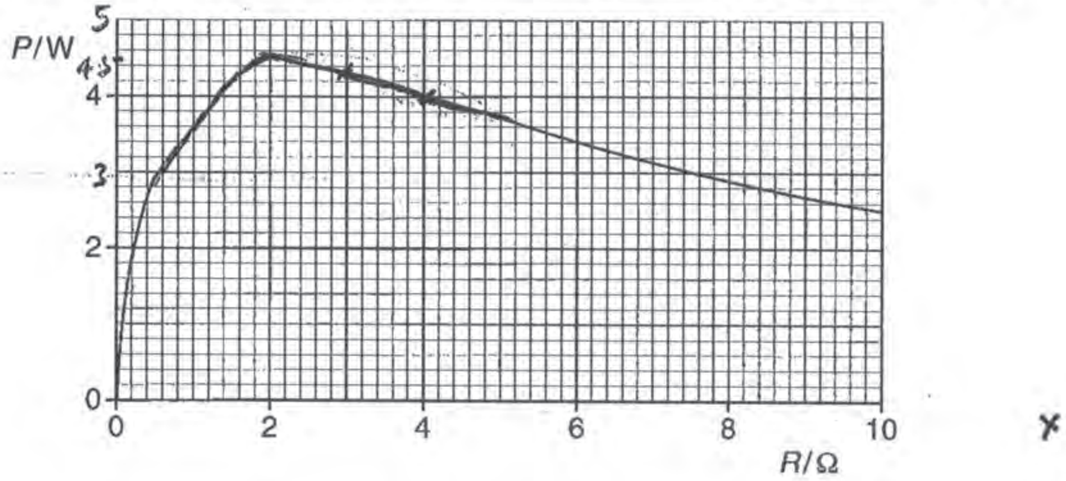
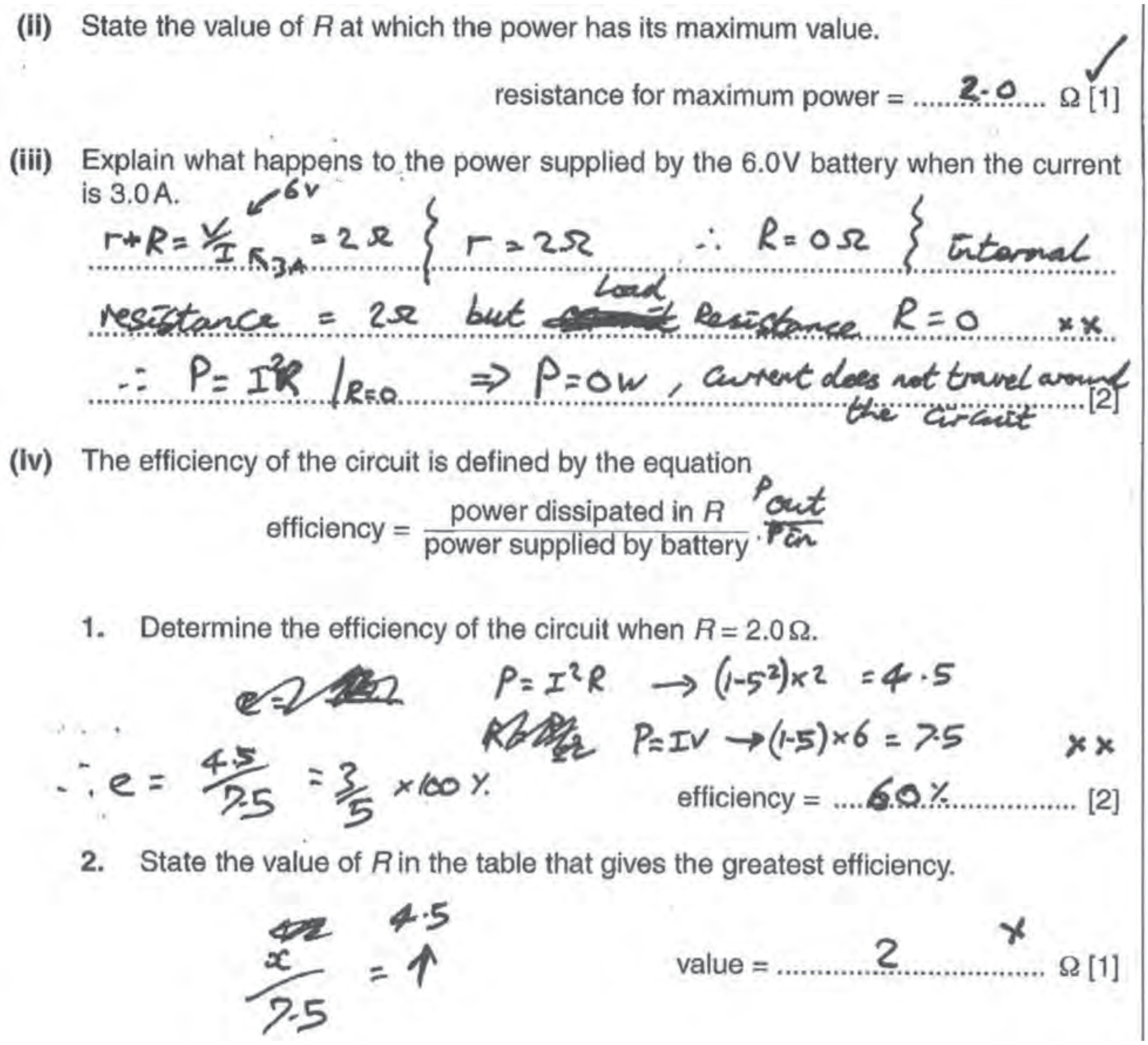


Fig. 4.3

(i) Complete the graph. [1]



(ii) State the value of R at which the power has its maximum value.

resistance for maximum power = ...2.0.... Ω [1] ✓

(iii) Explain what happens to the power supplied by the 6.0V battery when the current is 3.0A.

$r+R = \frac{V}{I}\Big|_{3A} = 2\Omega$ (V ← 6V) } $r = 2\Omega$ ∴ $R = 0\Omega$ } internal resistance = 2Ω but load Resistance $R = 0$ ××

∴ $P = I^2R\,\Big|_{R=0} \Rightarrow P = 0W$, current does not travel around the circuit [2]

(iv) The efficiency of the circuit is defined by the equation

$$\text{efficiency} = \frac{\text{power dissipated in } R}{\text{power supplied by battery}} \quad \frac{P_{out}}{P_{in}}$$

1. Determine the efficiency of the circuit when $R = 2.0\,\Omega$.

$P = I^2R \rightarrow (1.5^2)\times 2 = 4.5$

$P = IV \rightarrow (1.5)\times 6 = 7.5$ ××

$\therefore e = \frac{4.5}{7.5} = \frac{3}{5} \times 100\%$

efficiency = ...60%.................. [2]

2. State the value of R in the table that gives the greatest efficiency.

$\frac{x}{7.5} = \uparrow$ 4.5

value = ...2.......... Ω [1] ×

Examiner Comment

(a) The numbers that the candidate adds to the table are correct and full marks are scored here.

(b) **(i)** Although the points are correctly plotted, the line drawn is inadequate. In some places it is too thick and not sufficiently smooth. It is too straight in places where it should be curved.

(ii) This answer is correct.

(iii) The candidate is not sufficiently explicit that P = 0 W refers to the variable resistor and makes no reference to power dissipated elsewhere. The candidate states that there is no current in the circuit and does not appear to understand what is happening here.

(iv) 1.The candidate's answer is wrong because the power supplied has been calculated incorrectly; 1.5 × 6.0 = 9.0 not 7.5.

2. This answer is wrong.

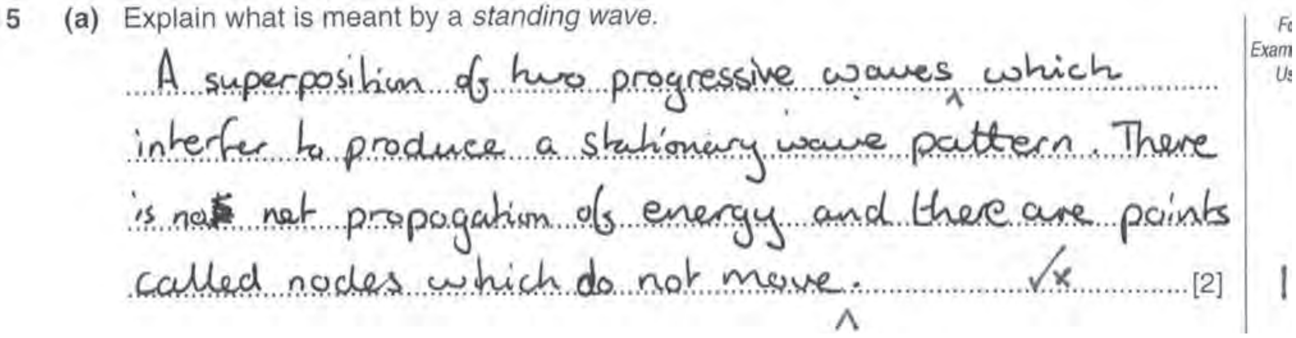
Question 5 Mark Scheme

(a) **two** points from:
a wave in which nodes and antinodes are set up
a wave made of two waves (of the same type and) of the same frequency (or wavelength), travelling in opposite directions
a wave not transmitting/storing energy (1 each) (2) [2]

(b)	source (e.g. of microwaves)	(1)	
	reflector/fixed point to produce waves in opposite direction	(1)	
	adjustment of distances to set up nodes and antinodes	(1)	
	correct diagram of arrangement	(1)	[4]
(c) (i)	the wavelength		[1]
(ii)	-sin wave; labelled/thick horizontal line; sin wave (amplitude~70%) (1 each)	(3)	[3]

[Total: 10]

Example Candidate Response – Distinction



5 (a) Explain what is meant by a *standing wave*.

A superposition of two progressive waves which interfer to produce a stationary wave pattern. There is ~~not~~ net propogation of energy and there are points called nodes which do not move. ✓✗ [2]

1

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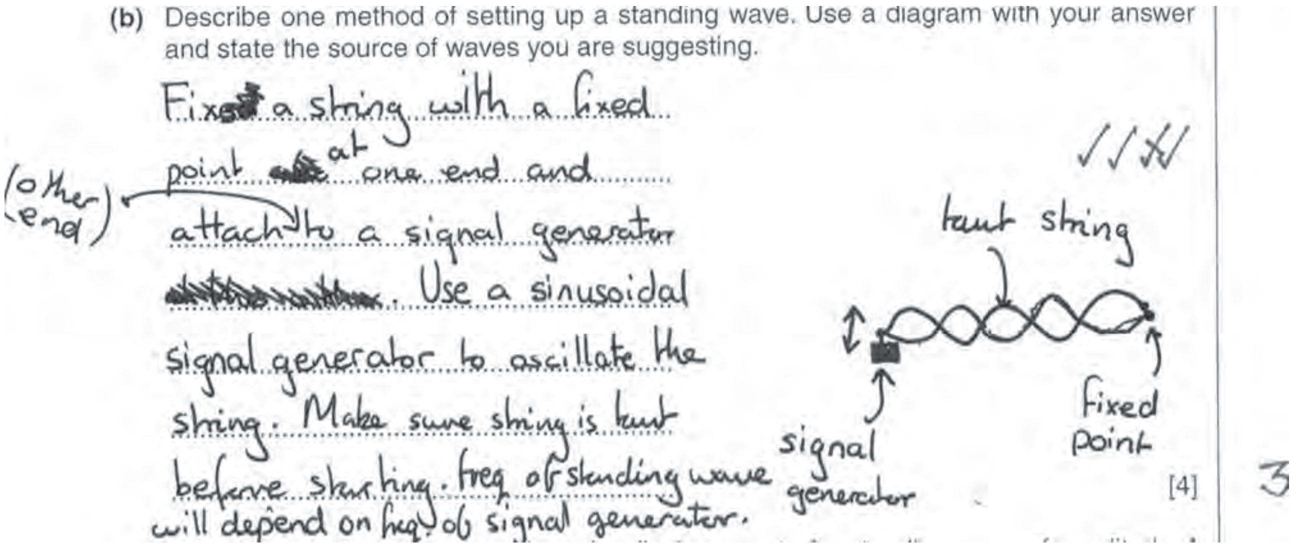


(b) Describe one method of setting up a standing wave. Use a diagram with your answer and state the source of waves you are suggesting.

Fix a string with a fixed point at one end and (other end) attach to a signal generator. Use a sinusoidal signal generator to oscillate the string. Make sure string is taut before starting. freq of standing wave will depend on freq of signal generator. [4]

✓✓✗✓

3

(c) The pattern in Fig. 5.1 shows how the displacement of a standing wave of amplitude *A* varies with the distance *x* along the wave at a time *t* = 0.

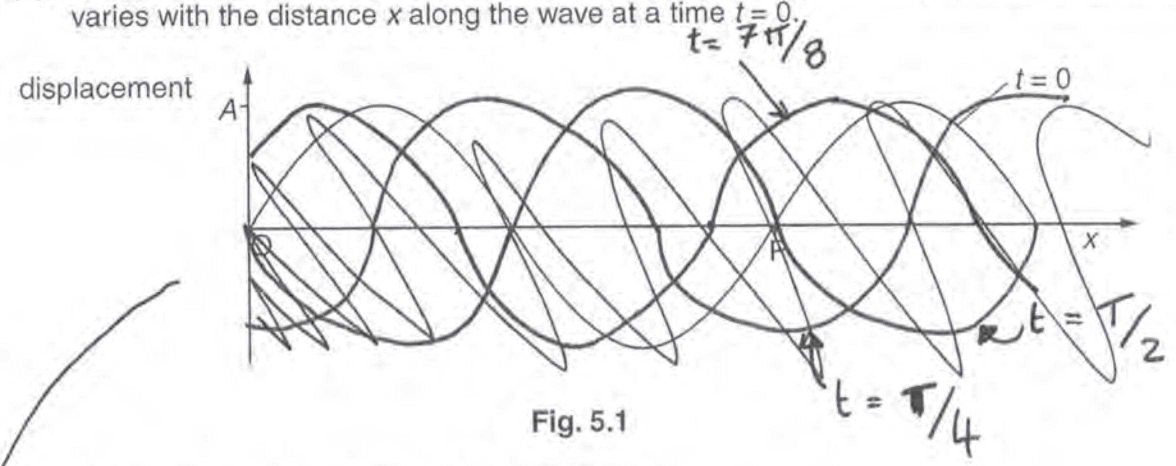


Fig. 5.1

(i) What does the distance OP represent?

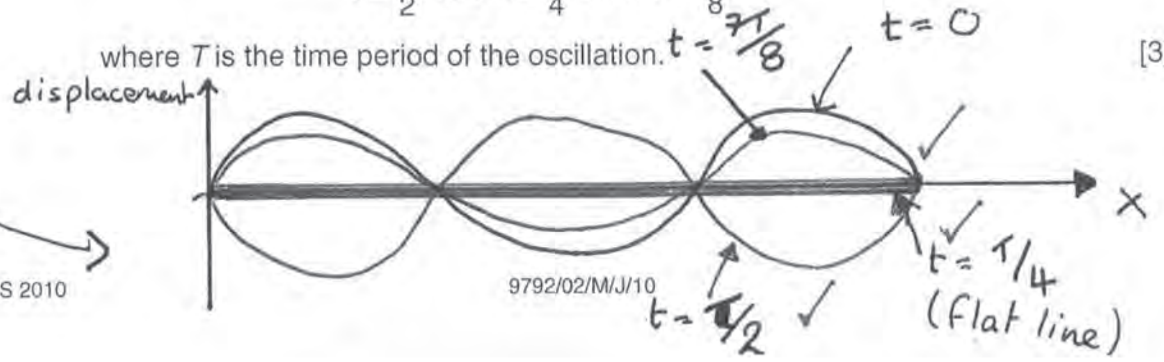
The wavelength of the standing wave. ✓ [1]

(ii) On Fig. 5.1, sketch and label graphs to show the pattern at times

$$t = \frac{T}{2} \text{ and } t = \frac{T}{4} \text{ and } t = \frac{7T}{8}$$

where *T* is the time period of the oscillation. [3]

4



8

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Examiner Comment

(a) The candidate scores a mark for stating that there is no net energy propagation in a standing wave. The two ways of scoring the second mark are both attempted but neither is completed. It should be made clear that the waves being superimposed are of equal frequency and travelling in opposite directions. Although the candidate refers to nodes being present, antinodes are not mentioned in the answer.

(b) The candidate does not state how the apparatus might need to be adjusted before the standing waves can be seen. The other points required are made.

(c) **(i)** The wavelength is correctly identified.

(ii) The candidate's initial attempt is crossed out and despite the rather complex diagram, the candidate draws it out and produces an excellent answer.

Example Candidate Response – Merit

(a) Explain what is meant by a *standing wave*.

For Examiner's Use

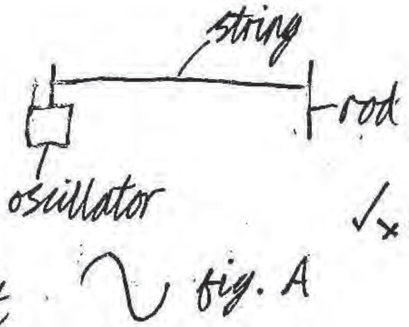
A standing wave is a wave that is stationary (it is not travelling through space). Any point on the wave only moves up and down over time. ××

[2]

0

(b) Describe one method of setting up a standing wave. Use a diagram with your answer and state the source of waves you are suggesting.

Attatch one end of a string to a rod and the other end to an oscillator, such as a pin that goes up and down with a sinusoidal signal from an attatched signal generator. Adjust the oscillator until the string appears not to be moving and has a shape such as in fig A.



✓×××

[4]

1

(c) The pattern in Fig. 5.1 shows how the displacement of a standing wave of amplitude *A* varies with the distance *x* along the wave at a time *t* = 0.

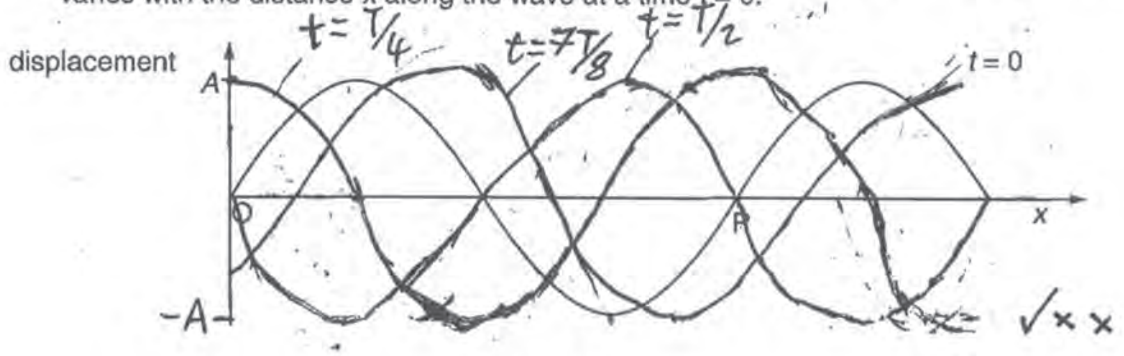


Fig. 5.1

(i) What does the distance OP represent?

The wavelength of the wave ✓ [1]

2

(ii) On Fig. 5.1, sketch and label graphs to show the pattern at times

$$t = \frac{T}{2} \text{ and } t = \frac{T}{4} \text{ and } t = \frac{7T}{8}$$

where *T* is the time period of the oscillation. [3]

Examiner Comment

(a) The candidate reveals some insight into the nature of a standing wave but none of the points made is sufficiently detailed for an answer at this level.

(b) The candidate realises that an oscillator is required but a rod was not a sufficiently clear reference to a fixed reflector. The candidate does not describe how the apparatus should be adjusted and the diagram does not add anything to the written responses.

(c) **(i)** This is correct.

(ii) The candidate treats the wave as a progressive wave and only the first pattern at t = T/2 but treats the wave as a progressive wave thereafter.

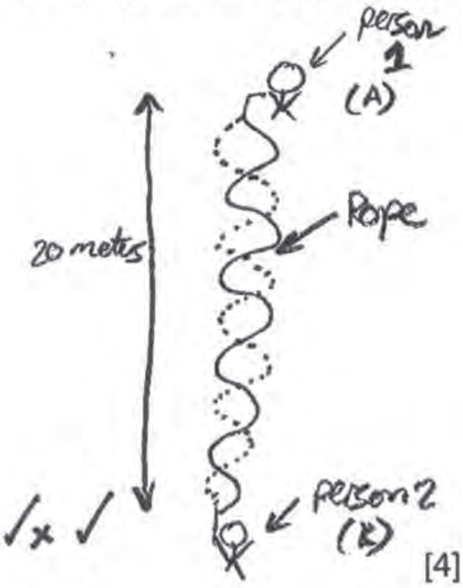
Example Candidate Response – Pass

5 **(a)** Explain what is meant by a *standing wave*.

a wave which has constant amplitude ✓
and is the product of 2 moving waves in opposite ×✓
(the algebraic sum of 2 waves)
directions ~~[illegible]~~
has same phase difference Nodes = No displacement [2]
Anti-Nodes = Max displacement

(b) Describe one method of setting up a standing wave. Use a diagram with your answer and state the source of waves you are suggesting.

A holds a rope and starts to move his arm from right to left at a set speed (oscillating Rope). B holds the rope and allows his arm to follow the oscillations of Rope, thus creating a standing wave



× ✓/× ✓ [4]

(c) The pattern in Fig. 5.1 shows how the displacement of a standing wave of amplitude A varies with the distance x along the wave at a time $t = 0$.

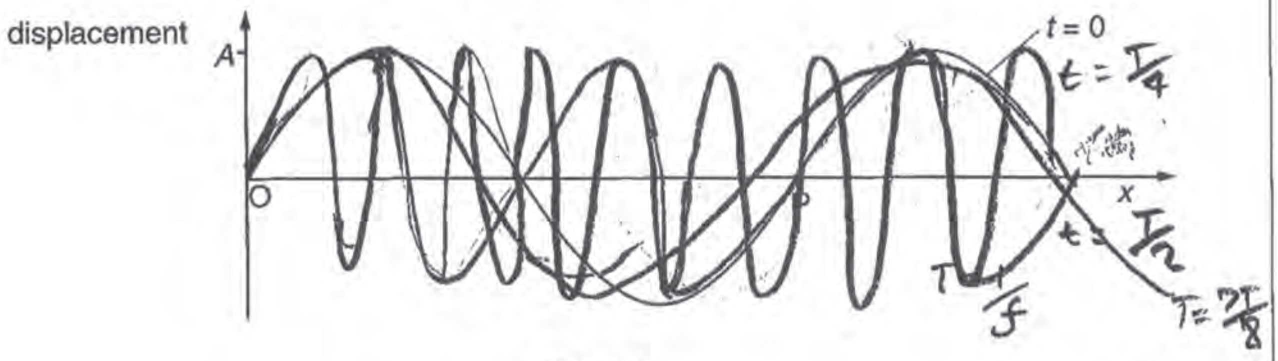


Fig. 5.1

× × ×

(i) What does the distance OP represent?

path difference × [1]

0

(ii) On Fig. 5.1, sketch and label graphs to show the pattern at times

$$t = \frac{T}{2} \text{ and } t = \frac{T}{4} \text{ and } t = \frac{7T}{8}$$

where T is the time period of the oscillation. [3]

Examiner Comment

(a) The candidate does not state that the two waves travelling in opposite directions are of the same frequency but reference is made to nodes and antinodes.

(b) This is not a very good answer but the diagram does show the production of a standing wave and for two people to generate a wave in the manner described is possible and so the second mark is also scored.

(c) **(i)** The answer given is not correct.

(ii) In none of the positions shown does the wave have the same wavelength as the one in the question and so no marks are scored here.

Question 6 Mark Scheme

(a) ${}^{28}_{14}\mathrm{Si}$, ${}^{29}_{14}\mathrm{Si}$ and ${}^{30}_{14}\mathrm{Si}$ [1]

(b) **(** ${}^{28}_{14}\mathrm{Mg} \rightarrow {}^{27}_{13}\mathrm{Al} + {}^{0}_{-1}$ß

a particle correct (penalise β –) (1)
equation balances (1) [2]

(ii) 12 protons become 13 protons **and** 15 neutrons become 14 neutrons (and an electron)
or a neutron changes into a proton (1)
a neutron changes into a proton and an electron/β-particle
(this scores both marks) (1) [2]

(c) ${}^{29}_{15}\mathrm{P} \rightarrow {}^{0}_{1}$e/ß + ${}^{29}_{14}\mathrm{Si}$

correct symbol for positron (penalise β+ but not as well as β –) (1)
correct equation (1) [2]

(d) half life for aluminium-29 is 6.6 (min) (1)
time is 5 half lives so **or** 5 used correctly (1)
activity = $4.8 \times 10^5 / 2^5 = 1.5 \times 10^4$ (Bq) (1) [3]

[Total: 10]

Example Candidate Response – Distinction

6 Fig. 6.1 shows some of the isotopes of the elements of proton numbers 11 to 15. For example, magnesium (Mg) has proton number 12 and has three stable isotopes. A stable nucleus of magnesium may contain 12, 13 or 14 neutrons to give three isotopes

$$^{24}_{12}\text{Mg},\ ^{25}_{12}\text{Mg and } ^{26}_{12}\text{Mg}.$$

The table also shows a few unstable isotopes together with their half-lives. The symbol β^- indicates that the isotope decays with the emission of a beta-particle.

number of neutrons	Na 11	Mg 12	Al 13	Si 14	P 15
12	stable	stable			
13	β^- 15h	stable			
14	β^- 60s	stable	stable	stable	β^+ 4.3s
15		β^- 9.5 min	β^- 2.3 min	stable	
16			β^- 6.6 min	stable	stable
17				β^- 157 min	
18					
19					
20					

Fig. 6.1

Use the information in Fig. 6.1 to answer the following.

(a) Give the symbols for the three stable isotopes of silicon (Si). ✓

$^{28}_{14}Si$ .... $^{29}_{14}Si$ .... $^{30}_{14}Si$ .... [1]

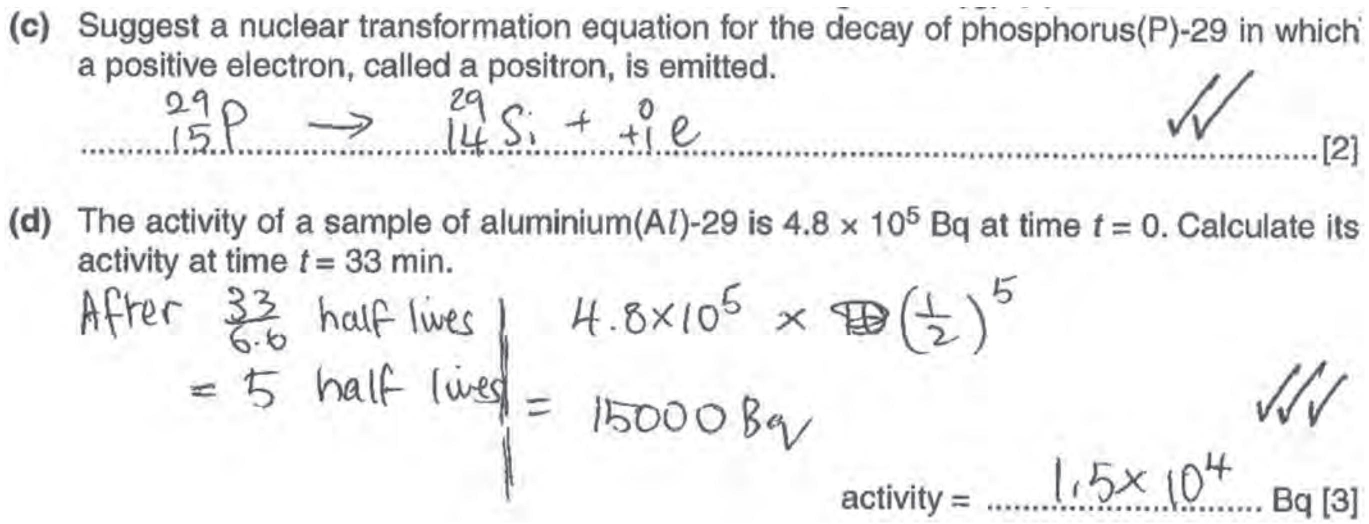
(b) **(i)** Write a balanced nuclear transformation, using standard notation, for the decay of magnesium-27.

$^{27}_{12}Mg \longrightarrow$ ~~[illegible]~~ $^{27}_{13}Al + ^{0}_{-1}e$ ✓✓ [2]

(ii) By counting the number of protons and neutrons on both sides of the equation in **(i)**, deduce what change has taken place in one nuclear particle to produce other particles.

✓✓

A neutron is transformed into one proton and one electron [2]



(c) Suggest a nuclear transformation equation for the decay of phosphorus(P)-29 in which a positive electron, called a positron, is emitted.

$^{29}_{15}P \rightarrow ^{29}_{14}Si + ^{0}_{+1}e$ ✓✓ [2]

(d) The activity of a sample of aluminium(Al)-29 is 4.8 × 10^5 Bq at time t = 0. Calculate its activity at time t = 33 min.

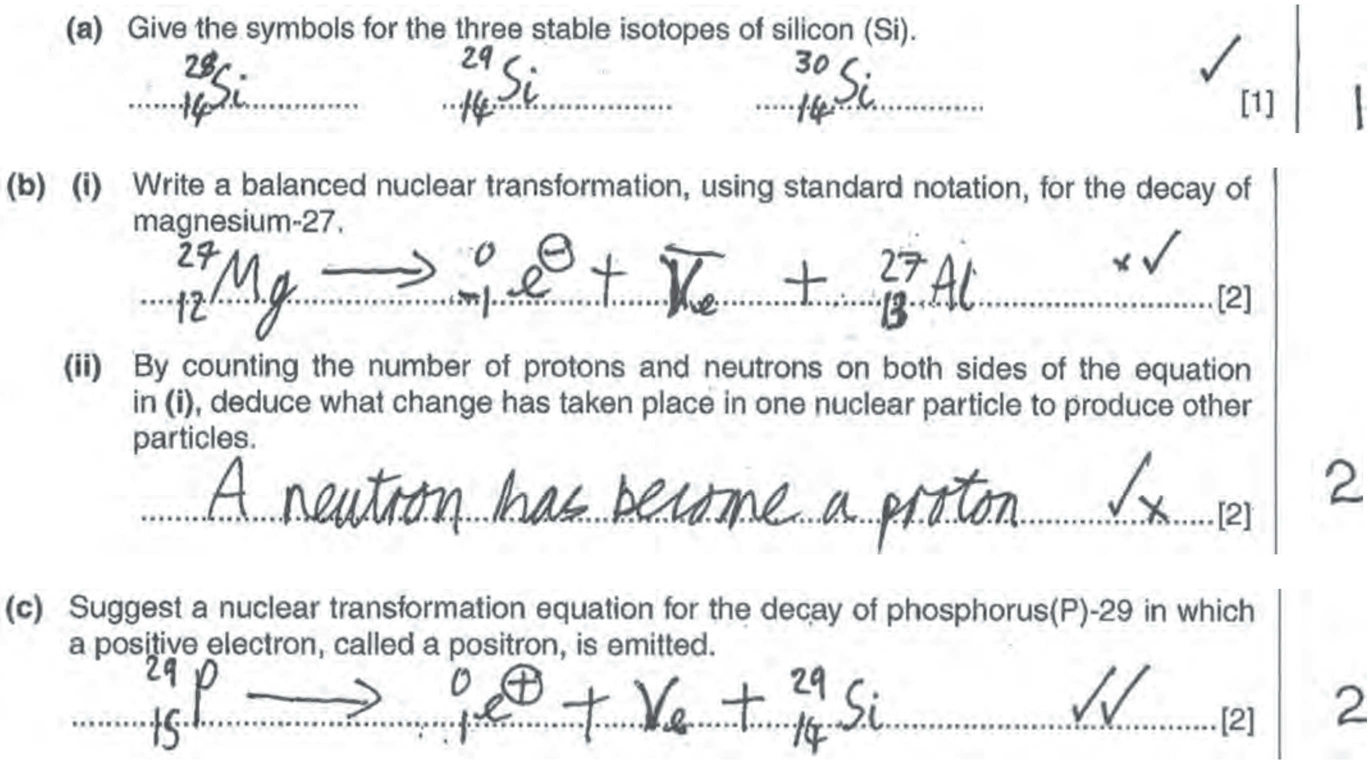
After $\frac{33}{6.6}$ half lives = 5 half lives | $4.8\times10^5 \times \left(\frac{1}{2}\right)^5$ = 15000 Bq ✓✓✓

activity = 1.5×10^4 Bq [3]

Examiner Comment

The candidate's answer to this question is fully correct and scores full marks.

Example Candidate Response – Merit



(a) Give the symbols for the three stable isotopes of silicon (Si).

$^{28}_{14}Si$ $^{29}_{14}Si$ $^{30}_{14}Si$ ✓ [1] 1

(b) **(i)** Write a balanced nuclear transformation, using standard notation, for the decay of magnesium-27.

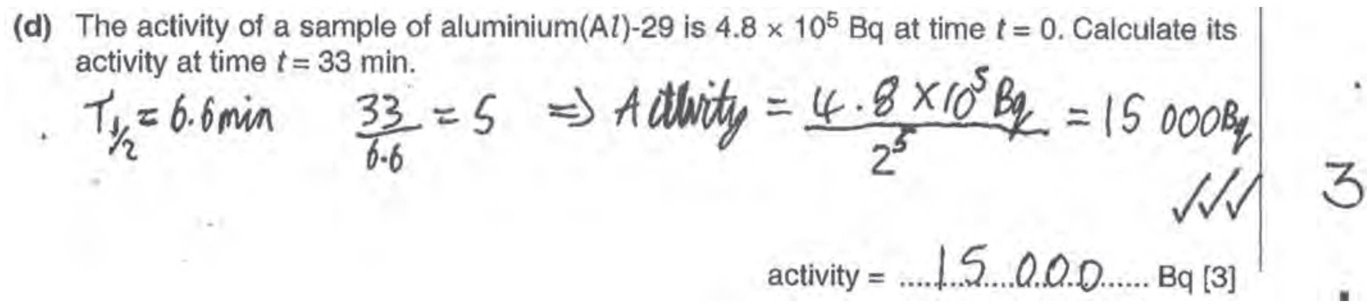
$^{27}_{12}Mg \longrightarrow ^{0}_{-1}e^{\ominus} + \bar{\nu}_e + ^{27}_{13}Al$ ✗✓ [2]

(ii) By counting the number of protons and neutrons on both sides of the equation in **(i)**, deduce what change has taken place in one nuclear particle to produce other particles.

A neutron has become a proton ✓✗ [2] 2

(c) Suggest a nuclear transformation equation for the decay of phosphorus(P)-29 in which a positive electron, called a positron, is emitted.

$^{29}_{15}P \longrightarrow ^{0}_{+1}e^{\oplus} + \nu_e + ^{29}_{14}Si$ ✓✓ [2] 2



(d) The activity of a sample of aluminium(A*l*)-29 is 4.8 × 10^5 Bq at time *t* = 0. Calculate its activity at time *t* = 33 min.

$T_{1/2} = 6.6\text{min} \quad \frac{33}{6.6} = 5 \Rightarrow \text{Activity} = \frac{4.8 \times 10^5 \text{Bq}}{2^5} = 15\,000\text{Bq}$

✓✓✓ 3

activity = ...15 000..... Bq [3]

Examiner Comment

(a) The candidate's answer lists the three stable isotopes of silicon correctly.

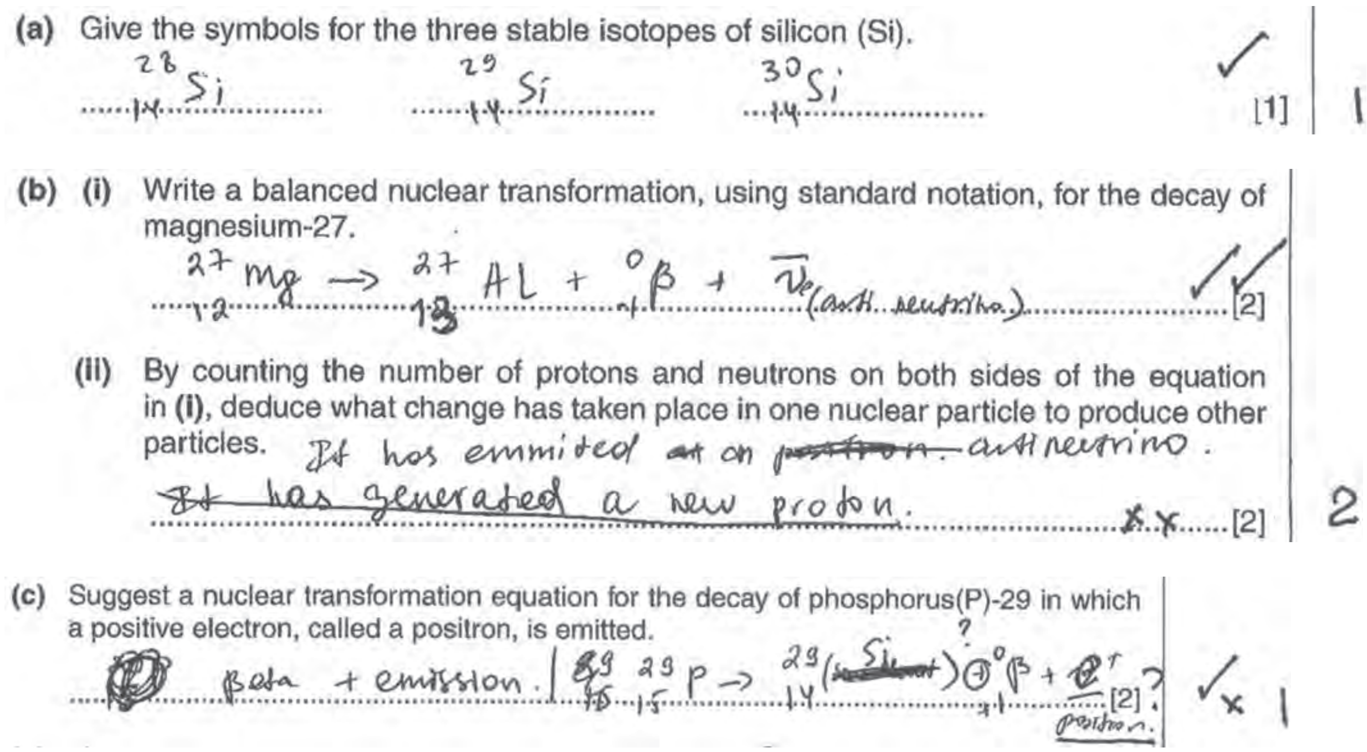
(b) **(i)** A mark is lost because of the negative sign on the ß-particle.

(ii) The candidate is correct to state that a neutron produces a proton but the accompanying electron is not mentioned. Hence only 1 mark is scored by this answer.

(c) The penalty incurred in **(b) (i)** is not reapplied in this case and so, in spite of the positive sign on the ß-particle, full marks are awarded.

(d) The correct calculation leads to the correct answer here.

Example Candidate Response – Pass



(a) Give the symbols for the three stable isotopes of silicon (Si).

$^{28}_{14}Si \qquad ^{29}_{14}Si \qquad ^{30}_{14}Si$ ✓ [1] 1

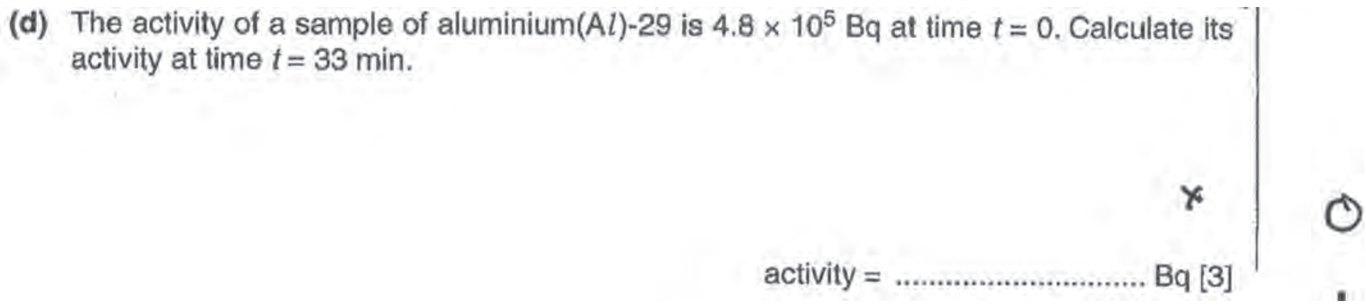
(b) **(i)** Write a balanced nuclear transformation, using standard notation, for the decay of magnesium-27.

$^{27}_{12}Mg \rightarrow {}^{27}_{13}AL + {}^{0}_{-1}\beta + \bar{\nu}_e$ (anti neutrino) ✓✓ [2]

(ii) By counting the number of protons and neutrons on both sides of the equation in **(i)**, deduce what change has taken place in one nuclear particle to produce other particles. It has emmited ~~at~~ an ~~positron.~~ anti neutrino. ~~It~~ has generated a new proton. ✗✗ [2] 2

(c) Suggest a nuclear transformation equation for the decay of phosphorus(P)-29 in which a positive electron, called a positron, is emitted.

Beta + emission. | $^{29}_{15}P \rightarrow {}^{29}_{14}(\text{Si}) \overset{?}{\ominus} {}^{0}_{+1}\beta + e^{+}$? positron. [2] ✓✗ 1



(d) The activity of a sample of aluminium(A*l*)-29 is 4.8×10^5 Bq at time $t = 0$. Calculate its activity at time $t = 33$ min.

✗

activity = ... Bq [3]

0

Examiner Comment

(a) The three correct isotopes are listed.

(b) **(i)** The correct nuclear transformation is listed in the correct manner.

(ii) The candidate merely states that an antineutrino is produced; this, though true, is not sufficient on its own for even 1 mark.

(c) The answer is unclearly set out but the best interpretation would seem to suggest that both a positive ß-particle and a positron are emitted. Although these are the same particle and are, therefore, both correct one particle is emitted and the answer suggests that two are given off.

(d) No answer was offered here.

Question 7 Mark Scheme

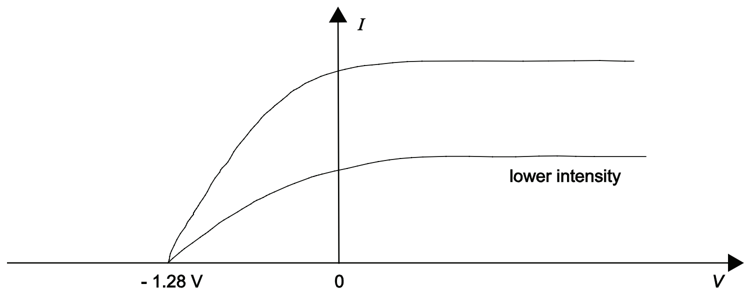
(a) photoelectric (effect) [1]

(b) **(i)** $E = hc/\lambda$ **and** knowing what the symbols stand for (1)
$6.63 \times 10^{-34} \times 3.00 \times 10^{8} / 250 \times 10^{-9} = 7.96 \times 10^{-19}$ (J) (1) [2]

(ii) $7.96 \times 10^{-19} / 1.60 \times 10^{-19} = 4.97$ (eV) [1]

(c) 4.97 eV – 3.69 eV = 1.28 (eV) [1]

(d)



[1]

graph/line for positive **and** negative values of V (1)
constant current for most but not all positive values of V (1)
becoming zero at –1.28 V **or** candidate's value from **(c)** (1) [3]

(e) lower intensity line with smaller values of current (1)
but becoming zero at same point (1) [2]

(f) any **three** of these four comments:
the wave theory makes intensity proportional to amplitude squared (1)
so it was expected that a brighter lamp would give higher energy photoelectrons (1)
here dim light is giving just as energetic photoelectrons as bright light (1) max 3
this cast doubt on the wave theory for electromagnetic radiation (1) [3]

[Total:13]

Example Candidate Response – Distinction

7 A clean magnesium plate is placed in an evacuated glass container and illuminated with ultra-violet radiation of wavelength 250 nm, as shown in Fig. 7.1. Another metal plate is at the opposite end of the container and the two plates are connected through a microammeter to a variable d.c. supply. The polarity of the variable d.c. supply can be reversed.

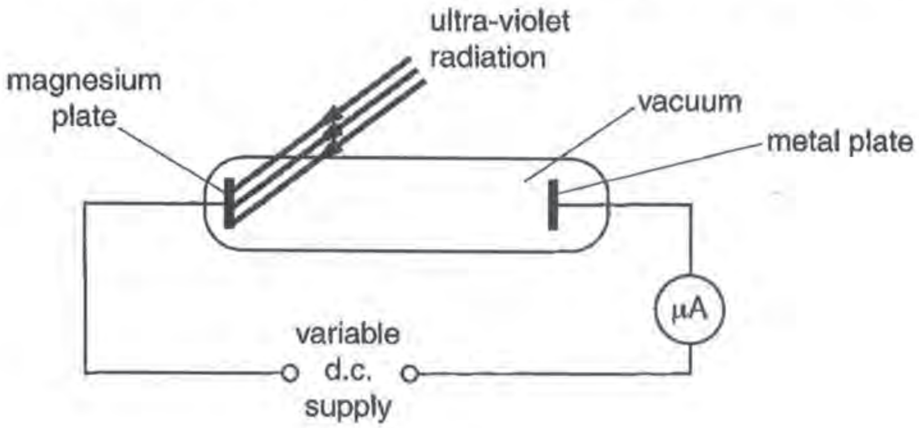


Fig. 7.1

(a) State the name of the effect that causes electrons to be emitted from the magnesium plate.

✓

Photoelectric effect ....[1]
by energetic photons

(b) Calculate the photon energy of the ultra-violet radiation

(i) in joules,

$$E = hf = h\left(\frac{3E8\ m\,s^{-1}}{250\,E-9\ m}\right)$$

$$= 7.956 \times 10^{-19}\ J$$

✓✓

energy = 7.956×10^{-19} J [2]

(ii) in electron-volts.

$$\frac{7.956 \times 10^{-19}\ J}{e}$$

✓

energy = 4.9725 eV [1]

(c) The work function of magnesium is 3.69 eV. Calculate the maximum energy, in eV, of electrons emitted from the magnesium plate.

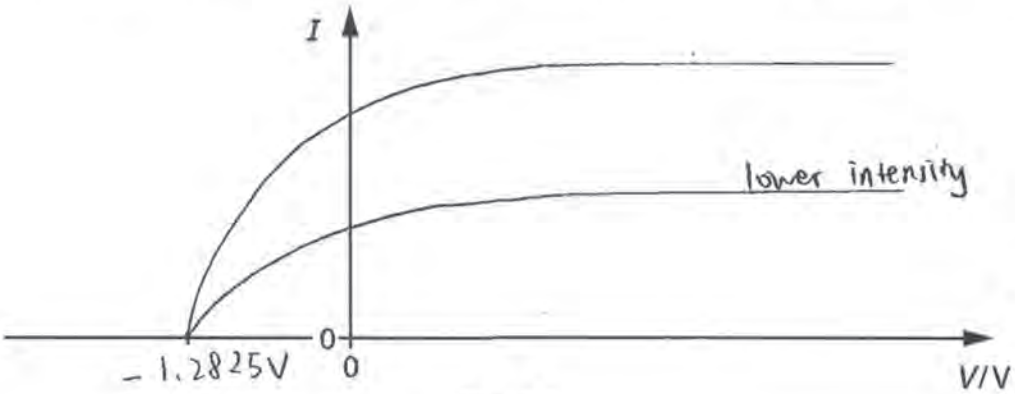
$E_k = hf - hf_0 = 1{\cdot}2825\ eV$

✓

energy = 1.2825 eV [1]

(d) Sketch a graph on the axes of Fig 7.2 to show how the current *I* in the microammeter will vary with the potential difference *V* between the two metal plates.

For Examiner's Use



✓✓✓

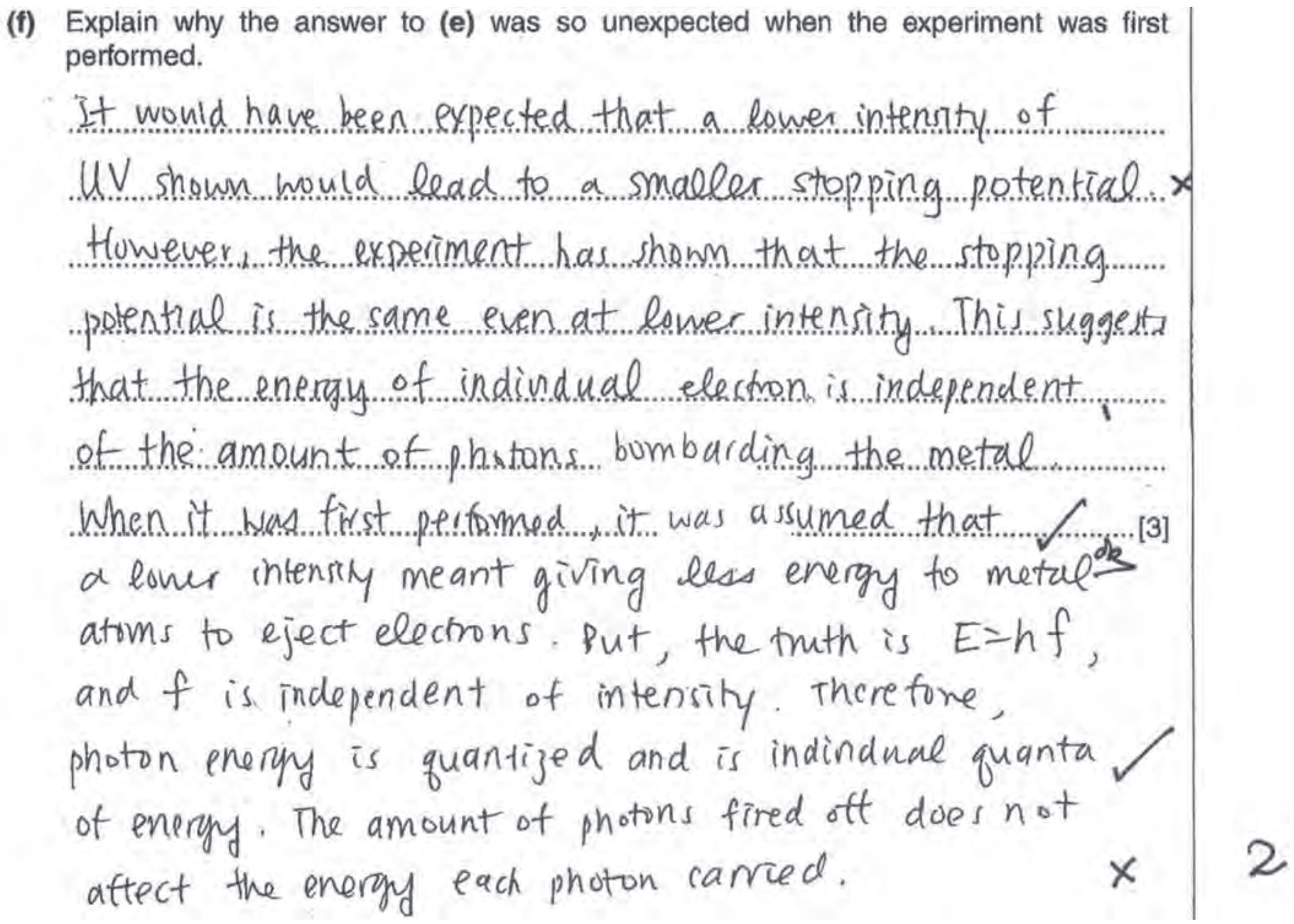
Fig. 7.2

[3]

3

(e) Add another line on your sketch graph to show the effect of reducing the intensity of the ultra-violet radiation. Label this line 'lower intensity'. ✓✓ [2]

2



(f) Explain why the answer to **(e)** was so unexpected when the experiment was first performed.

It would have been expected that a lower intensity of UV shown would lead to a smaller stopping potential. ✗
However, the experiment has shown that the stopping potential is the same even at lower intensity. This suggests that the energy of indindual electron is independent of the amount of photons bombarding the metal.
When it was first performed, it was assumed that ✓ [3]
a lower intensity meant giving less energy to metals atoms to eject electrons. But, the truth is $E=hf$, and f is independent of intensity. Therefore, photon energy is quantized and is indindual quanta ✓ of energy. The amount of photons fired off does not affect the energy each photon carried. ✗

2

Examiner Comment

(a) The candidate produces the only correct answer.

(b) **(i)** The candidate only writes down one of the formulae but assumes the other by substituting numbers correctly. The correct answer is generated. The excess of significant figures is not penalised.

(ii) The conversion to electron volts is correct.

(c) The work function is subtracted from the previous answer to obtain the correct value here.

(d) This section is for the line on the graph that was left unlabelled. The shape of the line scores 2 marks and the value of the stopping voltage is marked on the horizontal axis.

(e) The graph drawn is completely correct.

(f) The candidate only makes two marking points. The relationship between intensity and amplitude is not mentioned and neither is the doubt cast on the wave theory of electromagnetic radiation.

Example Candidate Response – Merit

7 **(a)** State the name of the effect that causes electrons to be emitted from the magnesium plate.

photo electric effect ✓ [1] 1

(b) Calculate the photon energy of the ultra-violet radiation

(i) in joules,

$E = hf \quad f = \frac{c}{\lambda} = \frac{3 \times 10^{8}}{250 \times 10^{-9}} = 1.2 \times 10^{15}$

$E = 6.63 \times 10^{-34} \times 1.2 \times 10^{15} = 8.0 \times 10^{-19}$

energy = 8.0×10^{-19} ✓✓ J [2]

(ii) in electron-volts.

$\frac{8.0 \times 10^{-19}}{1.6 \times 10^{-19}} = \cancel{4}\ 5.0$

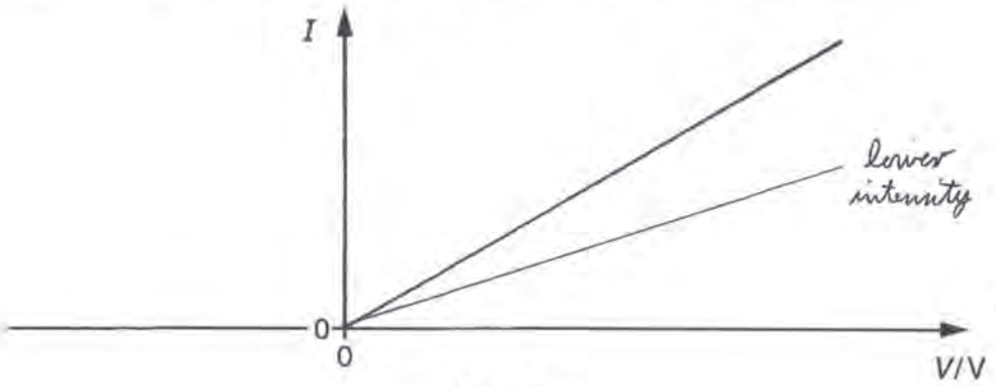
energy = 5.0 ✓ eV [1] 3

(c) The work function of magnesium is 3.69 eV. Calculate the maximum energy, in eV, of electrons emitted from the magnesium plate.

$5.0 - 3.7 = 1.3$

energy = 1.3 ✓ eV [1] 1

(d) Sketch a graph on the axes of Fig 7.2 to show how the current I in the microammeter will vary with the potential difference V between the two metal plates.



× × ×

Fig. 7.2

[3]

(e) Add another line on your sketch graph to show the effect of reducing the intensity of the ultra-violet radiation. Label this line 'lower intensity'. ✓✓ [2] | 2

(f) Explain why the answer to **(e)** was so unexpected when the experiment was first performed.

When ~~[illegible]~~ this experiment was performed for the first time, ✓
light was thought to be a wave only. So by lowering the
intensity, the current was expected to stop at some point.
~~I~~ Since A ~~wave~~ wave would not be able to provide the ×
energy to a single electron to leave the magnesium, so × ×
light must have been transfered in a discrete way. I.e. as
particles. [3]

Examiner Comment

(a) These three sections are correctly answered and where appropriate the working is shown.

(b) **(i)** These three sections are correctly answered and where appropriate the working is shown.

(ii) These three sections are correctly answered and where appropriate the working is shown.

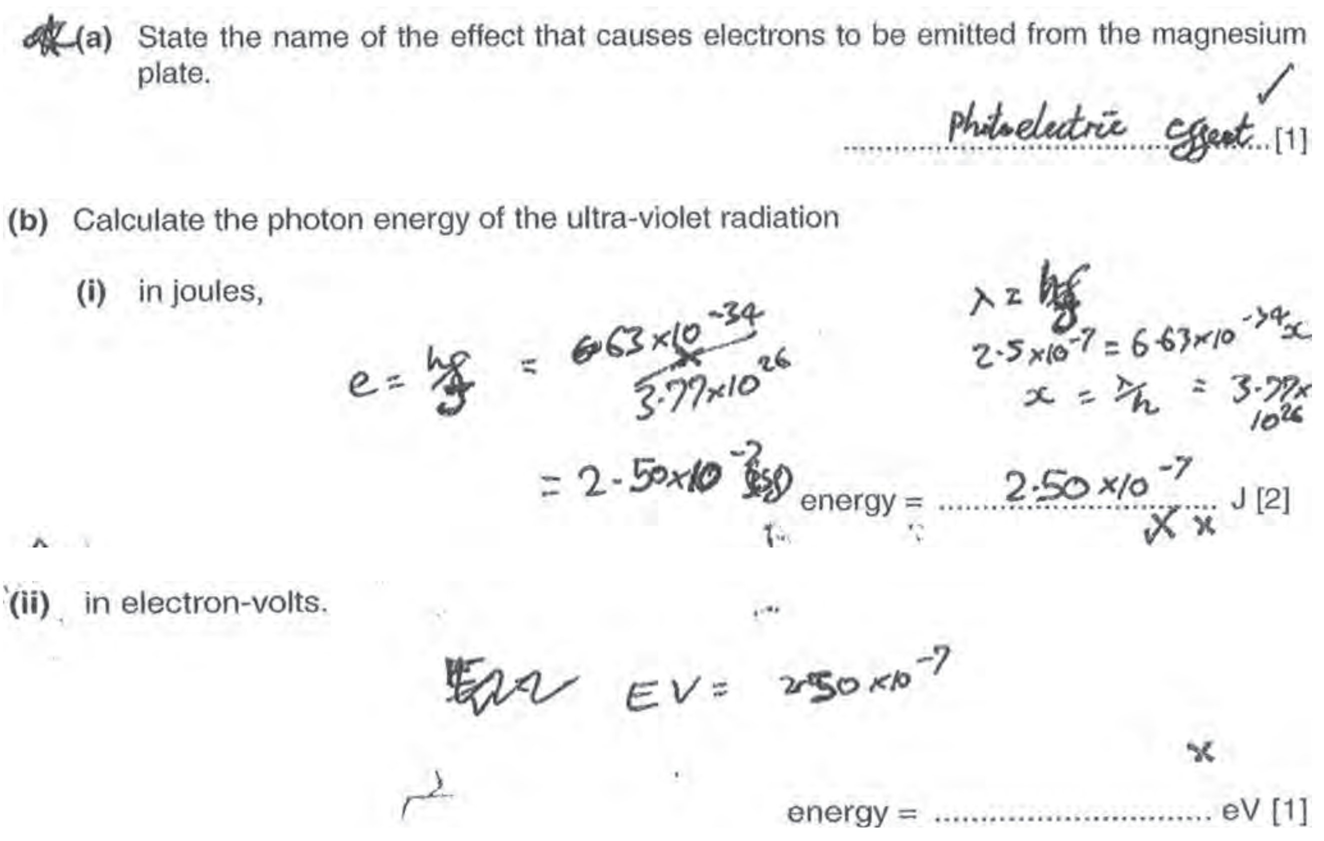
(c) These three sections are correctly answered and where appropriate the working is shown.

(d) The higher line is completely incorrect and makes none of the points from the mark scheme.

(e) The line is wrong but the current values are consistently below those of the previous line and it crosses the axis at the same value of V.

(f) In the first sentence, the candidate implies that the wave theory was shown to be inadequate by this effect.

Example Candidate Response – Pass



(a) State the name of the effect that causes electrons to be emitted from the magnesium plate.

Photoelectric effect ✓ [1]

(b) Calculate the photon energy of the ultra-violet radiation

(i) in joules,

$e = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}}{3.77\times10^{26}}$

$= 2.50\times10^{-7}$

$\lambda = \frac{h}{f}$

$2.5\times10^{-7} = 6.63\times10^{-34}x$

$x = \frac{\lambda}{h} = 3.77\times10^{26}$

energy = 2.50×10^{-7} J [2] ✗ ✗

(ii) in electron-volts.

~~Eav~~ EV = 2.50×10^{-7}

✗

energy = ... eV [1]

(c) The work function of magnesium is 3.69 eV. Calculate the maximum energy, in eV, of electrons emitted from the magnesium plate.

$\underline{\Phi} + \frac{1}{2} m v_{max}^2$

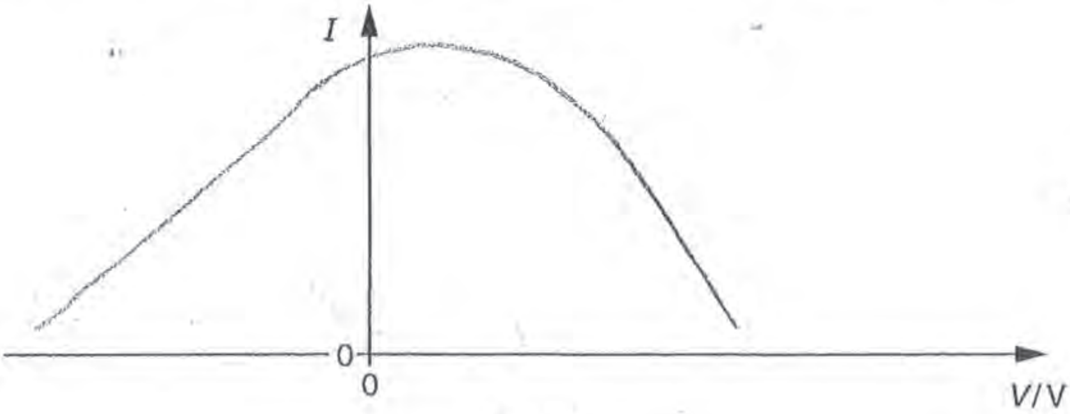
$\uparrow$

hf

✗

energy = ... eV [1]

(d) Sketch a graph on the axes of Fig 7.2 to show how the current *I* in the microammeter will vary with the potential difference *V* between the two metal plates.



✓ ✗ ✗

Fig. 7.2

✗ ✗ ✓ Amplitude [3] No bend

✗ ✗ ✓ Amplitude [3] No bend

0

(e) Add another line on your sketch graph to show the effect of reducing the intensity of the ultra-violet radiation. Label this line 'lower intensity'. [2]

(f) Explain why the answer to **(e)** was so unexpected when the experiment was first performed.

.... [3]

Examiner Comment

(a) This answer is correct.

(b) **(i)** The candidate does not use the correct formula and does not rearrange the formula correctly.

(ii) No attempt is made to convert the previous answer to electron-volts.

(c) The candidate does not produce a serious attempt at obtaining an answer.

(d) The line bears very little relation to the correct one but it does have current values for both positive and negative potential differences.

(e) No answer attempted.

(f) The candidate writes amplitude2 near to the word intensity in **(e)** but since this does not seem to be related to this section, no mark could be awarded.

Question 8 Mark Scheme

(a) **(i)** 1. velocity/speed increases with **time** / **rate** of change of velocity/speed (1)
2. 49(.0/1) **and** 200(196) (**n.b.** unit given in question) (1)

(ii) increasing gradient (1)
initial gradient zero (1)
clear **attempt** at correct final gradient **or** angle to vertical ≤ 20° (1) [5]

(b) **(i)** 54(.0) m **cao.** (1)

(ii) the aeroplane is travelling **very / extremely** fast
or (large distance in) short time
or time (for given distance) is inversely related to acceleration
or the pilot has a short time (to clear the tailplane) (1)
pilot must miss the empennage/tailplane/clear the aeroplane etc. (1) [3]

(c)

Momentum Conservation Method:	**Newton's Third Law Method:**		
gas (emerges with) downwards momentum	downwards force on gas	(1)	
conservation of momentum	upwards force (on cylinder/seat)	(1)	
(rest of) seat/cylinders gains upwards momentum	force upwards greater than weight	(1)	[3]

(d) **(i)** the pilot does not collide with/problem with the rotor blades (1)

(ii) (the parachute has to) slow down a fast/downwards moving object
or slow down in a short time (1)
before the pilot hits the ground / pilot too low (1)[3]

(e) **(i)**

Force, Impulse Method:	**Velocity, Acceleration Method:**	
(F =) 380 × 10 × 9.81/3.7(297) × 10^4	(v =) 1800/380 **or** 4.7(36842105)	(1)
I = Ft **or** 1800 / (380 × 10 × 9.81)	(t =) v/a	
or (t =) I/F **or** 1800/3.7(278) × 10^4	**or** 4.7(36842105)/(10 × 9.81)	(1)

0.048(28585225) s (allowing for weight of pilot and seat) (0.0439 s scores 2/3) (1)

(ii) smaller acceleration/onset rate/force **not** jerk (1) [4]

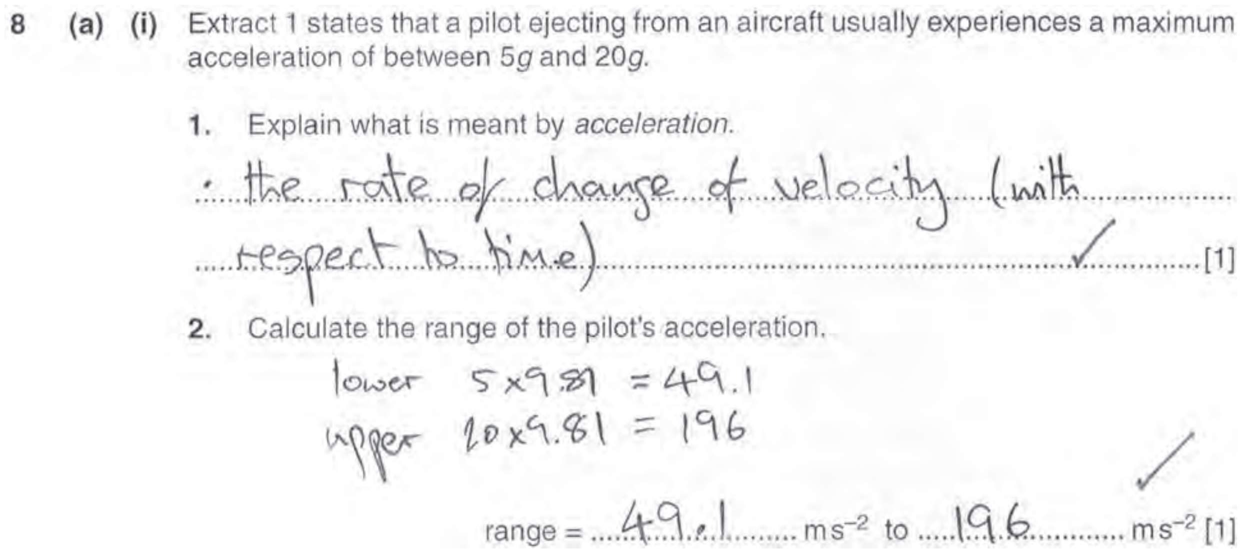
(f) **financial consequences:**
seats/helmets/parachutes/training expensive (to buy/install/maintain etc.) / not economically viable (1)
seats heavy (much heavier than a passenger) **or** bulkier (1)
fewer passengers/less income **or** more fuel (1)

hazards:
passengers untrained/unaware of danger / hull needs to be breached (1)
accidental operation possible (1)
rocket fuel highly flammable (1)
bolts/rocket ejecta etc hot/fast moving/dangerous (1)
forces/acceleration causes injury (1)
low oxygen pressure / cabin depressurized / low temperature (1)
some passengers elderly/unfit/sick/children/babies/disabled/obese (1)
flailing limbs/possessions/collisions cause injury (1)

practicality:
entire aeroplane roof needs to be removed first (1)
many passengers ejecting at once (1)
most accidents occur on take-off/landing/low altitude (1)
does not protect against all risks (1)
civilian airliner less likely to be target/in danger/less likely to crash (1)
delay before ejection (1)
tail fin higher (in commercial jet) (1)
seats designed for a particular weight / seats need to be adjusted for weight (1)
passengers belted up for the entire journey (1)
no hand luggage / no overhead lockers (1)
[max 7]

[Total: 25]

Example Candidate Response – Distinction



8 (a) (i) Extract 1 states that a pilot ejecting from an aircraft usually experiences a maximum acceleration of between 5*g* and 20*g*.

1. Explain what is meant by *acceleration*.

· the rate of change of velocity (with respect to time) ✓ [1]

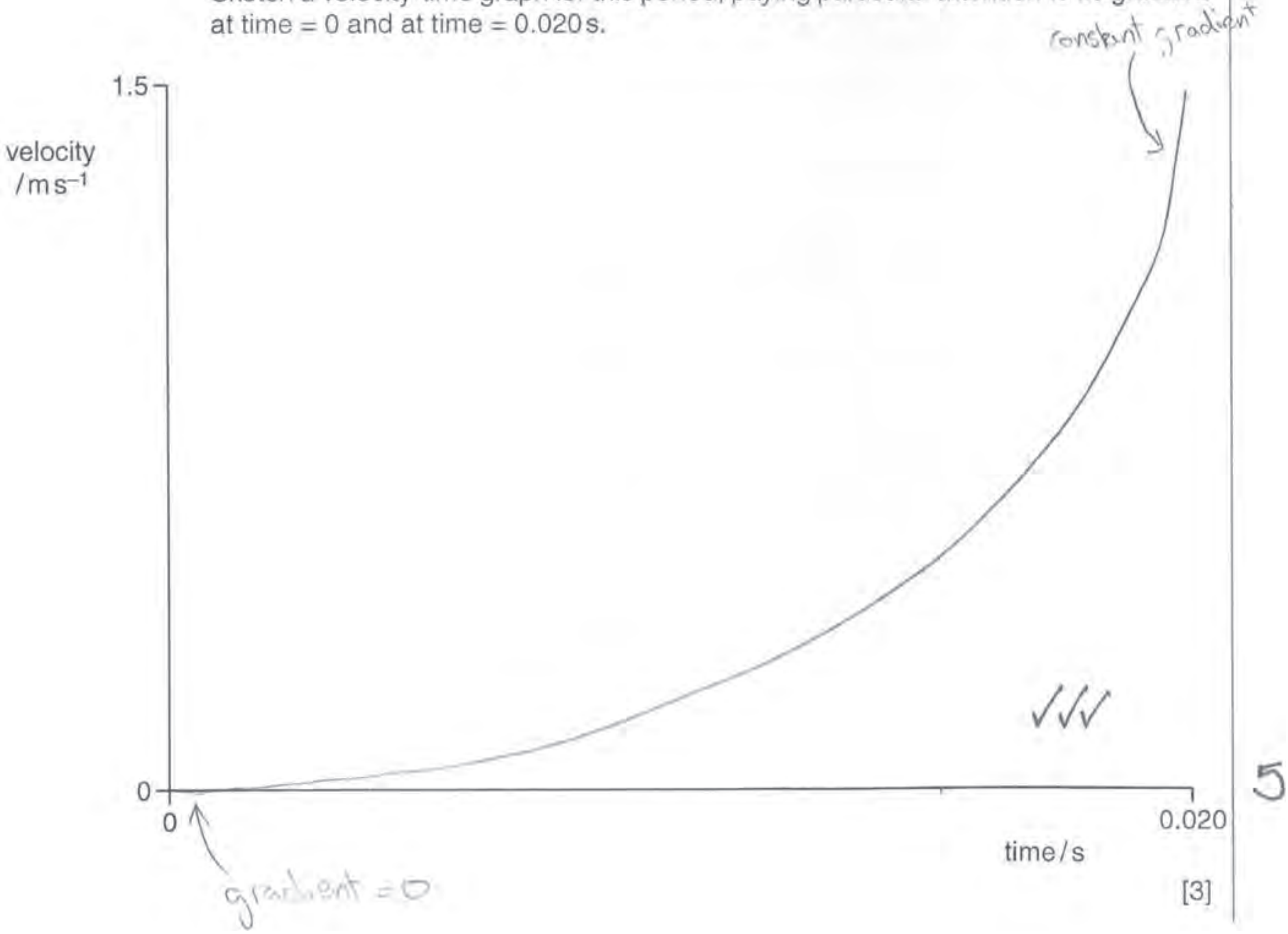
2. Calculate the range of the pilot's acceleration.

lower 5×9.81 = 49.1
upper 20×9.81 = 196
✓

range = 49.1 ms^{-2} to 196 ms^{-2} [1]

(ii) An ejecting pilot does not reach the maximum upwards acceleration immediately. In Extract 2, the onset rate of one ejector seat is such that the acceleration takes 0.020 s to increase from 0 to 16*g*. At 0.020 s, the velocity of the pilot is 1.5 m s^{-1}.

Sketch a velocity-time graph for this period, paying particular attention to its gradient at time = 0 and at time = 0.020 s.



[3]

5

(b) Extract 3 explains how an explosive cartridge in a catapult gun accelerates the seat up guide rails. Within 150 ms, a pilot using an ejector seat such as this is clear of the guide rails and has travelled more than 1.60 m upwards. Extract 4 mentions pilots who have ejected safely from aeroplanes travelling at more than 360 m s^{-1}.

(i) Calculate the distance travelled by an aircraft travelling at 360 m s^{-1} in 150 ms.

$s = ut = 360 \times 150 \times 10^{-3} = 54$

✓

distance = 54 m [1]

(ii) The large acceleration experienced during ejection may seriously injure the pilot. Explain why such large accelerations are necessary.

• plane moving very fast • if not moving sufficiently fast upwards pilot will not clear the tail of plane ∴ have to accelerate to high speed in v. short time ⇒ v. ~~short~~ large acceleration required as $\frac{\Delta v}{\Delta t}$ is large **[2]**

✓✓ 3

(c) Extract 5 refers to the use of rocket propulsion in modern ejector seats. When the rockets fire, a large mass of extremely hot gas is expelled downwards at an extremely high speed. Explain, in detail, how this causes the ejector seat to move upwards.

• the seat gives large amount of gas downward momentum in a short time • force is rate of change of momentum (by Newton's 2nd Law) ∴ seat exerts large force on gas ⇒ gas exerts large equal + opposite force on seat ⇒ seat accelerates upwards **[3]**

✓✓✗ 2

(d) Extract 4 mentions one design of ejector seat, in which the aircraft floor is jettisoned and the seat is ejected downwards through the gap.

(i) State why it is this type of ejector seat that is used in many helicopters.

• the spinning rotor blades could be very dangerous if ejected upwards ✓ **[1]**

(ii) Explain the problems encountered when ejector seats of this design are to be used at low altitude.

• pilot ejected v. close to ground • not enough time to deploy parachute + steady the fall, means a large likelihood of injury • pilot still accelerating fast when landing on ground – large force ⇒ injury **[2]**

✓✓ 3

(e) **(i)** A pilot of mass 80 kg is strapped into an ejector seat of mass 300 kg. The pilot ejects and an explosive cartridge exerts an 1800 N s impulse on the seat. The seat and pilot accelerate upwards at rate of 10*g*.

Assuming that the force that the explosive cartridge exerts on the seat remains constant as it is being fired, calculate the time for which the force is acting.

$M_{total} = 380\text{ kg}$ $I = 1800\text{ Ns}$ $a = 10g$

$F = ma = 380 \times 10 \times 9.81 = 37278\text{ N}$

$I = Ft$

$t = \frac{I}{F} = \frac{1800}{37278} = 0.0483$

✓✓✓

time = 0.0483 s [3]

(ii) Fig. E3.3 in Extract 3 refers to a rocket with a burn time of 0.30 s. Explosive cartridges, however, exert a force for a much shorter period of time.

Suggest one advantage of using this rocket to propel an ejector seat rather than an explosive cartridge.

- force acts over longer time as impulse is const. ⇒ reduced acceleration ⇒ reduced chance of injury ✓ [1]

4

(f) Since their introduction, ejector seats in military aircraft have saved the lives of several thousand crew members. No commercial airliners, however, are fitted with ejector seats for use by either the passengers or the crew. By considering

- the financial consequences,
- the hazards,
- the operational practicality

of such a system, suggest why this is so.

You may use information from any of the extracts.

- ejector seats are very expensive
  - some cost up to £100,000 each ✓
  - propellants, rocket fuel etc also very expensive
  - as they take up more room ⇒ less seats per flight ⇒ less passengers per flight ⇒ airlines earn less money ✓
  - v. heavy ⇒ more fuel required ⇒ expensive ✓
- hazardous to use
  - pilots require health checks, need to be extremely fit to survive, whereas passengers wouldn't be able to survive lower oxygen pressure ✓
  - loose items would fly around causing damage ✓
  - multiple ejections could lead to mid air collisions ✓
  - variable weights of passengers may lead to too little or to great an acceleration ✓
  - large amounts of pyrotechnics for the seat are dangerous to store

- impractical to operate

– large amounts of training required to use – how could this be given to passengers?

– passengers would have to wear belts all flight [7]

– no underseat storage or baggage compartments to allow adequate clearance

– airplane would have to be redesigned and remanufactured to support these seats

∴ for these reasons, it seems implausable to install ejector seats on commerial airlines, and this is why <u>no</u> commercial airliners <u>are</u> fitted with them.

7

Examiner Comment

(a) **(i)** 1. The candidate defines acceleration correctly.
2. The values offered by the candidate are correct.

(ii) The shape of the graph is correct and a clear attempt is made to get the final gradient correct.

(b) **(i)** The answer given is correct.

(ii) The candidate explains the answer and scores both marks.

(c) The candidate scores 2 marks by using a Newton's Third Law approach but does not state that the force upwards on the seat is greater than its weight.

(d) **(i)** This answer is good enough to score the mark.

(ii) Again, the points made correspond to those on the mark scheme and full credit is awarded.

(e) **(i)** The candidate does not take into consideration the weight of the seat and pilot but is still awarded all 3 marks, in accordance with the mark scheme.

(ii) The answer given makes the point expected and the mark is awarded.

(f) The mark scheme lists many different points that could be made here and this candidate makes an encouragingly large number of them. The first seven of these points are enough to ensure that full marks are awarded here.

Example Candidate Response – Merit

8 **(a)** **(i)** Extract 1 states that a pilot ejecting from an aircraft usually experiences a maximum acceleration of between 5*g* and 20*g*.

1. Explain what is meant by *acceleration*.

rate of change of velocity

or change in velocity / time. ✓ [1]

2. Calculate the range of the pilot's acceleration.

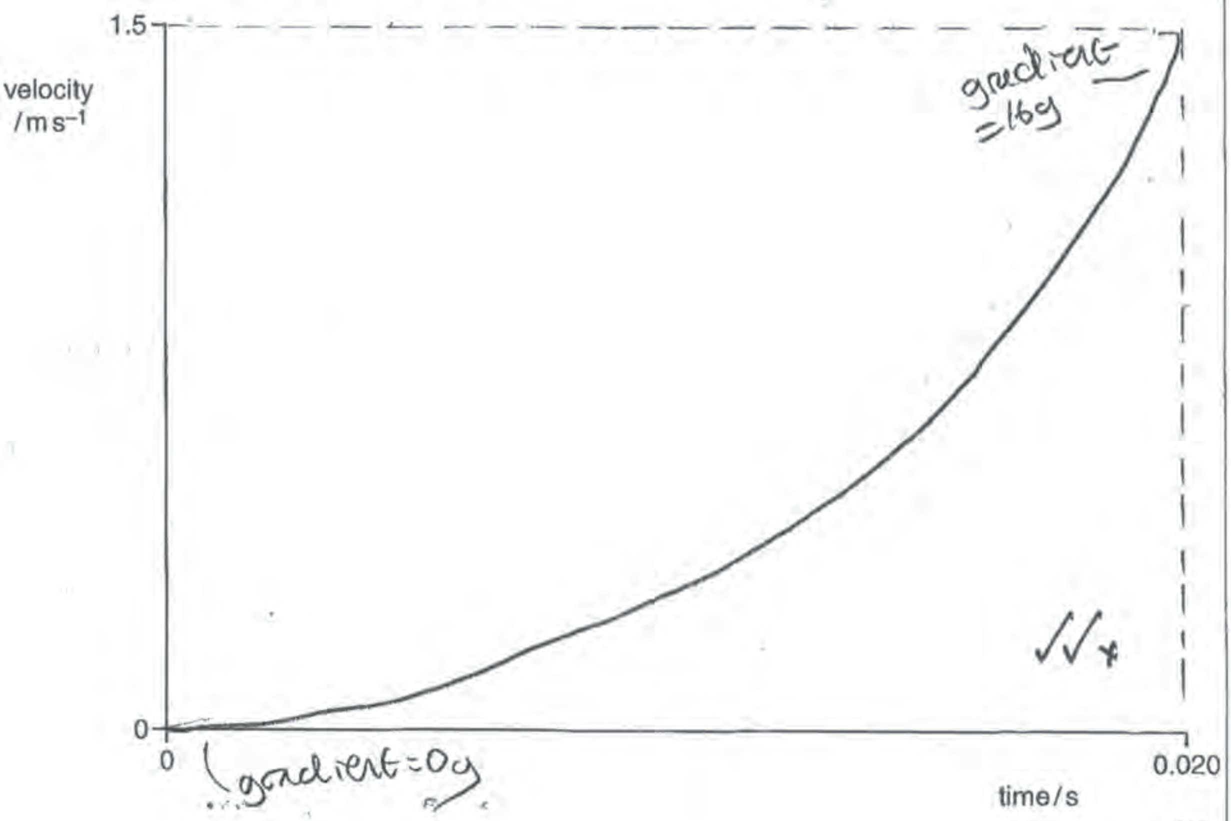
5×9.81
$= 49.05\,\text{ms}^{-2}$

20×9.81
$= 196.2$ ✓

range = 49.05 $\text{m}\,\text{s}^{-2}$ to 196.2 $\text{m}\,\text{s}^{-2}$ [1]

(ii) An ejecting pilot does not reach the maximum upwards acceleration immediately. In Extract 2, the onset rate of one ejector seat is such that the acceleration takes 0.020 s to increase from 0 to 16*g*. At 0.020 s, the velocity of the pilot is 1.5 $\text{m}\,\text{s}^{-1}$.

Sketch a velocity-time graph for this period, paying particular attention to its gradient at time = 0 and at time = 0.020 s.



[3]

4

(b) Extract 3 explains how an explosive cartridge in a catapult gun accelerates the seat up guide rails. Within 150 ms, a pilot using an ejector seat such as this is clear of the guide rails and has travelled more than 1.60 m upwards. Extract 4 mentions pilots who have ejected safely from aeroplanes travelling at more than 360 m s^{-1}.

(i) Calculate the distance travelled by an aircraft travelling at 360 m s^{-1} in 150 ms.

velocity = $\frac{\text{distance}}{\text{time}}$ $v = \frac{s}{t}$ $\therefore$ $s = 360\,\text{ms}^{-1} \times 150\times10^{-3}\,\text{s}$

$= 54\,\text{m}$

✓

distance = 54 m [1]

(ii) The large acceleration experienced during ejection may seriously injure the pilot. Explain why such large accelerations are necessary.

This is to ensure that the ejector seat quickly exits the aircraft ensuring that the pilot does not hit the tail of the plane. If the pilot does not have a quick enough ejection he may die. The purpose is 'survival not comfort'. ✗ [2] ✓ 2

(c) Extract 5 refers to the use of rocket propulsion in modern ejector seats. When the rockets fire, a large mass of extremely hot gas is expelled downwards at an extremely high speed. Explain, in detail, how this causes the ejector seat to move upwards.

This is essentially Newton's laws. The large mass of extremely hot gas is expelled downwards and thus exerts a force over an area (pressure) ✓ and this causes an equal and opposite force ✓ causing the pilot to accelerate upwards (hence high speed). The collision of molecules causes a change in momentum and that is how the force is applied by the gas. [3] ✗ 2

(d) Extract 4 mentions one design of ejector seat, in which the aircraft floor is jettisoned and the seat is ejected downwards through the gap.

(i) State why it is this type of ejector seat that is used in many helicopters.

This is to avoid the rotating blades at the top of the helicopter which if a collision occured could well result in death. Thus below is safer. ✓ [1]

(ii) Explain the problems encountered when ejector seats of this design are to be used at low altitude.

If ejection is downwards this means velocity downwards is greater and thus there will be less time to slow down this means impact with the Earths surface would be large and potentially fatal. ✓ ✓ [2]

3

(e) **(i)** A pilot of mass 80 kg is strapped into an ejector seat of mass 300 kg. The pilot ejects and an explosive cartridge exerts an 1800 N s impulse on the seat. The seat and pilot accelerate upwards at rate of 10*g*.

Assuming that the force that the explosive cartridge exerts on the seat remains constant as it is being fired, calculate the time for which the force is acting.

Total mass = 380

$$\text{Impulse} = F \times t$$

$$F = ma \qquad \therefore \text{Impulse} = m.a.t = 1800$$

$$\therefore 380\text{kg} \times 10g \times t = 1800\text{Ns}$$

$$\therefore t = \frac{1800}{380 \times 10 \times 9.81} = 0.048\text{sec}$$

✓✓✓

time = 0.048 seconds (2sf) [3]

(ii) Fig. E3.3 in Extract 3 refers to a rocket with a burn time of 0.30 s. Explosive cartridges, however, exert a force for a much shorter period of time.

Suggest one advantage of using this rocket to propel an ejector seat rather than an explosive cartridge.

a rocket can concentrate the force in one direction and an explosive cartridge is in all directions, thus less effective and more dangerous. ✗ [1]

3

(f) Since their introduction, ejector seats in military aircraft have saved the lives of several thousand crew members. No commercial airliners, however, are fitted with ejector seats for use by either the passengers or the crew. By considering

- the financial consequences,
- the hazards,
- the operational practicality

of such a system, suggest why this is so.

You may use information from any of the extracts.

Ejector seats are used widely in military aircraft. However in commercial or frieght flights this is not the case. Some ejector seats cost up to £100,000 each and thus it is important to analyse both the costs and benefits of using such ~~a~~ a system. There is clearly a trade off between risk and expensive safety.

In military aircraft clearly the chances of using an ejector ✓ seat is much higher as there may be instances of air battle combat. Thus the chances of it being used for effect are higher. Also military ✓ pilots are well trained and physically fit and so the chances of survival on impact on the earth will be much higher. A vertical force of 12-22g clearly is a significant amount, a force of up to 15700N. Non military personnel such as passengers in commercial airlines are less likely to survive ejection ✗ or impact. ^

With commercial planes there are also practical considerations to weigh up against financial costs. There are upto 800 passengers on an Airbus A-380 and thus the cost of using an ejection seats could ✓ be just £80 million for just one plane. The planes are also ~~more~~ less likely to require ejector seats [7] as air passenger safety is always a number one priority according to most airlines. Thus the planes have much more safety equipment than military aircraft. As they are also normally larger this means they are less susceptable to accidents. The practicallity of fitting hundreds of ejector seats would mean that the roof of the plane would have to be lower and that the seats would be less comfortable (no first class would be available!).

Thus both the costs and practical issues mean that it is not feasible for ejector seats to be put in passenger aircraft. The hazards /costs do not outweigh the benefits and low risk of it being needed. However, in military aircraft, they are clearly very important. Martin Baker seats saved 7028 lives by 2008. Military aircraft are designed for fighter combat and thus comfort is not a priority. The physical conditions endured when a pilot is ejected requires physical training and a certain level of fittness. For this to happen in passenger flights would involve discrimination against less physically fit people ✓ Thus on balance, by considering the financial consequences, danger hazards and the practicality in both cases it is clear to see how a conclusion of only using ejector seats in military, and not commercial flights can be reached.

28

4

Examiner Comment

(a) **(i)** 1. The candidate defines acceleration correctly.
2. The values offered by the candidate are correct.

(ii) The shape of the graph is correct but although the final gradient is marked 16g, it is clearly too shallow.

(b) **(i)** The answer given is correct.

(ii) No reference is made here to the high speed at which the aeroplane is travelling and only the second mark is awarded.

(c) The candidate scores 2 marks by using a Newton's Third Law approach but does not state that the force upwards on the seat is greater than its weight.

(d) **(i)** This answer is clearly good enough to score the mark here.

(ii) Again, the points made correspond to those on the mark scheme and full credit is awarded.

(e) **(i)** The candidate does not take into consideration the weight of the seat and pilot but is still awarded all 3 marks, in accordance with the mark scheme.

(ii) The answer given does not address the point of the question which is about the onset rate of the acceleration.

(f) Although this answer is lengthy and detailed, it does not make enough separate points to score full marks. Essentially, the points made are described in such detail that not enough points were raised.

Example Candidate Response – Pass

8 **(a)** **(i)** Extract 1 states that a pilot ejecting from an aircraft usually experiences a maximum acceleration of between $5g$ and $20g$.

1. Explain what is meant by *acceleration*.

acceleration is the change in ~~th~~ speed divided by the time gap, the speed change ✓ to occur. [1]

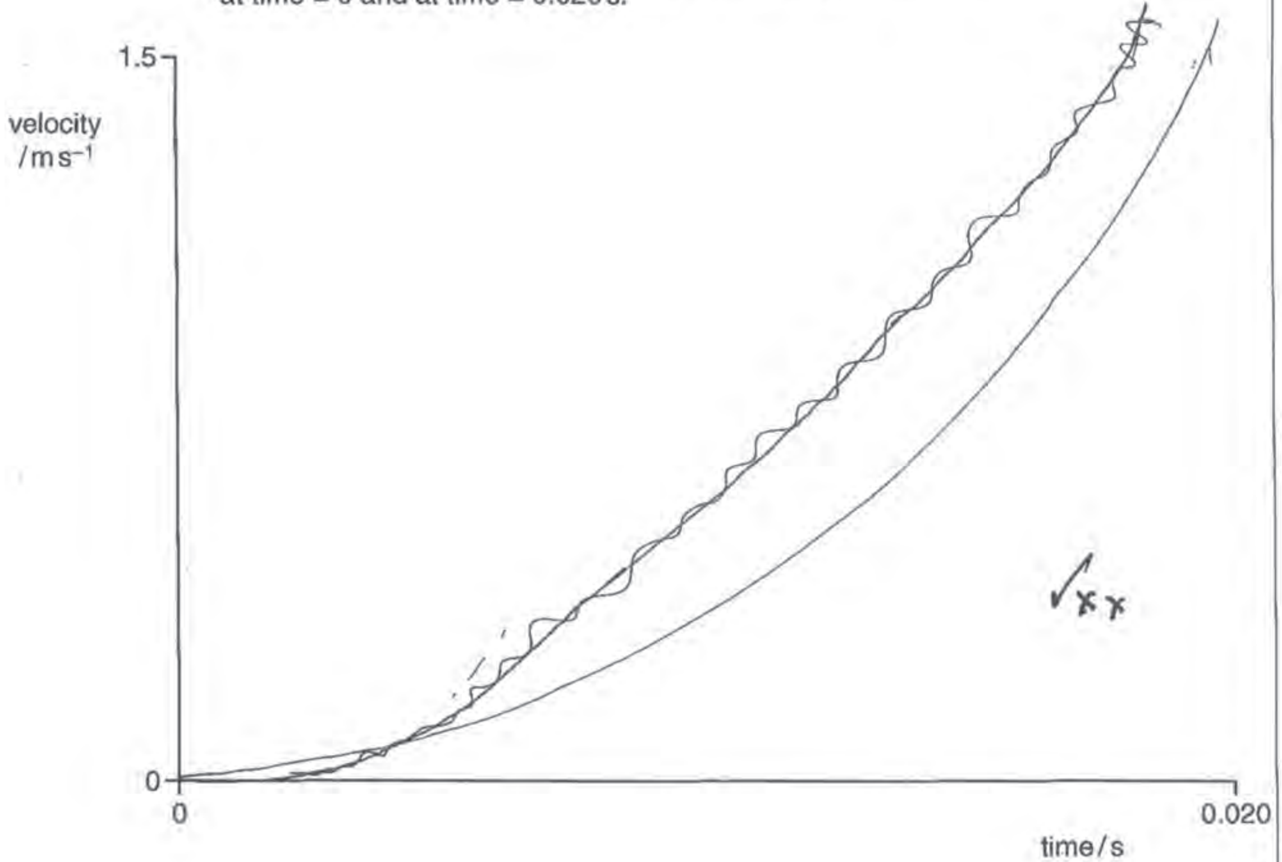
2. Calculate the range of the pilot's acceleration.

✓

range = 49.05 $\mathrm{m\,s^{-2}}$ to 196.2 $\mathrm{m\,s^{-2}}$ [1]

(ii) An ejecting pilot does not reach the maximum upwards acceleration immediately. In Extract 2, the onset rate of one ejector seat is such that the acceleration takes 0.020 s to increase from 0 to 16*g*. At 0.020 s, the velocity of the pilot is 1.5 m s^{-1}.

Sketch a velocity-time graph for this period, paying particular attention to its gradient at time = 0 and at time = 0.020 s.



3

[3]

(b) Extract 3 explains how an explosive cartridge in a catapult gun accelerates the seat up guide rails. Within 150 ms, a pilot using an ejector seat such as this is clear of the guide rails and has travelled more than 1.60 m upwards. Extract 4 mentions pilots who have ejected safely from aeroplanes travelling at more than 360 m s^{-1}.

(i) Calculate the distance travelled by an aircraft travelling at 360 m s^{-1} in 150 ms.

$s = \frac{d}{t}$

$d = s \times t$

$d = 360 \times 150 \times 10^{-6} = 0.054$

x

distance = 0.054 m [1]

(ii) The large acceleration experienced during ejection may seriously injure the pilot. Explain why such large accelerations are necessary.

If the ~~accel~~ ~~speed~~ acceleration of the pilot out of cockpit is not fast enough ~~ba~~ he could hit the tail fin. ✗✓ [2] 1

(c) Extract 5 refers to the use of rocket propulsion in modern ejector seats. When the rockets fire, a large mass of extremely hot gas is expelled downwards at an extremely high speed. Explain, in detail, how this causes the ejector seat to move upwards.

when the rockets fire the large amount of ~~heat~~ hot gas escapes this causes thrust as the atoms in the hot gas are moving extremly fast compared to the cold gas around this forces the ejector seat upwards at a tremendous speed. ✗✓✗ [3] 1

(d) Extract 4 mentions one design of ejector seat, in which the aircraft floor is jettisoned and the seat is ejected downwards through the gap.

(i) State why it is this type of ejector seat that is used in many helicopters.

in a helicopter there are blades that the pilot could hit if he went out the top. ✓ [1]

(ii) Explain the problems encountered when ejector seats of this design are to be used at low altitude.

if they eject at lower altitude there is a risk that the seat will not get you high enough for the parachute to function. ✗✗ [2] 1

(e) **(i)** A pilot of mass 80 kg is strapped into an ejector seat of mass 300 kg. The pilot ejects and an explosive cartridge exerts an 1800 N s impulse on the seat. The seat and pilot accelerate upwards at rate of 10*g*.

Assuming that the force that the explosive cartridge exerts on the seat remains constant as it is being fired, calculate the time for which the force is acting.

~~I = mas~~

I = Force x time

~~$\frac{1800}{380} = v = 4.7\ m s^{-1}$~~

~~1800m~~

I = $\frac{mv}{~~[illegible]~~}$ = ~~[illegible]~~

× ✓ ×

F = ma

$\frac{1800}{380}$ =

time = 0.00261 s [3]

(ii) Fig. E3.3 in Extract 3 refers to a rocket with a burn time of 0.30 s. Explosive cartridges, however, exert a force for a much shorter period of time.

Suggest one advantage of using this rocket to propel an ejector seat rather than an explosive cartridge. ✗

the explosive charges will create a faster exit from the air craft [1]

(f) Since their introduction, ejector seats in military aircraft have saved the lives of several thousand crew members. No commercial airliners, however, are fitted with ejector seats for use by either the passengers or the crew. By considering

- the financial consequences,
- the hazards,
- the operational practicality

of such a system, suggest why this is so.

You may use information from any of the extracts.

Firstly it is very expensive to install ejector seats ✓ into all seats on a plane. ~~There~~ on a comertial flight there are people of all sizes from babies to adults ✓ it is unlikely that all people on board will be able to withstand up to 20g's there are ✓ other issues such as how ~~th~~ is it possible to eject that number of people without causing injury, also people at the back of the plane must have a faster exit due to large tail fins. ✓ The tail fin is also much larger on a commercial liner than it is in a fighter jet.

[7]

4

Examiner Comment

(a) **(i)** 1. The candidate defines acceleration correctly.
2. The values offered by the candidate are correct.

(ii) Only the shape of the graph is correct; the initial gradient is greater than zero and the final gradient is too shallow.

(b) **(i)** The answer given is not correct; the candidate interprets 1.0 ms to mean 1.0×10^{-6} s.

(ii) The candidate only refers to the possibility of a collision and not to the high speed of the aircraft.

(c) There is no explanation here although the candidate does refer to an upwards force on the seat.

(d) **(i)** The candidate offers a simply worded and direct answer to the question asked and scores the mark.

(ii) The candidate does not produce an answer that has any particular reference to a downwards ejecting seat.

(e) **(i)** The candidate quotes a relevant formula I = force × time, but cannot use it correctly in this context.

(ii) The candidate has not understood the point that is being demanded.

(f) This is not a long answer, in terms of words, but the points made are direct and relevant. There are, however, too few points made for full marks to be awarded.

Paper 3 Part B Written Paper

Question 1 Mark Scheme

(a) **(i)** speed = $2\pi \times 148.1 \times 10^{9} / 365.25 \times 86400 = 29.5\ \text{km s}^{-1}$ (1) [1]

(ii) acceleration = v^{2} / r with v from **(i)** and r = 148.1×10^{9} (1)
$= 5.87 \times 10^{-3}\ \text{m s}^{-2}$ (1) [2]

(b) **(i)** 1 force = GMM_{e} / r^{2} with correct meaning of symbols (1)
$= 6.67 \times 10^{-11} \times 200 \times 5.98 \times 10^{24} / (1.51 \times 10^{9})^{2} = 3.499 \times 10^{-2}\ \text{N}$ (1)

2 force = $6.67 \times 10^{-11} \times 200 \text{ x } 1.99 \times 10^{30} / (148.1 \times 10^{9})^{2} = 1.210\ \text{N}$ (1) [3]

(ii) $1.210 - 0.035 = 1.175\ \text{N}$ (1) [1]

(c) centripetal acceleration = $F / m = 1.175\ \text{N} / 200\ \text{kg}$ (1)
$= 5.875 \times 10^{-3}\ \text{m s}^{-2}$ (towards the Sun) in agreement with **(a)(ii)** (1) [2]

(d) **(i)** the Sun is always visible to it (1)
because it does not go into the shadow of the Earth (as an Earth satellite would) (1) [2]

(ii) it is in unstable equilibrium / not a circular orbit / other influences (1)
so small changes of position would increase if not corrected (1) [2]
(allow 1 mark for less precise explanations)

(iii) it has greater potential energy than a geostationary satellite (1)
so rocket and fuel costs are greater (1) [2]
Alternatives greater speed and k.e. / further from Earth than geostationary

[Total: 15]

Example Candidate Response – Distinction

1 A satellite of mass 200 kg is placed between the Earth and the Sun. The satellite is at a distance of 1.51×10^9 m from the centre of the Earth and a distance of 148.1×10^9 m from the centre of the Sun, as shown in Fig 1.1.

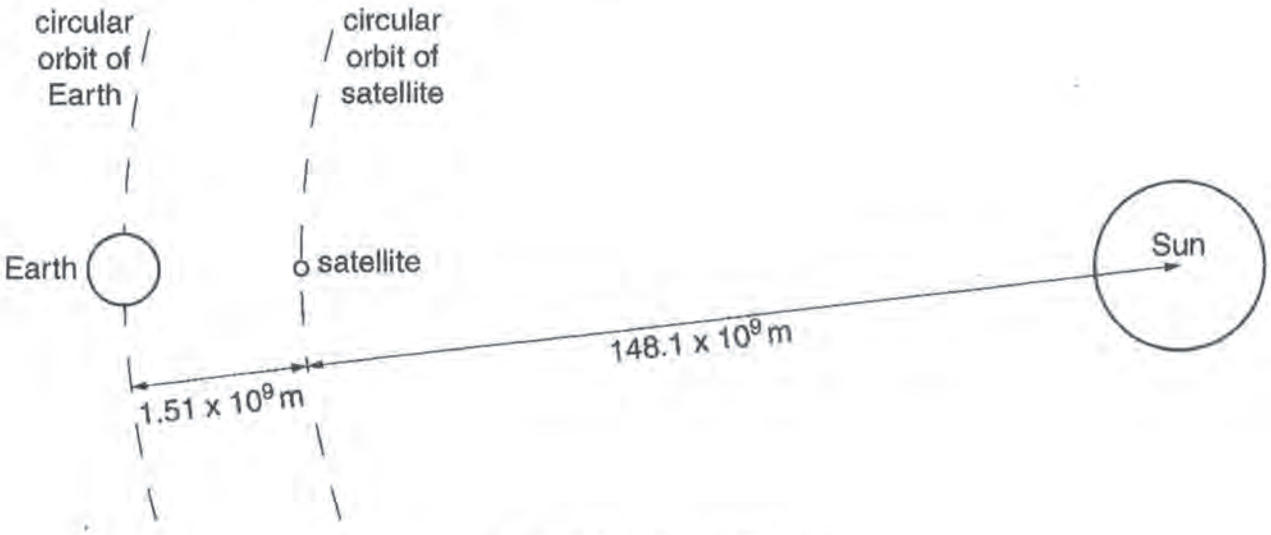


Fig. 1.1 (not to scale)

The speed of the satellite is adjusted so that it orbits the Sun with a period of 1 year (3.1526×10^7 s). The rocket motor is then switched off. The satellite then travels round the Sun in a circle, keeping constant the distances between the satellite, the Earth and the Sun.

(a) Calculate

(i) the speed of the satellite,

$T = \frac{2\pi}{\omega}$ $\omega = \frac{2\pi}{T}$

$V = \omega r$

$V = \frac{2\pi}{3.1526 \times 10^7 \text{s}} \times 148.1 \times 10^9 \text{m}$

(6sf)

$= 29516.6 \text{ ms}^{-1}$

29520 ✓

(4sf)

speed = ... ms^{-1} [1]

(ii) the centripetal acceleration of the satellite.

$a = \frac{v^2}{r}$

$= \frac{(29516.6 \text{ ms}^{-1})^2}{148.1 \times 10^9 \text{ m}}$

$= 5.883 \times 10^{-3} \text{ ms}^{-2}$

✓ ✓ (4sf) 2

centripetal acceleration = 5.883×10^{-3} ms^{-2} [2]

(b) The mass of the Sun is 1.99×10^{30} kg and the mass of the Earth is 5.98×10^{24} kg.

(i) Calculate the gravitational force exerted on the satellite by

1. the Earth,

$$F = \frac{GM_1M_2}{r^2}$$

$$= \frac{6.67\times10^{-11}\,\mathrm{Nm^2\,kg^{-2}} \times 5.98\times10^{24}\,\mathrm{kg} \times 200\,\mathrm{kg}}{(1.51\times10^{9}\,\mathrm{m})^2}$$

$= \cancel{0.035}$ 0.0350 N

✓ (3sf). ✓

force = 0.0350 N [2]

2

2. the Sun.

$$F = \frac{GM_1M_2}{r^2}$$

$$= \frac{6.67\times10^{-11}\,\mathrm{Nm^2\,kg^{-2}} \times 1.99\times10^{30}\,\mathrm{kg} \times 200\,\mathrm{kg}}{(148.1\times10^{9}\,\mathrm{m})^2}$$

$= 1.21$ N

(3sf) ✓

force = 1.21 N [1]

1

(ii) Calculate the resultant force on the satellite.

$(1.21 - 0.0350)$ N

$= \cancel{0.00}$ 1.18N (3sf)

✓

resultant force = 1.18 (3sf). N [1]

1

(c) Show that the centripetal acceleration of the satellite is caused by this resultant force.

$$\frac{mv^2}{r}$$

$= 200\,\mathrm{kg} \times 5.883\times10^{-3}\,\mathrm{ms^{-2}}$ ✓

$= 1.1766$N ✓

$= 1.18$N (3sf) = Resultant force.

2

[2]

(d) For such a satellite, suggest why

(i) the satellite has an advantage over a geostationary satellite for observing the Sun,

If the satellite were in a geostationary orbit, there will be a time when it will be on the other side of the Earth, so it won't be able observe the Sun at that time. ✓ ^ [2]

1

(ii) the satellite requires frequent small corrections of position and/or speed,

The satellite is not only in the gravitational field of the Sun and the Earth alone, other planetary masses may exert a force on the satellite, distorting its orbit. ✓ ✓ [2]

2

(iii) the satellite is considerably more expensive to put into orbit than a geostationary satellite circling the Earth.

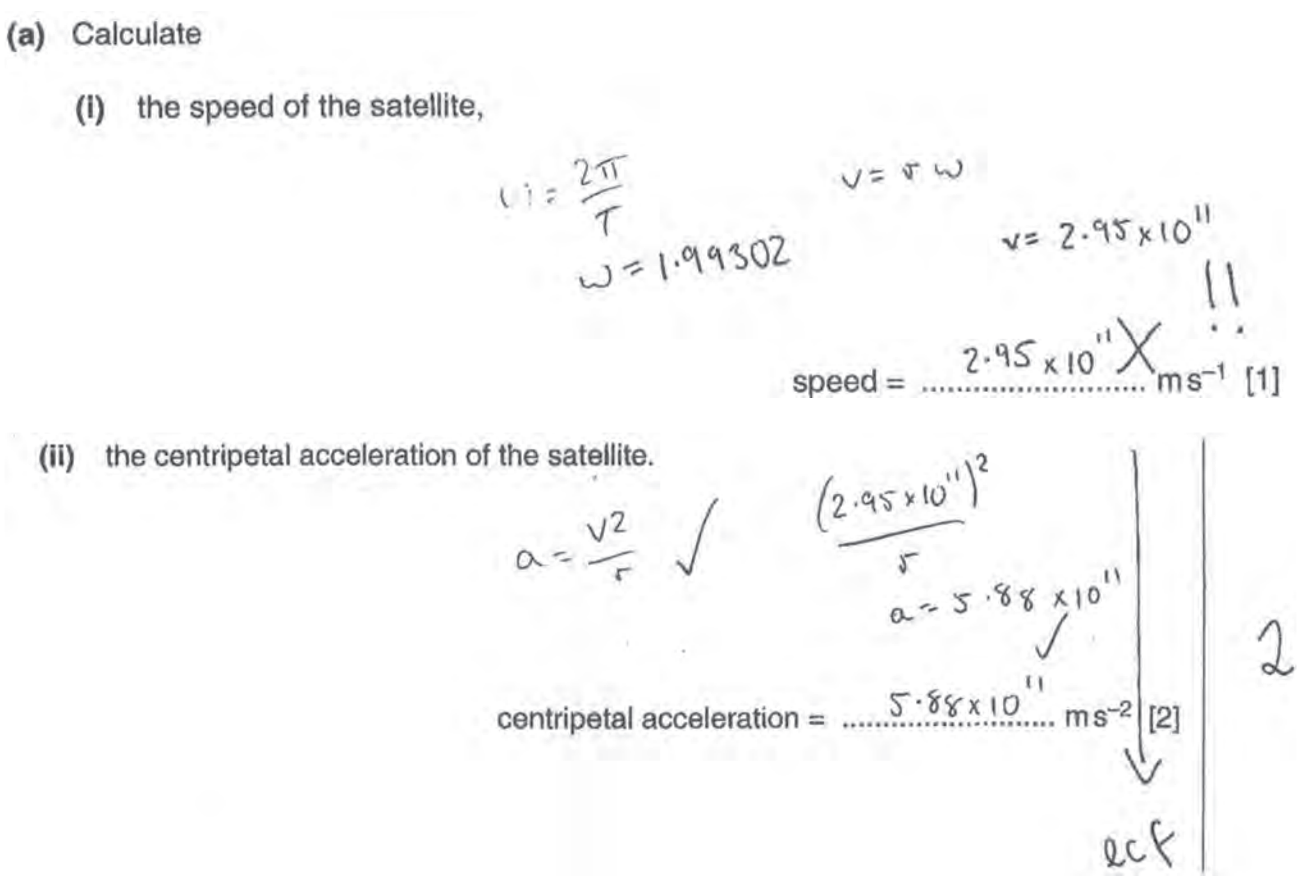
The distance from a the Earth of a geostationary orbit is much less ✓ than that of the orbit of this satellite. It will take a lot ✓ more fuel to bring the satellite to such an orbit. [2]

2

Examiner Comment

This candidate is able to answer this question in full. He realises that there is a slight problem with significant figures but copes with the difficulty sensibly.

Example Candidate Response – Merit



(a) Calculate

(i) the speed of the satellite,

$\omega = \frac{2\pi}{T}$ $v = r\omega$

$\omega = 1.99302$ $v = 2.95 \times 10^{11}$

!!

speed = 2.95×10^{11} ✗ m s^{-1} [1]

(ii) the centripetal acceleration of the satellite.

$a = \frac{v^2}{r}$ ✓ $\frac{(2.95 \times 10^{11})^2}{r}$

$a = 5.88 \times 10^{11}$ ✓

centripetal acceleration = 5.88×10^{11} m s^{-2} [2]

ecf

2

(b) The mass of the Sun is 1.99×10^{30} kg and the mass of the Earth is 5.98×10^{24} kg.

For Examiner's Use

(i) Calculate the gravitational force exerted on the satellite by

1. the Earth,

$$F = \frac{-G m_1 m_2}{r^2} \qquad F = \frac{-G(5.98 \times 10^{24})(200)}{1.51 \times 10^{92}}$$

$$G = 6.67 \times 10^{-11} \qquad F = 0.03499 \ ✓$$

force = -0.035 ✓ N [2]

2

2. the Sun.

$$F = \frac{-G(1.99 \times 10^{30})(\overset{200}{\cancel{5.98 \times 10^{24}}})}{(148.1 \times 10^{9})^2}$$

$$F = 1.21$$

✓

force = [illegible] 1.21 N [1]

1

(ii) Calculate the resultant force on the satellite.

✓

resultant force = 1.175 N [1]

1

(c) Show that the centripetal acceleration of the satellite is caused by this resultant force.

$$F = 1.175 \qquad F = \frac{mv^2}{r} \qquad m\omega^2 r = 1.175$$

✓

~~$\frac{mv^2}{r} = 1.175$~~

~~$\frac{v^2}{r} = \frac{1.175}{m}$~~

~~a~~

$$\frac{mv^2}{r} = 1.175$$

$$\frac{v^2}{r} = \frac{1.175}{m}$$

✓

$$a = \frac{1.175}{m}$$

[2]

2

(d) For such a satellite, suggest why

(i) the satellite has an advantage over a geostationary satellite for observing the Sun,

It can take pictures and readings of the sun from all sides ✓ as opposed to a geostationary that stays fixed. [2]

1

(ii) the satellite requires frequent small corrections of position and/or speed,

As it orbits other small gravity forces such as ones from other planets pull it off ✓ course slightly and has to be readjusted. [2]

1

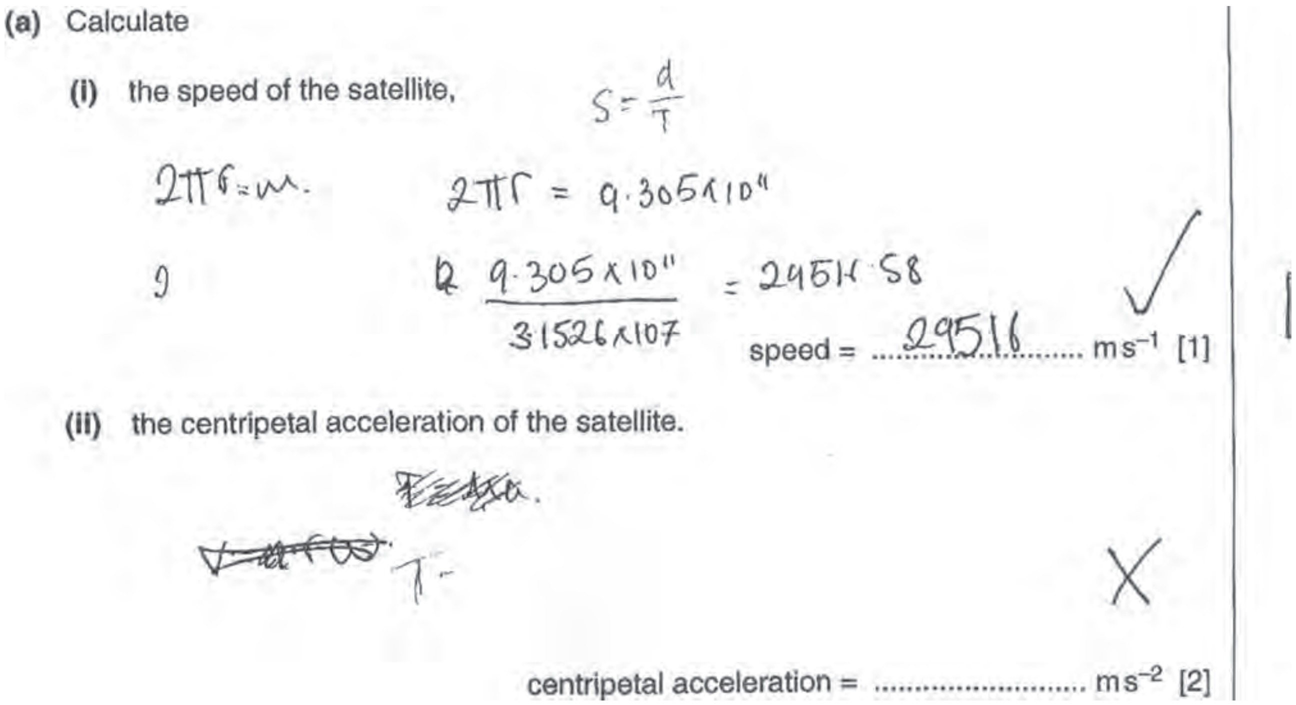
(iii) the satellite is considerably more expensive to put into orbit than a geostationary satellite circling the Earth.

Once in the correct position it can just turn off all engines and will not use any energy to ~~rotate~~ orbit. [2]

Examiner Comment

This candidate makes a careless mistake with part **(a) (i)** where he omits a 10^7 term and does not realise that the speed he obtains is totally unrealistic. Nevertheless he proceeds accurately, using error carried forward, with all of parts **(b)** and **(c)**. His descriptive answer for part **(d)** does not contain any idea that the satellite is basically in a position of unstable equilibrium, so any deviation from its correct position would be disastrous without position corrections.

Example Candidate Response – Pass



(a) Calculate

(i) the speed of the satellite,

$S = \frac{d}{T}$

$2\pi r = m.$

$2\pi r = 9.305 \times 10^{11}$

9

$\frac{9.305 \times 10^{11}}{3.1526 \times 10^{7}} = 29514.58$

✓

speed = 29516 m s^{-1} [1]

(ii) the centripetal acceleration of the satellite.

~~[illegible]~~

~~[illegible]~~ $T =$

✗

centripetal acceleration = ... m s^{-2} [2]

(b) The mass of the Sun is 1.99 × 10^{30} kg and the mass of the Earth is 5.98 × 10^{24} kg.

(i) Calculate the gravitational force exerted on the satellite by

1. the Earth,

$$F = \frac{Gm_1m_2}{r^2} = \frac{6.67\times10^{-11}\times5.98\times10^{24}\times200}{(1.51\times10^9)^{\textcircled{2}}} = 5282\cancel{493}3$$

not used

force = 52829933. N [2]

0

2. the Sun.

$$F = \frac{6.67\times10^{-11}\times\overset{1.99\times10^{30}}{\cancel{5.98\times10}}\times200}{(148.1\times10^9)^{\textcircled{2}}} = 1.792478\times10^{11}\,N.$$

not used.

same mistake

force = 1.792 x10^{11} N [1] ✓

1

(ii) Calculate the resultant force on the satellite.

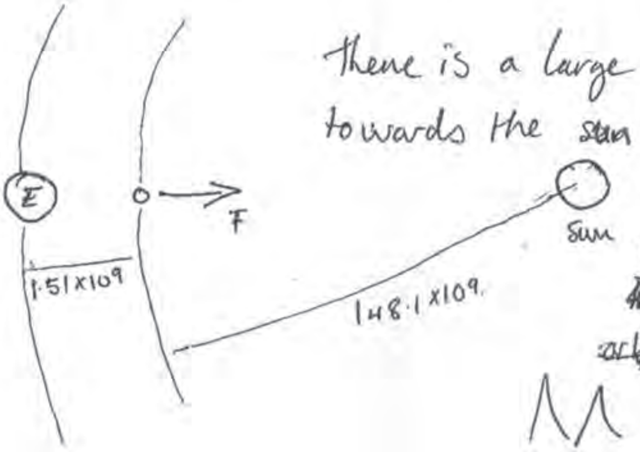
~~1.792x10^{11} -~~

$1.792478\times10^{11} - 52829433 = 1.79194\times10^{11}$ ✓ecf

1

resultant force = 1.79194x10^{11} N [1]

(c) Show that the centripetal acceleration of the satellite is caused by this resultant force.



There is a large force F pointing towards the sun causing the satilite to accelerate round the sun.

[redacted]

~~orbit with the earth~~.

[2]

X

0

M

(d) For such a satellite, suggest why

(i) the satellite has an advantage over a geostationary satellite for observing the Sun,

For this Satllite it is able to ~~[illegible]~~ opserve ✓ the sun all year round whereas the if it was geostationary it would only have certain time of the ~~yr~~ day to observe the sun ✓ [2]

(ii) the satellite requires frequent small corrections of position and/or speed,

this is so that the satelite has a similar ✗ year to earth.

[2]

(iii) the satellite is considerably more expensive to put into orbit than a geostationary satellite circling the Earth.

the satilite has to ~~be~~ in the sun gravitational field more then the earths one which means ✓ more fuel is needed to get to this destination [2]

Examiner Comment

This candidate does get the initial speed correct but is unable to calculate the centripetal acceleration. This is a fundamental lack of knowledge and is compounded in parts **(b)** and **(c)** where additional mistakes are made. The candidate makes a couple of good points in his answers to part **(d)**.

Question 2 Mark Scheme

(a)	the force/acceleration acting is proportional to the displacement	(1)	
	the force/acceleration is directed towards a fixed point with – sign	(1)	[2]
(b) (i)	single sinusoidal waveform	(1)	
	constant amplitude	(1)	[2]
(ii)	bounded on + and – *x*-axis by the amplitude	(1)	
	both positive and negative halves symmetrical	(1)	
	ellipse/circle	(1)	[3]
(c) (i)	$T = 2\pi\sqrt{(2.3 / 63)} = 1.20\,\text{s}$	(1)	
	$\omega = 2\pi / T = 2\pi / 1.20 = 5.23\,\text{rad s}^{-1}$	(1)	[2]
	OR directly from $\omega = \sqrt{(k / m)}$		
(ii)	correct substitution	(1)	
	giving $E = ½ \times 2.3 \times 0.28^2 \times 5.23^2 = 2.47\,\text{J}$	(1)	[2]
(iii)	$2.47 = ½ \times 2.3 \times v_{max}{}^2$		
	giving $v_{max} = 1.47\,\text{m s}^{-1}$	(1)	[1]

(d)

	kinetic energy / J	gravitational potential energy / J	elastic potential energy / J	total energy / J
top	**0**	**6.32**	–3.85	**2.47**
middle	**2.47**	reference zero	reference zero	**2.47**
bottom	**0**	**– 6.32**	**8.79**	**2.47**

kinetic energy column correct	(1)	
$mgh = 2.3 \times 9.81 \times 0.28 = 6.32\,\text{J}$	(1)	
giving +6.32 at top and –6.32 at bottom	(1)	
total energy constant at 6.32 – 3.85 = 2.47 J	(1)	
so e.p.e. at bottom = 8.79 J	(1)	[5]

[Total: 17]

Example Candidate Response – Distinction

2 **(a)** State the conditions necessary for an object to have *simple harmonic motion.*

The acceleration should be proportional to the displacement from the centre of oscillation ✓ ✓

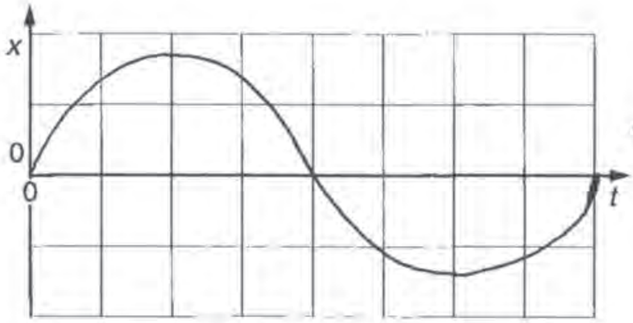
i.e. acceleration ∝ - displacement from centre

[2]

2

(b) Draw sketch graphs to show how, for a single time period of simple harmonic motion,

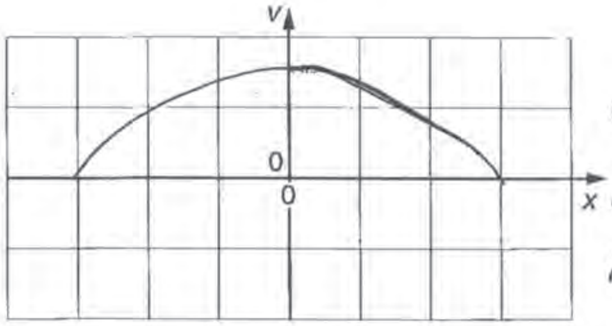
(i) the displacement x varies with time t,



✓ ✓ 2

[2]

(ii) the velocity v varies with displacement x.



✓ 1

[3]

(c) A mass $m = 2.3\,\text{kg}$ is oscillating vertically with simple harmonic motion on a spring. The spring has a spring constant k of $63\,\text{N}\,\text{m}^{-1}$.The amplitude A of the oscillation is A 0.28 m and the period T of the oscillation is given by the equation

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

(i) Calculate the angular frequency ω of the oscillation.

$$T = 2\pi\sqrt{\frac{2.3}{63}} = 2\pi\sqrt{\frac{23}{630}}$$

$$\omega = \frac{2\pi}{T} = \sqrt{\frac{630}{23}}$$

$$= 5.23 \ (3sf) \ \checkmark\checkmark \quad 2$$

$\omega =$ 5.23 (3sf) rad s^{-1} [2]

(ii) Use the expression $E = \frac{1}{2}mA^2\omega^2$ to find the maximum kinetic energy E of the oscillating mass.

$$\text{By } E = \tfrac{1}{2}mA^2\omega^2$$

$$\text{max KE} = \tfrac{1}{2}(2.3)(0.28)^2\left(\frac{630}{23}\right)$$

$$= 2.4696$$

$\checkmark\checkmark$ 2

$E =$ 2.47 (3sf) J [2]

(iii) Deduce the maximum speed of the oscillating mass.

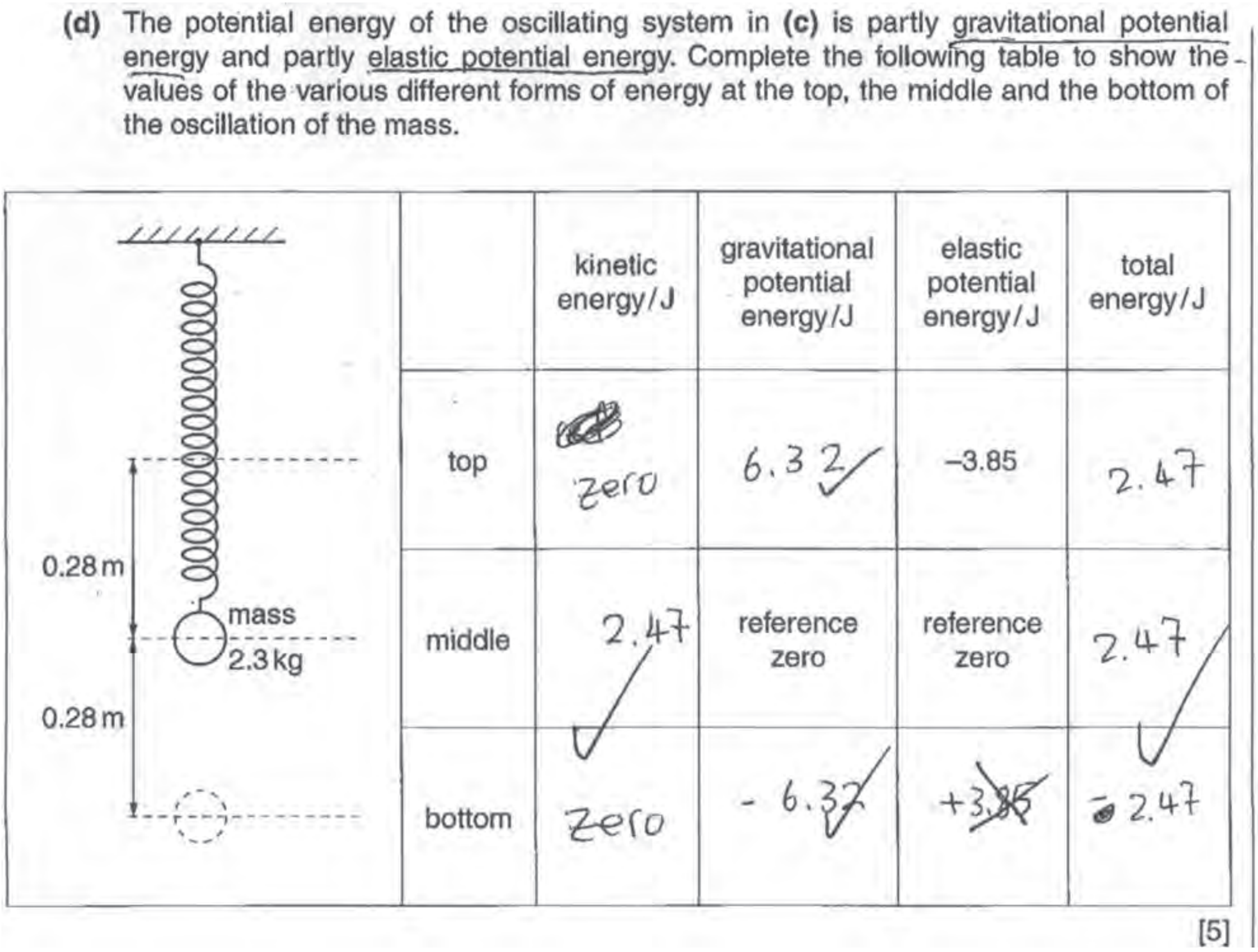
$$\tfrac{1}{2}m(V_{max})^2 = \text{max KE}$$

$$\tfrac{1}{2}(2.3)(V_{max})^2 = 2.4696$$

$$V_{max} = 1.47 \ (3sf)$$

$\checkmark$ 1

maximum speed = 1.47 (3sf) m s^{-1} [1]



(d) The potential energy of the oscillating system in **(c)** is partly gravitational potential energy and partly elastic potential energy. Complete the following table to show the values of the various different forms of energy at the top, the middle and the bottom of the oscillation of the mass.

	kinetic energy/J	gravitational potential energy/J	elastic potential energy/J	total energy/J
top	zero	6.32 ✓	–3.85	2.47
middle	2.47 ✓	reference zero	reference zero	2.47 ✓
bottom	zero	- 6.32 ✓	+3.85 ✓	- 2.47

[5]

4

Examiner Comment

With this question the candidate only made a couple of errors. The candidate did not give the negative velocities on the sketch graph in part **(b) (ii)** and did not have the courage of her convictions in the last line of part **(d)**. The candidate tried to follow the pattern of the gravitational potential energy and was therefore forced to cross out a correct plus sign in the bottom total energy column.

Example Candidate Response – Merit

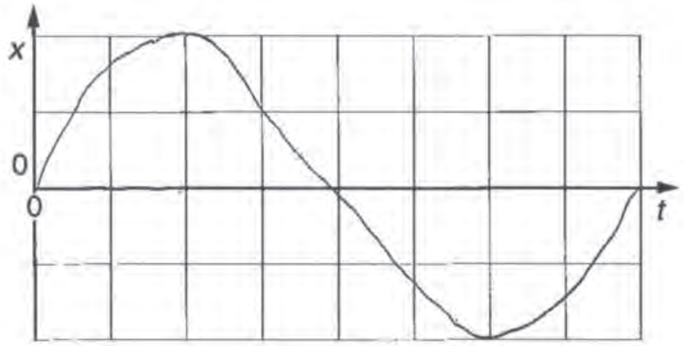
2 **(a)** State the conditions necessary for an object to have *simple harmonic motion.*

The object's displacement ~~is~~ is proportional ✓ to its acceleration ⋏ 1

[2]

(b) Draw sketch graphs to show how, for a single time period of simple harmonic motion,

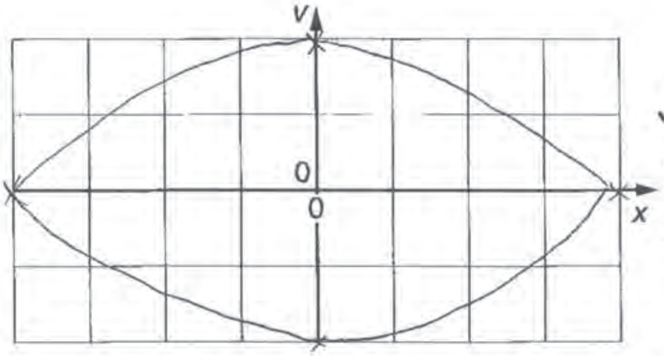
(i) the displacement x varies with time t,



✓ ✓ 2

[2]

(ii) the velocity v varies with displacement x.



✓ ✓ ✓ 3

[3]

(c) A mass $m = 2.3$ kg is oscillating vertically with simple harmonic motion on a spring. The spring has a spring constant k of 63 N m^{-1}.The amplitude A of the oscillation is 0.28 m and the period T of the oscillation is given by the equation

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

(i) Calculate the angular frequency ω of the oscillation.

$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi \times \sqrt{\frac{2.3}{63}} = \underline{\underline{1.2 s}}$ For 2π rads, 1.2 s

$\therefore w = \cancel{\frac{1.2}{2\pi}}\ \cancel{x}\ \frac{2\pi}{1.2} = \underline{\underline{5.26 \text{rads}^{-1}}}$ ✓

✓ 2

ω = 5.26 rad s^{-1} [2]

(ii) Use the expression $E = \frac{1}{2}mA^2\omega^2$ to find the maximum kinetic energy E of the oscillating mass.

$E = \frac{1}{2} \times 2.3 \times 0.28^2 \times 5.26^2 = \underline{\underline{2.44 J}}$ ✓

✓ 2

E = 2.44 J [2]

(iii) Deduce the maximum speed of the oscillating mass.

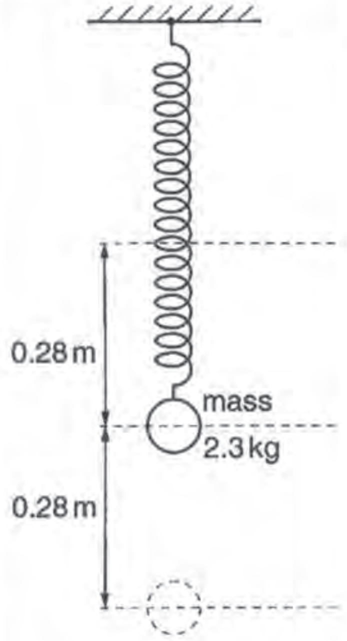
$V = -A w \sin wt$

$= -0.28 \times 5.26 \times \sin(5.26 \times 1.2)$ ✗ 0

$\approx \underline{\underline{0.4 ms^{-1}}}$

maximum speed = ~~0.4~~ m s^{-1} [1]

(d) The potential energy of the oscillating system in **(c)** is partly gravitational potential energy and partly elastic potential energy. Complete the following table to show the values of the various different forms of energy at the top, the middle and the bottom of the oscillation of the mass.

		kinetic energy/J	gravitational potential energy/J	elastic potential energy/J	total energy/J
	top	0	12.64 ~~1.29~~ ✗	−3.85	8.74
	middle	0.84 ✗	reference zero	reference zero	0.86
	bottom	0	−6.32 0 ✓	2.47 ✗	−3.85

[5]

1

Examiner Comment

This candidate only had half of the bookwork correct in part **(a)** but did all of **(b)** correctly. Parts **(c)** **(i)** and **(c)** **(ii)** were correct but he did not deduce the speed of the mass directly from the kinetic energy he had just calculated. Mistakes in calculating the potential energy compounded the problems with the table in part **(d)**. He did not have the total energy constant throughout nor did he get the potential error carried forward mark for the kinetic energy value he had calculated.

Example Candidate Response – Pass

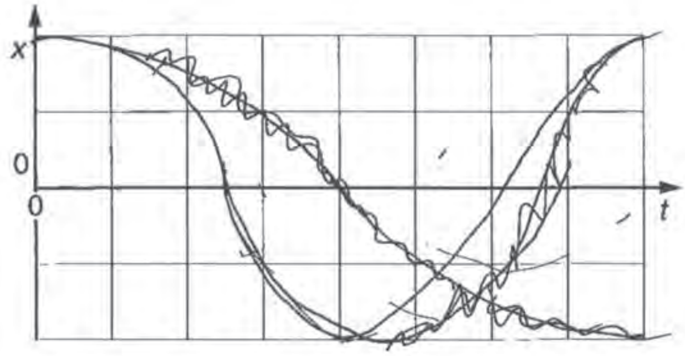
2 **(a)** State the conditions necessary for an object to have *simple harmonic motion*.

a is directly proportional to the ✓
displacement or a = -(constant)x ✓ just

[2] 2

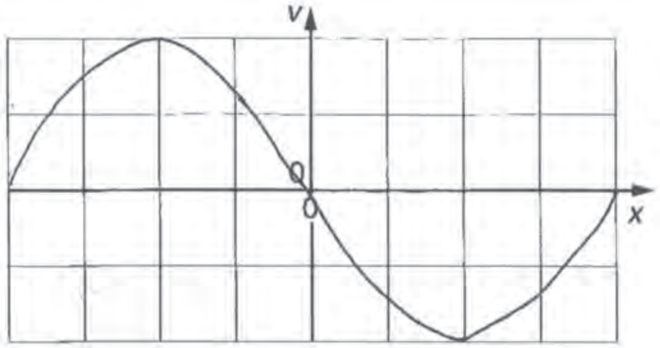
(b) Draw sketch graphs to show how, for a single time period of simple harmonic motion,

(i) the displacement x varies with time t,



[2] ✓ ✓ 2

(ii) the velocity v varies with displacement x.



[3] ✗ 0

(c) A mass m = 2.3 kg is oscillating vertically with simple harmonic motion on a spring. The spring has a spring constant k of 63 N m^{-1}.The amplitude A of the oscillation is 0.28 m and the period T of the oscillation is given by the equation

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

(i) Calculate the angular frequency ω of the oscillation.

$$\omega = \frac{2\pi}{T}$$

$$\omega = \frac{\cancel{2\pi}}{\cancel{2\pi}\sqrt{\frac{m}{k}}}$$

✓✓

2

ω = ...5.2...... rad s^{-1} [2]

(ii) Use the expression $E = \frac{1}{2}mA^2\omega^2$ to find the maximum kinetic energy E of the oscillating mass.

$$E = \frac{1}{2}(2.3)(0.28)^2(5.2)^2 =$$

✓✓

2

E = ...2.4...... J [2]

(iii) Deduce the maximum speed of the oscillating mass.

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

$$v = -0.28 \times 5.2 \times \sin(5.2)(1.2)$$ uses degrees.

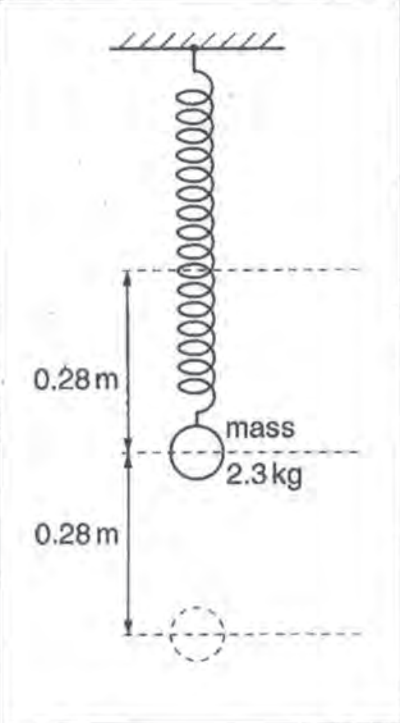
$$v =$$

X

0.158.

maximum speed = ...[illegible]...... m s^{-1} [1]

(d) The potential energy of the oscillating system in **(c)** is partly gravitational potential energy and partly elastic potential energy. Complete the following table to show the values of the various different forms of energy at the top, the middle and the bottom of the oscillation of the mass.

		kinetic energy/J	gravitational potential energy/J	elastic potential energy/J	total energy/J
	top	0	2.63 ✗	−3.85	8.78 ✗
	middle	2.4	reference zero	reference zero	2.4 ✗
	bottom	0 ✓	0 ✗	2.4 ~~[illegible]~~. ✗	2.4.

[5]

$\frac{1}{2}mv^2$ $E = \cancel{\frac{GMm}{r}}$ mgh $\frac{1}{2}kx^2$ KE+PE

Examiner Comment

This candidate's bookwork was almost accurate in **(a)** but he gave a velocity-time graph for **(b) (ii)**. Correct work followed for **(c) (i)** and **(ii)** but he was not able to use the radian measure of his calculator for **(c) (iii)**. The table was completed poorly with only the kinetic energy column gaining a mark.

Question 3 Mark Scheme

(a) the force acting per unit positive charge at the point (1) [1]

(b) with calculus notation OR as follows
for a charge q moving a distance *d* against a field E; work, W = Eqd (1)
potential difference V = W / q therefore potential gradient = V / x = W / qd = E (1) [2]

(c) **(i)** 200 V / 0.015 m (= 13 000) (1)
V m^{-1} OR N C^{-1} (1) [2]

(ii) 320 (± 10) V (1) [1]

(iii) $(400\,\text{V} - 200\,\text{V}) \times 3.0 \times 10^{-6}\,\text{J}$ (1)
$= 6.0 \times 10^{-4}\,\text{J}$ (1) [2]

(d) **(i)** straight line (tangent to curve and) in opposite direction to arrow (1) [1]

(ii) line parallel to vertical sides and ¼ distance from side to 200 V (1)
curving near corners then flat along the bottom – ¼ distance still (1) [2]

[Total: 11]

Example Candidate Response – Distinction

3 **(a)** Define *electric field strength* at a point in an electric field.

The amount of Newtons that the electric field would cause a particle of +1 C charge to feel. [1]

0

(b) The magnitude of the potential gradient in an electric field is always equal to that of the electric field strength. Show that this is true for a uniform electric field *E* between two parallel plates a distance *d* apart when the potential difference between the plates is *V*.

At a point half way between the plates, the gradient is equal to $\frac{V}{d}$. The electric field ✓ strength is equal to the charge over $4\pi\varepsilon_0 r^2$ ^

[2]

1

(c) Fig. 3.1 shows a full-scale cross-section of the electric field in the region of a charged circular metal rod and a U-shaped metal frame. The potential difference between the rod and the frame is 600 V with the metal frame earthed at 0 V. The dotted lines on the diagram are equipotential lines at labelled potentials.

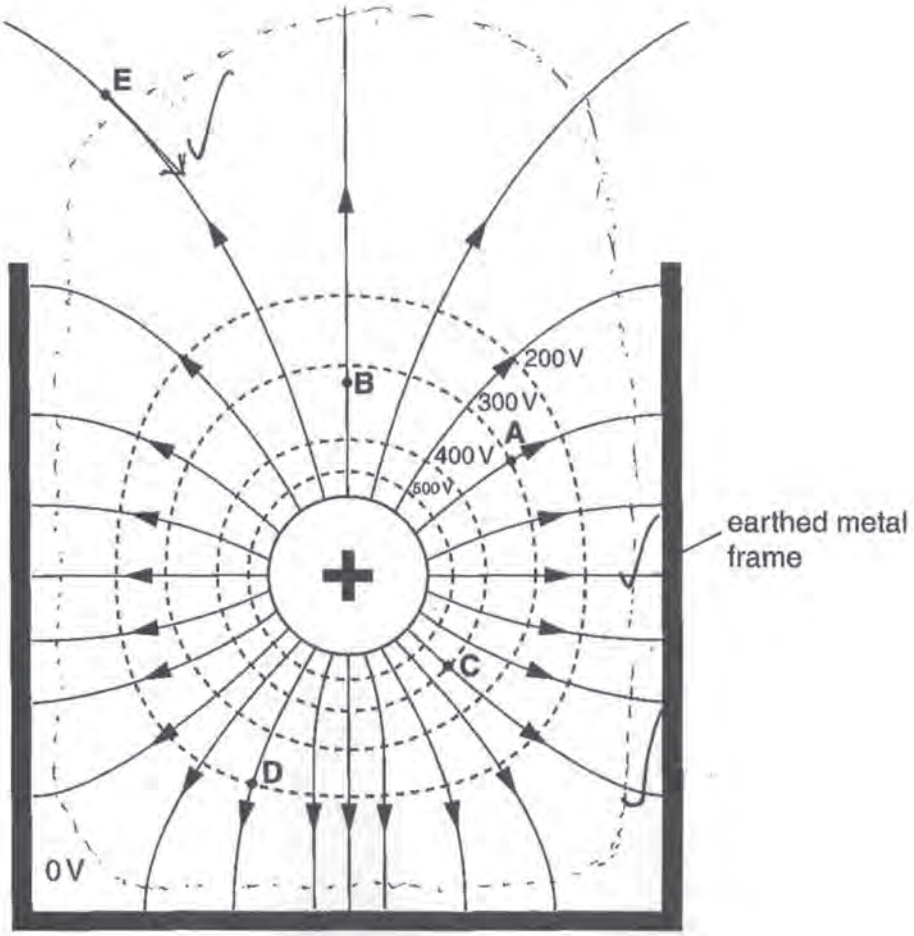


Fig. 3.1 (actual scale)

By taking measurements from the diagram, determine approximate values of

(i) the magnitude of the electric field strength at point A, giving the unit of electric field strength,

$E = \frac{V}{d} = \frac{200\text{V}}{1.5\text{cm}} = 1.33 \times 10^4\ \text{NC}^{-1}$ ✓ ✓

BOD

electric field strength = $1.33 \times 10^4\ \text{NC}^{-1}$ [2]

2

(ii) the electric potential at point B,

$300 + \underline{0.2} \times 100 = 320$

✓

electric potential = 320 V [1] 1

(iii) the work done in moving a charge of 3.0 μC from point D to point C.

$W = 200\text{V} \times 3.0\mu\text{C}$ ✓

$= 2\times10^{-6}$ J ✗

work = 2×10 [illegible] J [2] 1

(d) Draw on Fig. 3.1

(i) an arrow showing the direction of the force on an electron at point E, [1] 1

(ii) an equipotential line at 50 V. [2] 2

Examiner Comment

This question was poorly answered by many candidates. Even many of the Distinction candidates were unable to define electric field as force per unit positive charge. Part **(b)** caused even greater problems; few candidates were able to consider the work done on unit charge to move it unit distance against the force provided by the field. Most of this candidate's marks came from part **(c)**, which was entirely correct.

Example Candidate Response – Merit

3 (a) Define *electric field strength* at a point in an electric field. ~~of~~ positive accepted.

The force experienced by one unit of charge ✓

when passed through a potential difference of 1V. [1] 1

(b) The magnitude of the potential gradient in an electric field is always equal to that of the electric field strength. Show that this is true for a uniform electric field *E* between two parallel plates a distance *d* apart when the potential difference between the plates is *V*.

....

....

....

....

.... [2] 0

(c) Fig. 3.1 shows a full-scale cross-section of the electric field in the region of a charged circular metal rod and a U-shaped metal frame. The potential difference between the rod and the frame is 600V with the metal frame earthed at 0V. The dotted lines on the diagram are equipotential lines at labelled potentials.

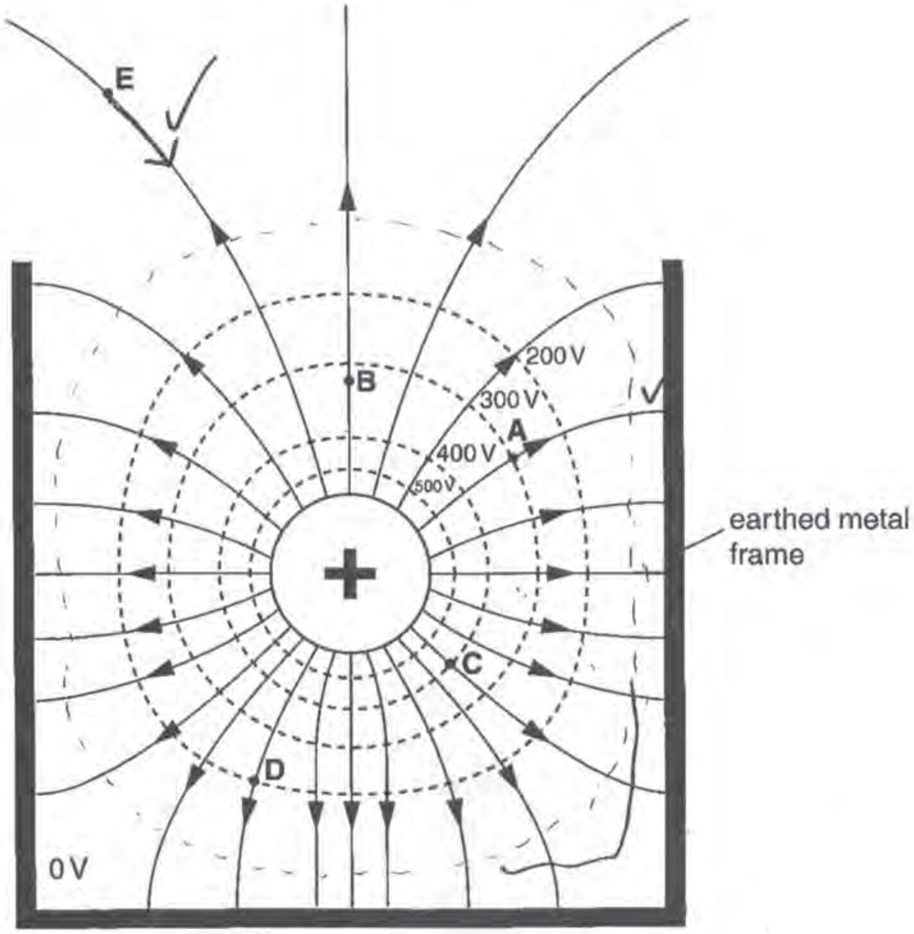


Fig. 3.1 (actual scale)

By taking measurements from the diagram, determine approximate values of

(i) the magnitude of the electric field strength at point A, giving the unit of electric field strength,

F = BIl

electric field strength = 10 T ✗ [2]

(ii) the electric potential at point B,

electric potential = 325 ✓ V [1]

1

(iii) the work done in moving a charge of 3.0 μC from point D to point C.

200 − 400 V = 200 V difference

3.0 μC = 3 × 10⁻⁹ C   PT

∴ work = 200 × 3 × 10⁻⁹

= 6 × 10⁻⁷ J

✓

work = 6.0 × 10⁻⁷ J [2]   1

(d) Draw on Fig. 3.1

(i) an arrow showing the direction of the force on an electron at point E, [1]   1

(ii) an equipotential line at 50 V. [2]   1

Examiner Comment

This candidate scored the mark for part **(a)** but left **(b)** blank. $F = BIL$ appeared in **(c) (i)** and a 10 T answer was given. He gave the correct electrical potential in **(c) (ii)** and started correctly with the work done in **(c) (iii)** but had a power of 10 error. Part **(d)** was mostly correct (2/3 marks) but there was doubt about the position of the equipotential line and whether the direction of the arrow was a tangent to the curve or was itself curved.

Example Candidate Response – Pass

3 **(a)** Define *electric field strength* at a point in an electric field.

electric field strength is the force multiplied by the charge at that point

X [1]

(b) The magnitude of the potential gradient in an electric field is always equal to that of the electric field strength. Show that this is true for a uniform electric field E between two parallel plates a distance d apart when the potential difference between the plates is V.

$E = V/d$ $F = E/q$ $F = Fq$

$Fq = V/d$

$F = \frac{V}{qd}$

∧ ∧

[2]   0

(c) Fig. 3.1 shows a full-scale cross-section of the electric field in the region of a charged circular metal rod and a U-shaped metal frame. The potential difference between the rod and the frame is 600V with the metal frame earthed at 0V. The dotted lines on the diagram are equipotential lines at labelled potentials.

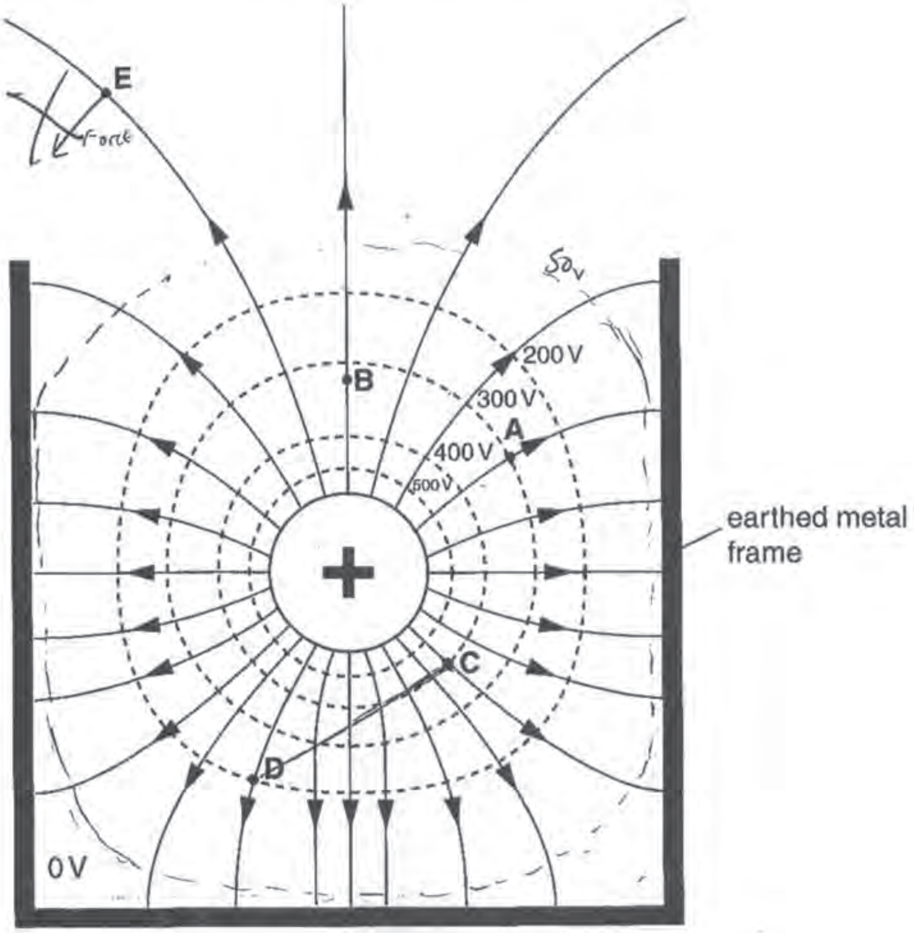
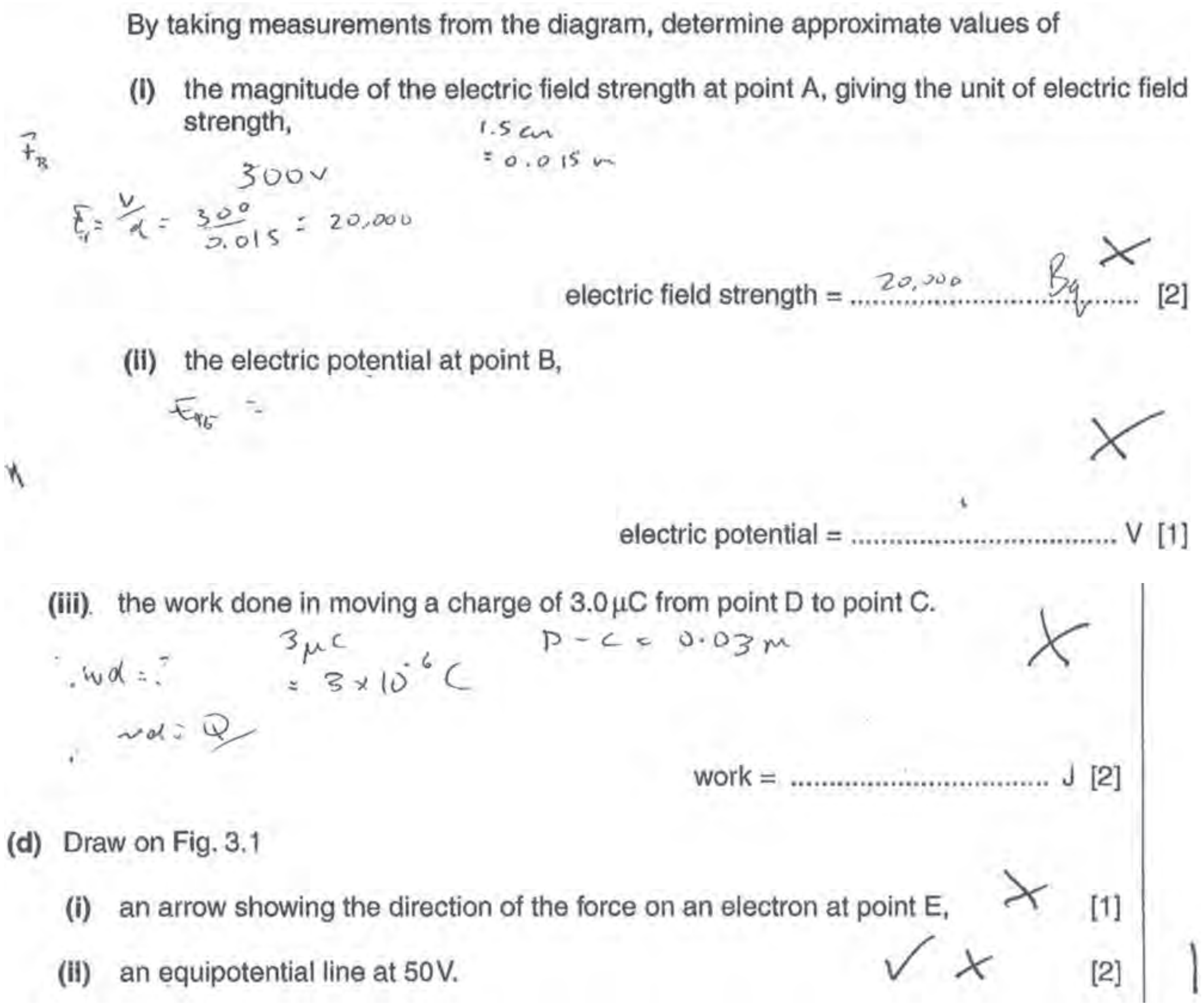


Fig. 3.1 (actual scale)



By taking measurements from the diagram, determine approximate values of

(i) the magnitude of the electric field strength at point A, giving the unit of electric field strength,

$\vec{F}_R$

1.5 cm

= 0.015 m

300 V

$E_1 = V/d = \frac{300}{0.015} = 20{,}000$

electric field strength = 20,000 Bq ✗ [2]

(ii) the electric potential at point B,

E_{BG} =

✗

electric potential = ... V [1]

(iii) the work done in moving a charge of 3.0 μC from point D to point C.

wd = ?

3 μC

= 3×10^{-6} C

D − C = 0.03 m

✗

wd = Q

work = ... J [2]

(d) Draw on Fig. 3.1

(i) an arrow showing the direction of the force on an electron at point E, ✗ [1]

(ii) an equipotential line at 50 V. ✓ ✗ [2]

Examiner Comment

This candidate's answer scored no marks in parts **(a)**, **(b)** and **(c)**. In part **(d)** his arrow was at right angles to the field but he did have part of the equipotential line correct. Weaker candidates often struggle with the concept of electric field.

Question 4 Mark Scheme

(a) Three from:
no intermolecular attractions
particles in totally random motion
all collisions elastic
contact time negligible
volume of molecules is negligible compared with volume of container
gravitational effects ignored [3]

(b) p is the pressure, V is the volume (1)
N is the number of molecules, m is the mass of one molecule (1)
$<c^2>$ is the mean value of the square of the speed of a molecule (1) [3]

(c) K.E. = $\frac{1}{2}Nm<c^2> = 3pV / 2$ OR working from $\frac{1}{2}m<c^2> = 3kT / 2$ (1)
$= 3nRT / 2$ (1)
$T = 350 + 273 = 623\,K$ (1)
K.E $= 3 \times 0.36 \times 8.31 \times 623 / 2 = 2800\,J$ (1) [4]

[Total: 10]

Example Candidate Response – Distinction

4 **(a)** State three assumptions made in deriving the equation $pV = \frac{1}{3}Nm<c^2>$ from the kinetic theory model of a gas.

1. All collisons between ~~particles~~ molecules of gas or ~~particles~~ molecules and wall of the Container are elastic ✓

2. The volume of the ~~particles~~ molecules are much smaller to the volume of the container. ✓

3. There are no long distance forces between molecules. ✓

[3] 3

(b) Give the meaning of each symbol in the equation given in **(a)**.

p pressure of gas.

V Volume of gas. ✓

N number of molecules

m mass of a molecule ✓

$<c^2>$ ~~root~~ mean square speed of molecules

[3] 2

(c) Determine the internal energy of 0.36 mol of an ideal gas at a temperature of 350 °C.

~~[illegible]~~ Average $E_{Km} = \frac{3}{2}kT$ ✓

$= \frac{3}{2} \times 1.38 \times 10^{-23}\ JK^{-1} \times (350+273)K$

$= 1.28961 \times 10^{-20}\ J$ ✓

Number of molecules in 0.36 mol

$= 0.36\ mol \times 6.02 \times 10^{23}\ mol^{-1}$ ✓

$= 2.1672 \times 10^{23}$

Total $E_{Kin} = 2.1672 \times 10^{23} \times 1.28961 \times 10^{-20}\ J$

$= 2795\ J$

internal energy = 2800 ✓ (3sf) J [4] 4

Examiner Comment

This question posed few problems for Distinction candidates. They were well able to deal with the bookwork parts of the question though many saw the mean value symbol and incorrectly wrote "the root mean square speed of the molecules" as did this candidate. This needed to be written carefully to get the mark. The symbol is the mean value of the squares of the speeds of the molecules. This candidate worked well through the question where there are many pitfalls for the unwary.

Example Candidate Response – Merit

4 **(a)** State three assumptions made in deriving the equation $pV = \frac{1}{3}Nm\langle c^2\rangle$ from the kinetic theory model of a gas.

1. Random movement of gas molecules ✓

2. No intermolecular interactions between the molecules ✓

3. completely elastic collisions between the molecules. ✓

[3] 3

(b) Give the meaning of each symbol in the equation given in **(a)**.

p pressure V volume ✓ 1

N number of molecules m mass of what?

$\langle c^2\rangle$ average square of speed ✓ BOD 1

[3]

(c) Determine the internal energy of 0.36 mol of an ideal gas at a temperature of 350 °C.

$KE = \frac{1}{2}mv^2$

$pV = nRT$

$= 0.36 \times 8.31 \times (350-273)$

$pV = 230.4$

$PV = mkT$

$=$

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

$230.41 = \frac{1}{3} \times (2.17\times10^{23}) \times 1.8\times10^{24} \times \bar{c}^2$

$\bar{c}^2 = 1.8\times10^{-45}$

$\bar{c} = 4.2\times10^{-23}$

internal energy = 36 ~~$\times10^{3}$~~ J [4] 0

Examiner Comment

This candidate started well with her assumptions but lost a mark saying simply that *m* was "mass" but with no indication that it was the mass of a molecule. In part **(c)** the mistake of putting the temperature into kelvin by *subtracting* 273 from the Celsius temperature was followed by having the mass of (a molecule?) as 1.8 x 10^{+24}, resulting in no marks being given for **(c)**. Candidates should be aware of the physical significance of the quantities they are using in calculations so they can avoid giving answers of clearly incorrect magnitude.

Example Candidate Response – Pass

4 **(a)** State three assumptions made in deriving the equation $pV = \frac{1}{3}Nm<c^2>$ from the kinetic theory model of a gas.

1. Volume of gas is constant

2. gas pressure is constant ^ ^ ^

3. constant temperature of gas.

[3] 0

(b) Give the meaning of each symbol in the equation given in **(a)**. ✓

p Pressure

V Volume

N number of moles

m mass of gas ✗

$<c^2>$ mean speed squared ✗

[3] 1

(c) Determine the internal energy of 0.36 mol of an ideal gas at a temperature of 350 °C.

PV=nkT

^

internal energy = ... J [4] 0

Examiner Comment

This Pass candidate did not know what was meant by the assumptions of the kinetic theory; he got 1 mark for knowing *p* and *V*.

4 **(a)** State three assumptions made in deriving the equation $pV = \frac{1}{3}Nm<c^2>$ from the kinetic theory model of a gas.

1. Volume of gas is constant

2. gas pressure is constant ⋀ ⋀ ⋀

3. constant temperature of gas.

[3] 0

(b) Give the meaning of each symbol in the equation given in **(a)**. ✓

p Pressure

V Volume

N number of moles

m Mass of gas ✗

$<c^2>$ mean speed squared ✗

[3] 1

(c) Determine the internal energy of 0.36 mol of an ideal gas at a temperature of 350 °C.

PV=nkT

⋀

internal energy = ... J [4] 0

Examiner Comment

This Pass candidate did not know what was meant by the assumptions of the kinetic theory; he got 1 mark for knowing *p* and *V*.

Question 5 Mark Scheme

(a) $^{210}_{84}\mathrm{Po} \Rightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$

polonium symbol and helium symbol correct (or helium as alpha particle) (1)
lead symbol correct and equation numbers correct (1) [2]
OR top numbers correct (1), bottom numbers correct (1)

(b) 1 eV = 1V × e = 1.6×10^{-19} J (1)
1 MeV = 1.6×10^{-13} J so 5.2 MeV = $1.6 \times 10^{-13} \times 5.2 = 8.32 \times 10^{-13}$ J (1) [2]

(c) 2500 W / 8.32×10^{-13} J (1)
= $3.00 \times 10^{15}\,\mathrm{s}^{-1}$ (1) [2]

(d) **(i)** decay constant λ = ln 2 / time constant: 138 days = 1.192×10^{7} s (1)
decay constant = ln 2 / $1.192 \times 10^{7} = 5.81 \times 10^{-8}\,\mathrm{s}^{-1}$ (1) [2]

(ii) N = rate of decay / λ = $3.0 \times 10^{15} / 5.81 \times 10^{-8} = 5.16 \times 10^{22}$ (1)
210 g of Polonium contain 6.02×10^{23} molecules (1)
mass required = 210 g × 5.16 / 60.2 = 18 g (1) [3]

(e) alpha particles are absorbed in around 7 cm of air so
will be absorbed within a few mm of being produced in polonium
the energy is therefore contained as heat within the polonium
less dangerous radiation emitted for those preparing the satellite
2 comments expected; [1] mark each [2]

(f) mass: with a longer half-life (the decay constant will be much smaller)
to get the same heating effect will therefore require a much greater mass (1)
half-life: being longer will mean that power is supplied for a longer time
(than the mission is likely to last) (1)
the short half-life will mean that the power output will drop significantly
(even on a comparatively short mission) (1)
safety: not much difference assuming that the count rate is the same (1) [4]

[Total: 17]

Example Candidate Response – Distinction

5 A spacecraft to be sent to explore the outer planets could be provided with a radioactive source of polonium-210 as a source of energy. Alpha particles of average energy 5.2 MeV are emitted and cause the temperature of the polonium to rise.

(a) The proton number of polonium is 84. Write a nuclear equation for the decay of a polonium (Po) nucleus into a lead (Pb) nucleus.

$$^{210}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\alpha + {}^{206}_{82}\mathrm{Pb}$$

✓✓ 2

[2]

(b) Convert an energy of 5.2 MeV into joules.

$5.2\times10^{6}\ \mathrm{eV} \times 1.60\times10^{-19}\ \mathrm{C}$

$=$ ~~[illegible]~~ $8.32\times10^{-13}\ \mathrm{J}$

✓✓ 2

energy = 8.3×10^{-13} J [2]

(c) Calculate the decay rate required for a power of 2500 W.

$$\frac{2500\ \mathrm{Js^{-1}}}{8.3\times10^{-13}\ \mathrm{J}}$$

$= 3.00\times10^{15}\ \mathrm{s^{-1}}$

✓✓ 2

rate = 3.00×10^{15} $\mathrm{s^{-1}}$ [2]

For Examiner's Use

(d) The half-life of polonium-210 is 138 days. Calculate

(i) its decay constant λ,

$t_{\frac{1}{2}} = (138 \times 24 \times 3600)\,s$

$= 11923200\ s$

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

$= \frac{\ln 2}{11923200s}$

$= 5.81 \times 10^{-8}\ s^{-1}$

✓✓

$\lambda =$ 5.81×10^{-8} s^{-1} [2]

2

(ii) the mass of polonium required to provide 2500 W.

$A = \lambda N$

$N = \frac{A}{\lambda}$

$= \frac{3.00 \times 10^{15}\ s^{-1}}{5.81 \times 10^{-8}\ s^{-1}}$ ✓

$= 5.16 \times 10^{22}$ atoms. ✓

$m = \frac{5.16 \times 10^{22}}{6.02 \times 10^{23}\ mol^{-1}} \times 210g\ mol^{-1}$ ✓

$= 18.00\ g = 0.0180kg.$

mass = 0.0180 kg [3]

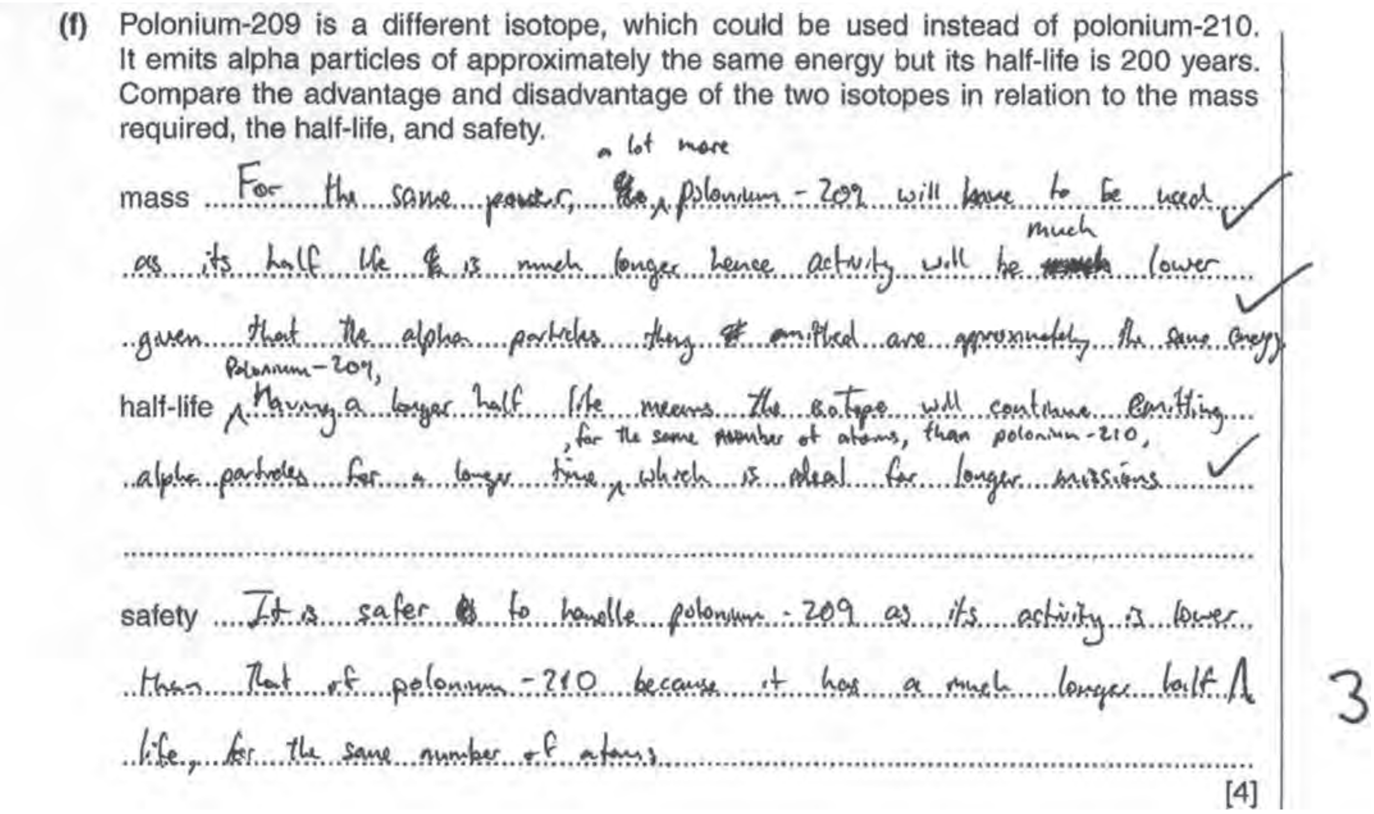
3

(e) Suggest and explain why it is an advantage, for this application, that this source produces alpha particles rather than beta particles or gamma rays.

~~For use a radioactive~~ Alpha ~~particles~~ radiation are the least penetrating form of radiation, that means that nearly ~~al~~ all of the ~~energy~~ particles emitted from ✓ the source can be absorbed. More penetrating radiation like beta and gamma will pass through the walls of the container without transferring much energy.

[2]

1



(f) Polonium-209 is a different isotope, which could be used instead of polonium-210. It emits alpha particles of approximately the same energy but its half-life is 200 years. Compare the advantage and disadvantage of the two isotopes in relation to the mass required, the half-life, and safety.

mass For the same power, ~~the~~ a lot more polonium-209 will have to be used as its half life ~~is~~ is much longer hence activity will be ~~much~~ much lower given that the alpha particles they ~~#~~ emitted are approximately the same energy ✓ ✓

half-life Polonium-209, Having a longer half life means the isotope will continue emitting alpha particles for a longer time, for the same number of atoms, than polonium-210, which is ideal for longer missions ✓

safety It is safer ~~is~~ to handle polonium-209 as its activity is lower than that of polonium-210 because it has a much longer half life, for the same number of atoms. Λ

[4]

3

Examiner Comment

Distinction candidates had no problems with either the bookwork or the quantitative parts of this question. This candidate answered all of parts **(a)** – **(d)** correctly and in part **(e)** only lost a mark by not giving some extra detail such as typical penetration of alpha particles in comparison with beta particles or gamma rays. In part **(f)** he made a minor mistake because he stated that the activity of the two isotopes is different.

Example Candidate Response – Merit

5 A spacecraft to be sent to explore the outer planets could be provided with a radioactive source of polonium-210 as a source of energy. Alpha particles of average energy 5.2 MeV are emitted and cause the temperature of the polonium to rise.

(a) The proton number of polonium is 84. Write a nuclear equation for the decay of a polonium (Po) nucleus into a lead (Pb) nucleus.

$$^{210}_{84}Po \rightarrow ^{4}_{2}\alpha + ^{206}_{82}Pb$$

✓ ✓

2

[2]

(b) Convert an energy of 5.2 MeV into joules.

$5200000 \times 1.6\times10^{-19}$

✓ ✓

2

energy = 8.32×10^{-13} J [2]

(c) Calculate the decay rate required for a power of 2500 W.

$P=FV$ $W=Fd$ $P\times t=W$ $P=\frac{W}{t}$

$P=F\frac{d}{t}$

3×10^{13} sec

$$\frac{dN}{dt}=-\lambda N$$

~~8.23~~

$2500=\frac{8.32\times10^{-13}}{t}$ ✗

$t=3.3\times10^{-16}$

0

rate = ~~3×10^{-15}~~ 3.3×10^{16} s^{-1} [2]

(d) The half-life of polonium-210 is 138 days. Calculate

(i) its decay constant λ,

$138 = \frac{\ln 2}{\lambda}$ ✓

✓

$\lambda =$ 5.02 s^{-1} [2]

1

(ii) the mass of polonium required to provide 2500 W.

$\underline{5.02 \times 3 \times 10^{15}} = \lambda N$

~~$P = \frac{W}{t}$~~

~~$210 \times 3 \times 10^{15}$~~

~~$\left(\frac{6.02 \times 10^{23}}{3 \times 10^{15}}\right)^{-1} \times 210$~~

~~$0.000001\,g$~~

~~$N = N_0 e^{-\lambda t}$~~

ecf

$\frac{3.3 \times 10^{16}}{5.02} = 6.57 \times 10^{15}$ ✓

$\frac{6.57 \times 10^{15}}{6.02 \times 10^{14}} = 1.1 \times 10^{-5}$

$1.1 \times 10^{-5} \times 210$

mass = 2.24×10^{-3} ~~1×10^{-9}~~ kg [3]

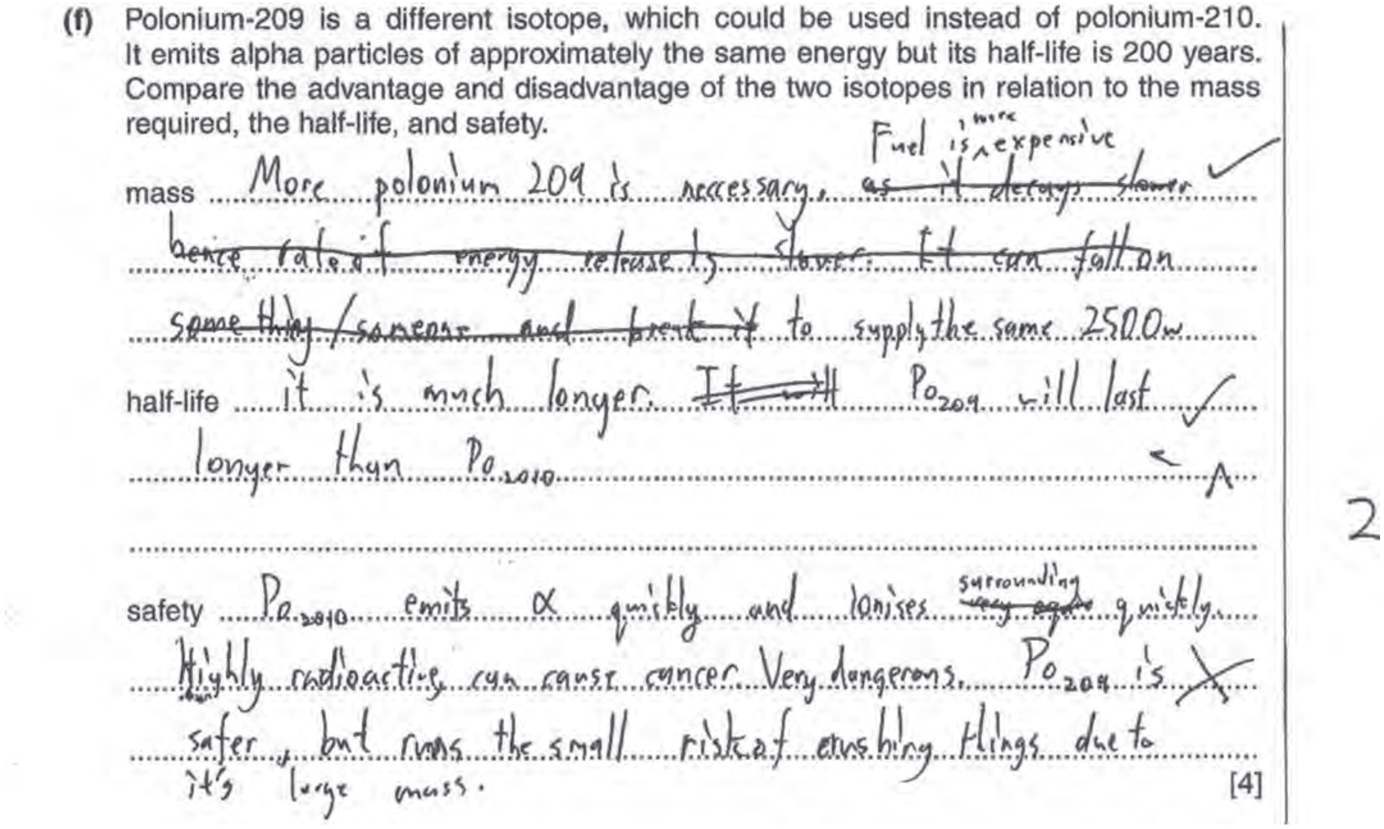
1

(e) Suggest and explain why it is an advantage, for this application, that this source produces alpha particles rather than beta particles or gamma rays.

It does not affect equipment if contained by small ✓ amounts of shielding as α particles cannot travel very far, but produces alot of energy. ✓

[2]

2



(f) Polonium-209 is a different isotope, which could be used instead of polonium-210. It emits alpha particles of approximately the same energy but its half-life is 200 years. Compare the advantage and disadvantage of the two isotopes in relation to the mass required, the half-life, and safety.

mass More polonium 209 is neccessary. Fuel is more expensive ~~as it decays slower hence rate of energy release is slower. It can fall on some thing / someone and break it~~ to supply the same 2500w ✓

half-life it is much longer. ~~It will~~ Po_{209} will last longer than Po_{2010} ✓

safety Po_{2010} emits α quickly and Ionises surrounding ~~very~~ [illegible] quickly. Highly radioactive can cause cancer. Very dangerous. Po_{209} is safer, but runs the small risk of crushing things due to it's large mass. ✗

[4]

2

Examiner Comment

This candidate correctly answered parts **(a)** and **(b)** but in **(c)** he made a careless mistake with the energy equation. Once he obtained an impossible answer he switched the answer he had, from 3.3 x 10^{-16} to 3.3 x 10^{+16}. If candidates attach units to their numbers, when dealing with simple three term equations, they will not make such mistakes. Here the correct answer was crossed out. In part **(d)** he used a time in days and assumed it was in seconds. Error carried forward was very important for this candidate. Answers to **(e)** and **(f)** added a few more marks but he did not emphasise the extra mass of the polonium-209 or that a short half-life of the polonium-210 will result in output power falling appreciably during an expedition to outer planets.

Example Candidate Response – Pass

5 A spacecraft to be sent to explore the outer planets could be provided with a radioactive source of polonium-210 as a source of energy. Alpha particles of average energy 5.2 MeV are emitted and cause the temperature of the polonium to rise.

(a) The proton number of polonium is 84. Write a nuclear equation for the decay of a polonium (Po) nucleus into a lead (Pb) nucleus.

$$^{210}_{84}Po \longrightarrow {}^{4}_{2}\alpha + {}^{206}_{82}Pb$$ ✓ ✓

[2] 2

(b) Convert an energy of 5.2 MeV into joules.

∧

3·1x10^5 ✗

~~8.01~~

energy = ...[illegible]......... J [2] 0

(c) Calculate the decay rate required for a power of 2500 W.

rate = ... s^{-1} [2]

(d) The half-life of polonium-210 is 138 days. Calculate

(i) its decay constant λ,

$138 = \frac{\ln 2}{\lambda}$

$\lambda = \frac{\ln 2}{138}$ ^

$\lambda =$ ....5×10^{-3}.... s^{-1} [2] 0

(ii) the mass of polonium required to provide 2500W.

mass = ... kg [3]

(e) Suggest and explain why it is an advantage, for this application, that this source produces alpha particles rather than beta particles or gamma rays.

alpha particle are highly ionising ✓

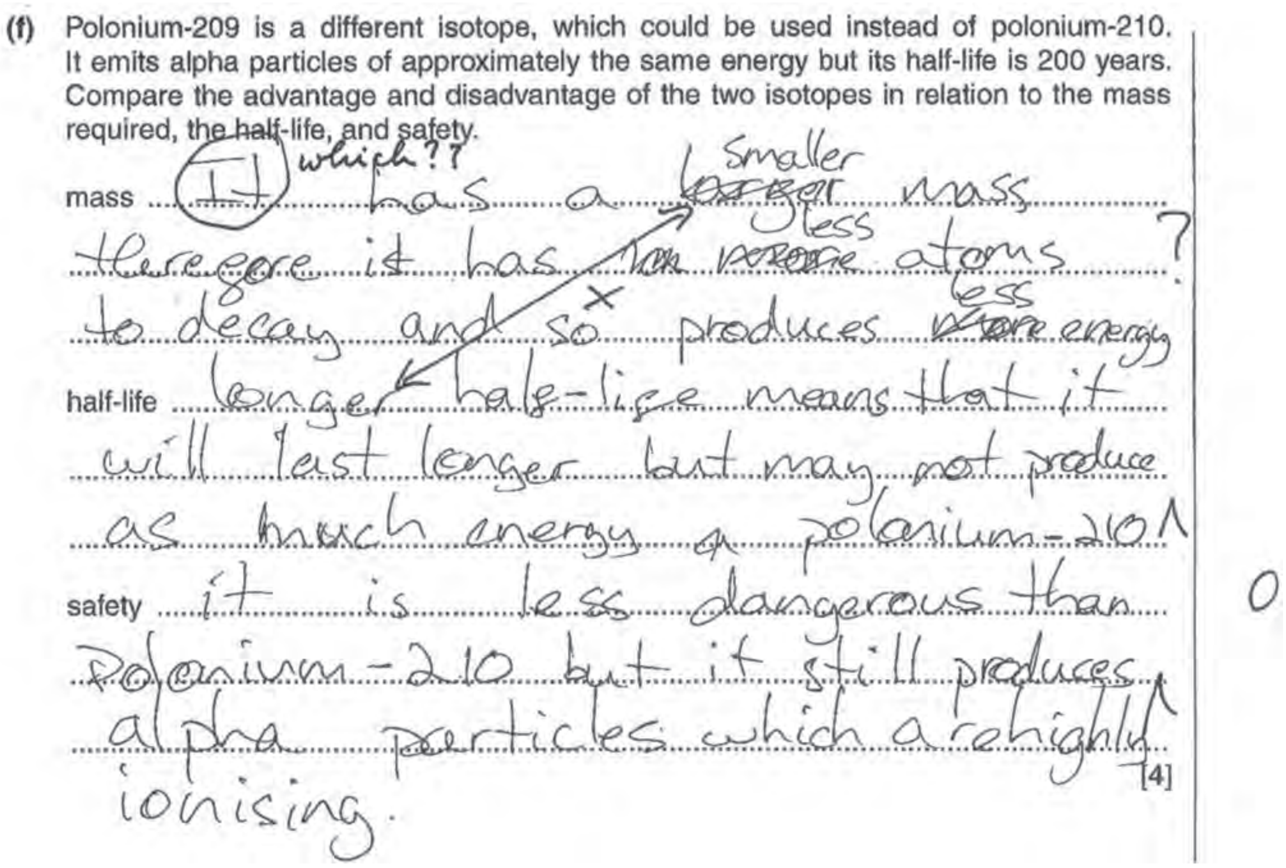
but not deeply penetrating ✓

there more energy is focused

on a smaller area ~~the heat~~ therefore

the temperature rises more

quickly [2] 1



(f) Polonium-209 is a different isotope, which could be used instead of polonium-210. It emits alpha particles of approximately the same energy but its half-life is 200 years. Compare the advantage and disadvantage of the two isotopes in relation to the mass required, the half-life, and safety.

which??

mass It has a ~~larger~~ smaller mass therefore it has ~~[illegible]~~ ~~more~~ less atoms to decay and so produces ~~more~~ less energy ?

×

half-life longer half-life means that it will last longer but may not produce as much energy a polonium-210

safety it is less dangerous than Polonium-210 but it still produces alpha particles which are highly ionising.

[4]

0

Examiner Comment

This candidate struggled with this question. He had the nuclear equation correct but could not convert MeV into joules so could not do part **(c)**. In part **(d)** the candidate confused days and seconds so no marks were given. His answer to **(e)** scored 1 mark but answer **(f)** was unclear. He did not say which isotope he was writing about and he did not appreciate that the mass of the two isotopes will be different if the output power is to be the same.

Question 6 Mark Scheme

(a) $\Delta\lambda = 137.6$ nm $= 1.376 \times 10^{-7}$ m (1)
$v = c\Delta\lambda / \lambda = 3.00 \times 10^{8} \times 1.376 \times 10^{-7} / 4.861 \times 10^{-7} = 8.49 \times 10^{7}\,\text{m}\,\text{s}^{-1}$ (1) [2]

(b) The recession velocity of a (distant) galaxy (1)
is directly proportional to its distance (1) [2]
OR *v* = *HD* (1) with symbols explained (1)

(c) a unique point at which space and matter started – the Big Bang (1)

\+ if everything is moving away from everything else then space is increasing;
idea that it is space that is increasing not that the space was there already;
the future of the Universe can (in theory) be programmed;
when (the computer programme) working backwards in time all the galaxies get closer together and end up at a point;
space shrinks;
3 additional comments expected: [1] mark each (3) [4]

(d) hubble constant is the reciprocal of the age of the Universe (1)
time $= 1 / 2.3 \times 10^{-18} = 4.35 \times 10^{17}$ s (= 13.8 billion years) (1) [2]

[Total: 10]

Example Candidate Response – Distinction

6 **(a)** The line spectrum of light from a distant galaxy has a known line in the hydrogen spectrum of wavelength 623.7 nm. The wavelength of the same line, when measured in the laboratory, has wavelength 486.1 nm. Calculate the speed of recession of the galaxy using the equation

$$\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}.$$

$$\frac{(623.7 - 486.1)}{623.7} \checkmark \approx \frac{v}{3\times10^{8}} \times$$

speed of recession ≈ 6.6×10^{7} m s^{-1} [2]

1

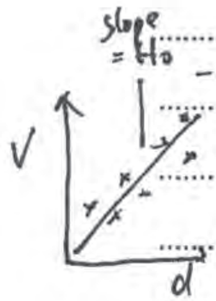
(b) State Hubble's law.

v = Hd

The law states that $V = H_0 d$, where V is the recession ~~velocity~~ speed ~~in [illegible]~~, H_0 is the Hubble [illegible] constant (which is subject to debate), and d is the distance between the observer and the observed object (i.e. star) [2] ✓ ✓ 2

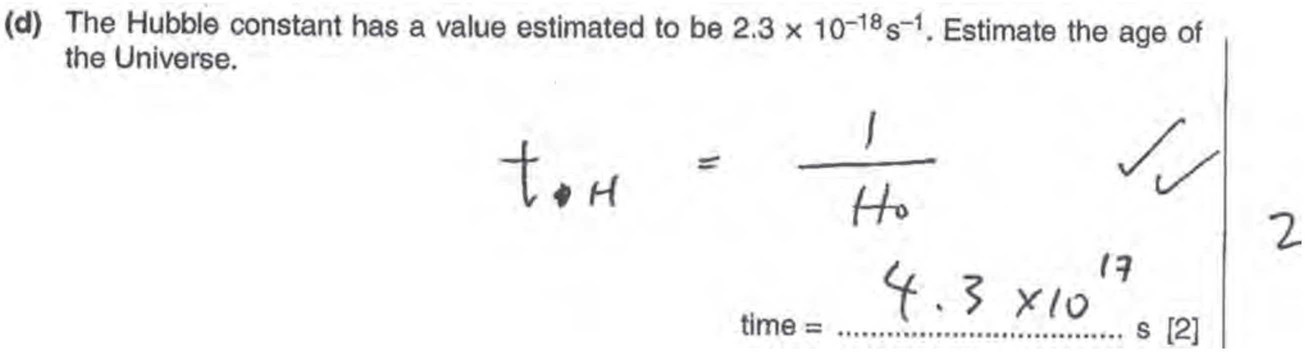
(c) Explain how redshift leads to the ideas of the expanding Universe and to the Big Bang theory.

- Redshift shows that objects in the Universe seem to have larger wavelength than they do and it increases as a function of time, ✓ suggesting that the objects are moving further away from us.



- Hubble found that $\frac{V}{d}$ is ~~a~~ roughly a ~~proportional~~ constant (H_0) empirically from observation, where V is the ~~speed velocity~~ of recession and d is the distance away from us, meaning that the further an object is from us, the faster is its ~~velocity~~ speed relative to us, meaning that the Universe is expanding ✓
- This ~~subject~~ suggests that back in the past, their recession ~~velocity~~ speed ~~[illegible]~~ is lower and that ~~at the [illegible] [illegible]~~ di there must be ✓ a point at which the Universe just began to expand, which is thought to be the [4] Big Bang. ✓ 4

∴ - The existence of cosmic microwave background also ~~suggests~~ supports the theory that Big Bang happened at the beginning of the Universe



(d) The Hubble constant has a value estimated to be 2.3 × $10^{-18}\,s^{-1}$. Estimate the age of the Universe.

$$t_H = \frac{1}{H_0}$$ ✓✓

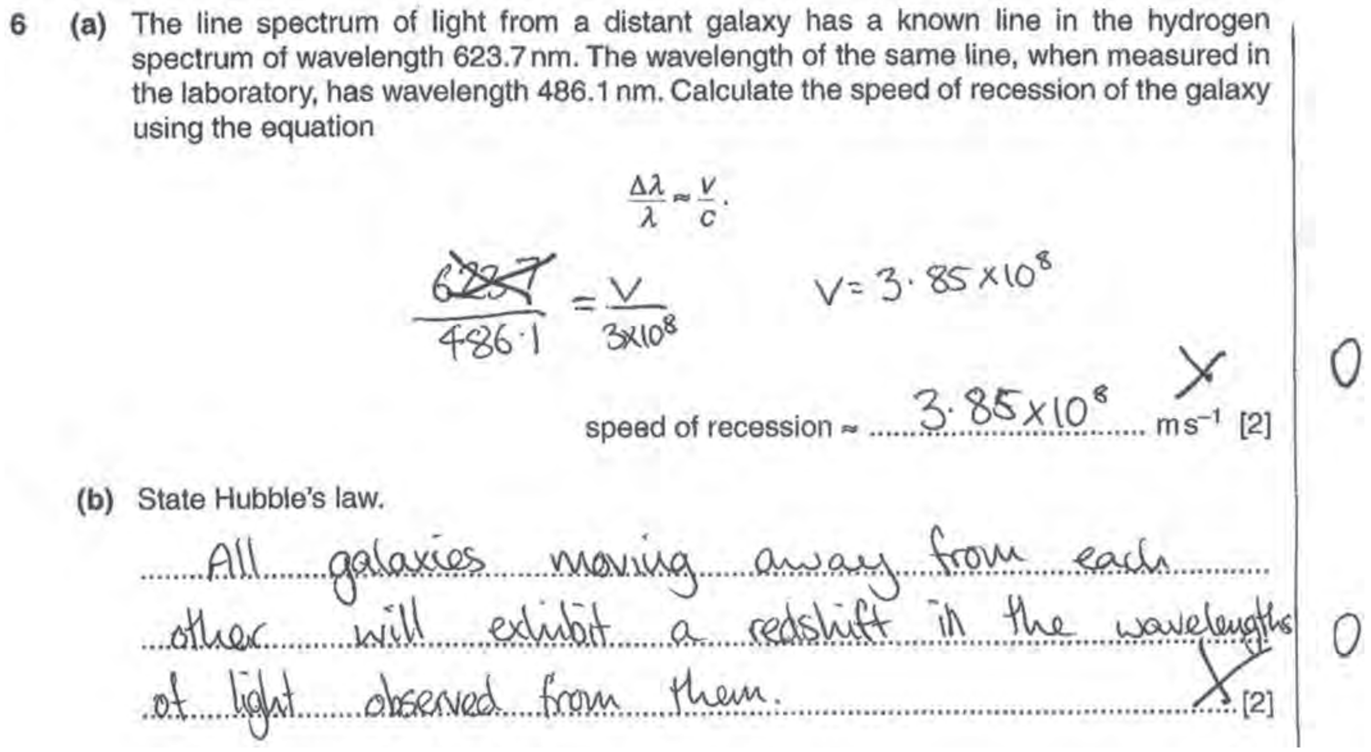
time = 4.3×10^{17} s [2]

2

Examiner Comment

This candidate produced a very good answer to this question. His only mistake was to use the incorrect wavelength on the bottom of his expression in part **(a)**. Good candidates can and do score full marks on descriptive questions. They are able to find enough *different* comments to make. Weaker candidates tend to make too few responses and repeat themselves.

Example Candidate Response – Merit



6 (a) The line spectrum of light from a distant galaxy has a known line in the hydrogen spectrum of wavelength 623.7 nm. The wavelength of the same line, when measured in the laboratory, has wavelength 486.1 nm. Calculate the speed of recession of the galaxy using the equation

$$\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}.$$

$$\frac{\cancel{6237}}{486{\cdot}1} = \frac{V}{3\times10^8} \qquad V = 3{\cdot}85\times10^8$$

speed of recession ≈ $3{\cdot}85\times10^8$ m s^{-1} [2] ✗

0

(b) State Hubble's law.

All galaxies moving away from each other will exhibit a redshift in the wavelengths of light observed from them. ✗ [2]

0

(c) Explain how redshift leads to the ideas of the expanding Universe and to the Big Bang theory.

As all of the galaxies around us are exibiting redshift we know that they are ✓ moving away from us, or that we are moving away from them. Galaxies further away from us are ~~[illegible]~~ exibiting larger redshift ✓ and so are moving away quicker. This leads to the idea that all the galaxies are moving away from one common point – galaxies ✓ further away are travelling quicker, and galaxies closer are moving less quickly. This means that the Universe is ~~a~~ constantly expanding, and supports the idea of the Big Bang where ✓ all the galaxies were formed from one ✓ common position and time. [4]

3

(d) The Hubble constant has a value estimated to be 2.3 × 10^{-18} s^{-1}. Estimate the age of the Universe.

$$\frac{1}{2.3\times10^{-18}} = 4.35\times10^{17}\ \text{secs}$$ ✓

✓

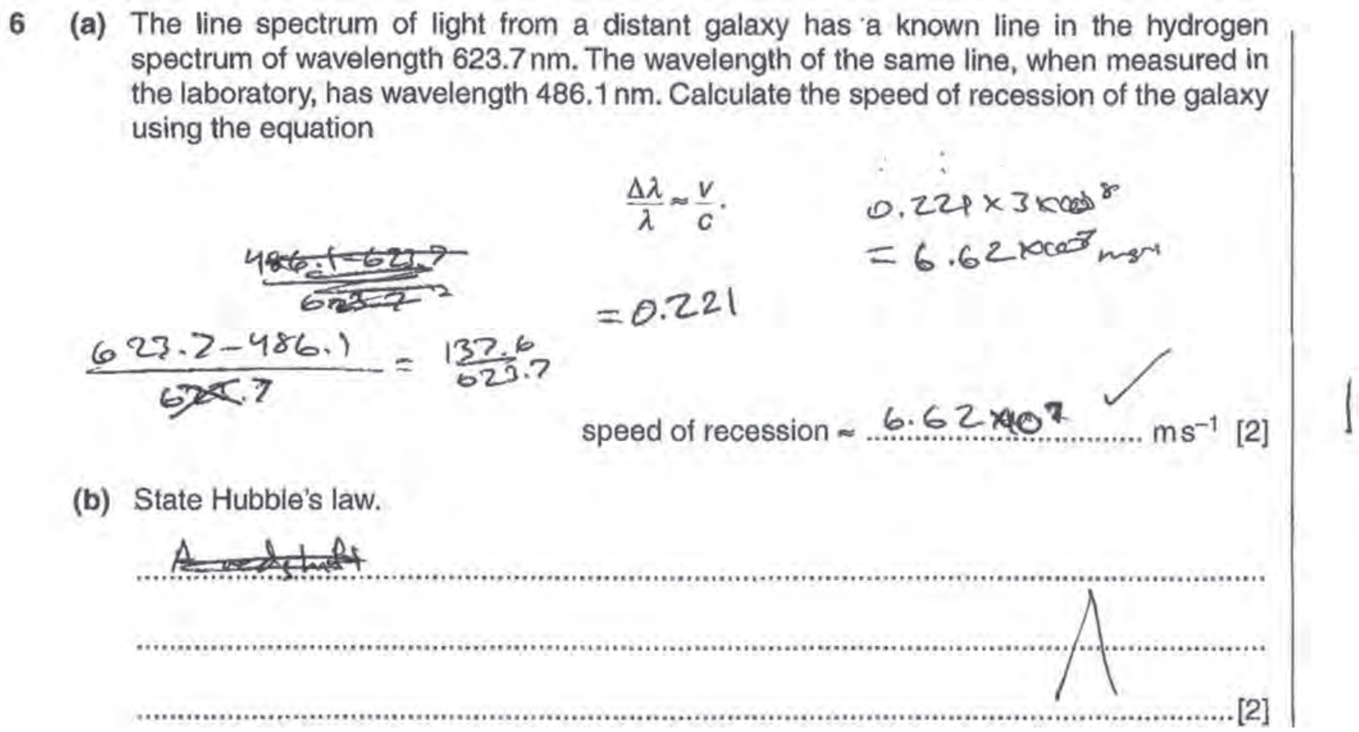
time = 4.35×10^{17} s [2]

2

Examiner Comment

This candidate spoilt his answer by not using the wavelength difference in part **(a)**. The fact that his answer for the speed of recession was greater than the speed of light did not seem to worry him and he wrote it down twice. His answer to part **(b)** showed that he did not know the Hubble law. From this point on, his answer was good. He made three distinct points about the expanding Universe and correctly calculated the age of the Universe in part **(d)**.

Example Candidate Response – Pass



6 **(a)** The line spectrum of light from a distant galaxy has a known line in the hydrogen spectrum of wavelength 623.7 nm. The wavelength of the same line, when measured in the laboratory, has wavelength 486.1 nm. Calculate the speed of recession of the galaxy using the equation

$$\frac{\Delta\lambda}{\lambda} \approx \frac{v}{c}.$$

~~$\frac{486.1-623.7}{623.7}$~~

$\frac{623.7-486.1}{623.7} = \frac{137.6}{623.7}$

$= 0.221$

$0.221 \times 3\times10^{8}$

$= 6.62\times10^{7}$ ms^{-1}

speed of recession ≈ 6.62×10^{7} ✓ ms^{-1} [2]

(b) State Hubble's law.

~~A redshift~~

[2]

(c) Explain how redshift leads to the ideas of the expanding Universe and to the Big Bang theory.

A redshift Indicates that the galaxy in question is heading away from our galaxy. ✓ This has lead to the idea that if galaxies are getting farther and farther apart, the Universe itself must be getting bigger and bigger. Thus the Universe is constantly expanding. But for this to happen the galaxies and the Universe as a whole, must have started off at a single point. From there, the ✓ Universe and its galaxies began as stated in the Big Bang theory, when there was a large explosion that sent galaxies flying off into different directions, as we can see as redshifts today.

..................[4]

3

(d) The Hubble constant has a value estimated to be 2.3 × 10^{-18} s^{-1}. Estimate the age of the Universe.

λ

time = ... s [2]

0

Examiner Comment

This candidate used the incorrect denominator in **(a)**. After gaining 3 marks from a sensible answer to **(c)** he was unable to relate the age of the Universe to the Hubble constant in **(d)**.

Question 7 Mark Scheme

(a) Recall sin $c = 1/n$ (1)

sin 24° = 0.41322 = 2.42^{-1}

$n = 2.46$ (2.4586) (1) [2]

(b) **(i)** $n = 2.46 = \dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{\sin\theta_1}{\sin 19}$

$\theta_1 = 53.2°$ [1]

(ii)

Wave Property of the light	**Effect**			
	Increase	Unchanged	Decrease	
Speed	✓			(1)
Wavelength	✓			(1)
Frequency		✓		(1)

[3]

(c) **(i)** Substitution in $\omega = 2\pi f$ (1)

$$\omega = \frac{2\pi 4000}{60} = 2\pi 66.7 = 418.8$$

[Ignore failure to convert to revs per second i.e., ω = 25133 rads^{-1}]

ω = 418.8 *or* 419 (rads^{-1}) (1) [2]

(ii) Idea that diamond is harder than phosphor-bronze. (1) [1]

(d)

Linear motion	**Rotational motion**	
Work = force × displacement	Work = torque × angular displacement	(1)
Momentum = mass × velocity	Angular momentum = moment of inertia × angular velocity Allow mass × velocity × distance to centre DO NOT allow angular speed as an alternative to angular velocity	(1) [2]

Answers must be in words, as requested.

(e) **(i)** Expression for mass of one of the concentric rings

$dm = 2\pi rpt.dr$ (1)

Basic expression for the moment of inertia

$I = \int r^2 dm$ (1)

Integration expression for the disc

$$I = \int_0^R r^2 2\pi r\rho t.dr = \rho 2\pi t \int_0^R r^3 dr$$ (1)

Substitution of $M = \pi R^2 \rho t$ *into* $I = \frac{R^4 \rho \pi t}{2}$

to give final expression for moment of inertia $I = \frac{MR^2}{2}$ (1) [4]

(ii) Substitution in correct formula for I (ignore errors in powers of 10) (1)

$$R^2 = \frac{2I}{M} = 2\frac{1.13 \times 10^{-4}}{35.4 \times 10^{-3}}$$

$R = 8.0$ cm or 8×10^{-2} (m) (1) [2]

(iii) RKE = ½ $I\omega^2$ (1)

Substitution RKE = ½[$1.13 \times 10^{-4} \times$ {418.8 or their value for $\omega\}^2$ (1)

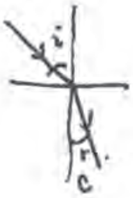
Correct answer only. RKE = 9.9(1) (J) (1) [3]

[Total: 20]

Example Candidate Response – Distinction

7 Diamonds sparkle because light entering the diamond undergoes numerous internal reflections before emerging.

Fig. 7.1 shows the path of a ray of light through a diamond.



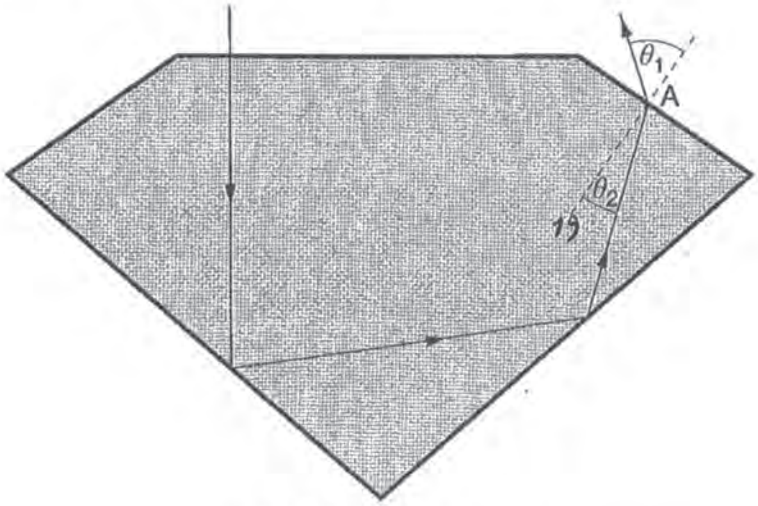


Fig. 7.1 (not to scale)

(a) The critical angle of light in diamond is 24°. Calculate the refractive index n of diamond to 2 decimal places.

$$n = \frac{\sin 90°}{\sin 24°}$$

✓✓ 2

n = 2.46 (2d.p.) [2]

(b) The ray finally emerges at the point labelled A. The angle of incidence θ_2 within the diamond is 19.0°.

(i) Calculate the angle of refraction θ_1 in air.

$$\frac{\sin \theta_1}{\sin \theta_2} = n$$

✓ 1

θ_1 = 53.2 (2d.p.) [1]

(ii) Place ticks in the table below to identify the effect on waves of light as they refract from diamond into air at A.

wave property of the light	**effect**		
	increase	unchanged	decrease
speed	✓		
wavelength	✓		
frequency		✓	

↑ $v = f\lambda$

✓ ✓ ✓ 3

[3]

(c) A very thin phosphor-bronze disc is used to saw through rough uncut diamonds. The disc rotates about a horizontal axis at 4000 revolutions each minute.

(i) Calculate the angular speed ω of the disc. rev min⁻¹

$$\omega = \frac{4000 \times 2\pi}{60}$$

420 (2sf) ✓ ✓ 2

~~1.5×10^5 (2sf)~~

ω = ... rad s^{-1} [2]

(ii) The rim of the disc is initially impregnated with diamond dust, which is replenished as the diamond is cut. Without this dust, the disc would fail to cut through the diamond. What does this tell us about the relative hardness of diamond and phosphor-bronze?

~~The~~ ~~diamond~~ Diamond is harder than ~~the~~ phosphor-bronze. ✓ 1

[1]

(d) Laws of rotational motion can be deduced by comparison with Newton's laws of linear motion.
Complete the table below by stating the equivalent formulae, in words, for rotational motion.

linear motion	**rotational motion**
work = force × displacement	angular work = Torque × angular displacement ✓
momentum = mass × velocity	angular momentum = moment of inertia × angular velocity ✓

[2]

2

(e) Fig. 7.2a and Fig. 7.2b show a phosphor-bronze cutting disc of mass M and thickness t with radius R. The uniform density of the disc is ρ.

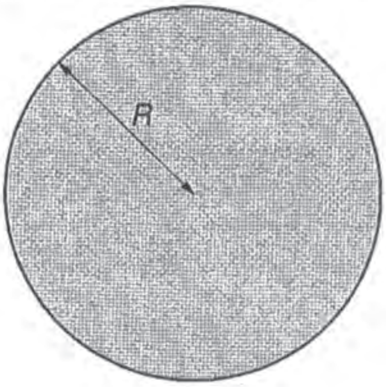


Fig. 7.2a (front view)

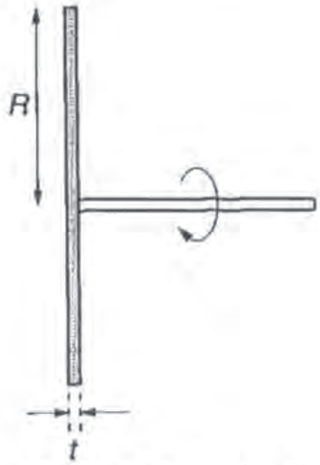
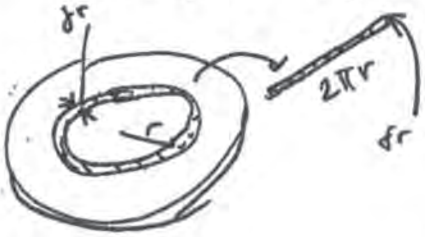


Fig. 7.2b (side view)

(i) Use integration to derive an expression for the moment of inertia I of the disc. You may draw on Fig. 7.2a to help illustrate your working.



$$\frac{\delta A}{A} = \frac{\delta m}{M}$$

$$\delta A = 2\pi r\,\delta r \quad ✓$$

$$I = \int_0^R r^2\, dm$$

$$= \int_0^R r^2 \frac{M \delta A}{A} \quad ~~dm~~ \quad ✓$$

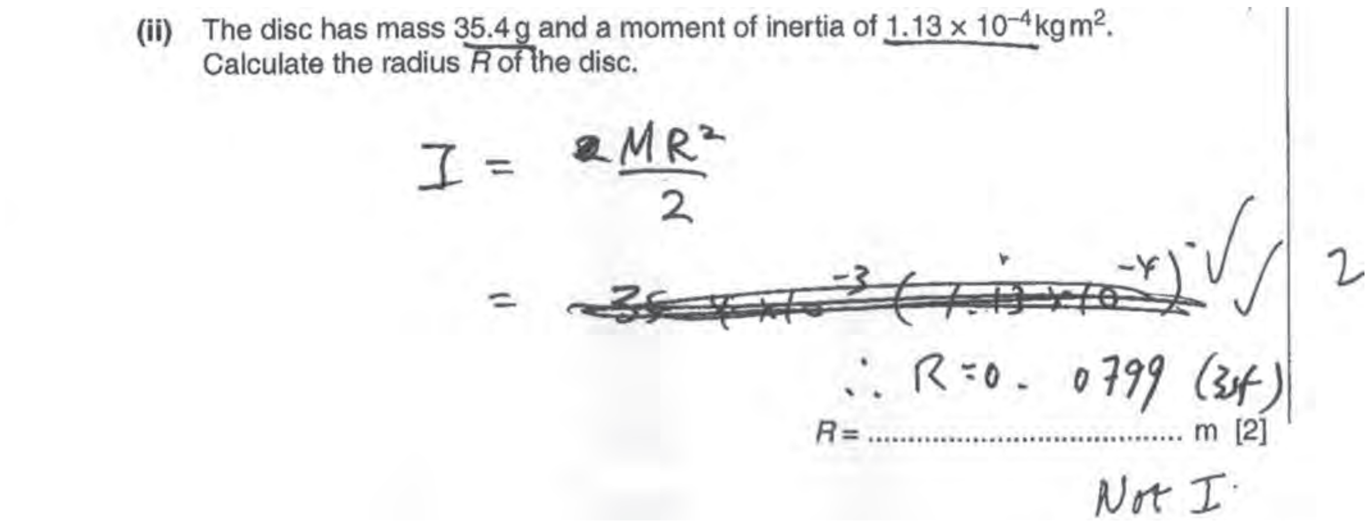
$$= \int_0^R r^2 \frac{M 2\pi r\,\delta r}{\pi R^2} \quad ✓$$

$$= \frac{2M}{R^2}\int_0^R r^3\,\delta r$$

$$= \frac{2M}{R^2}\left[\frac{r^4}{4}\right]_0^R = \frac{MR^2}{2} \quad ✓$$

[4]

4



(ii) The disc has mass 35.4 g and a moment of inertia of 1.13 x 10^{-4} kg m^2.
Calculate the radius *R* of the disc.

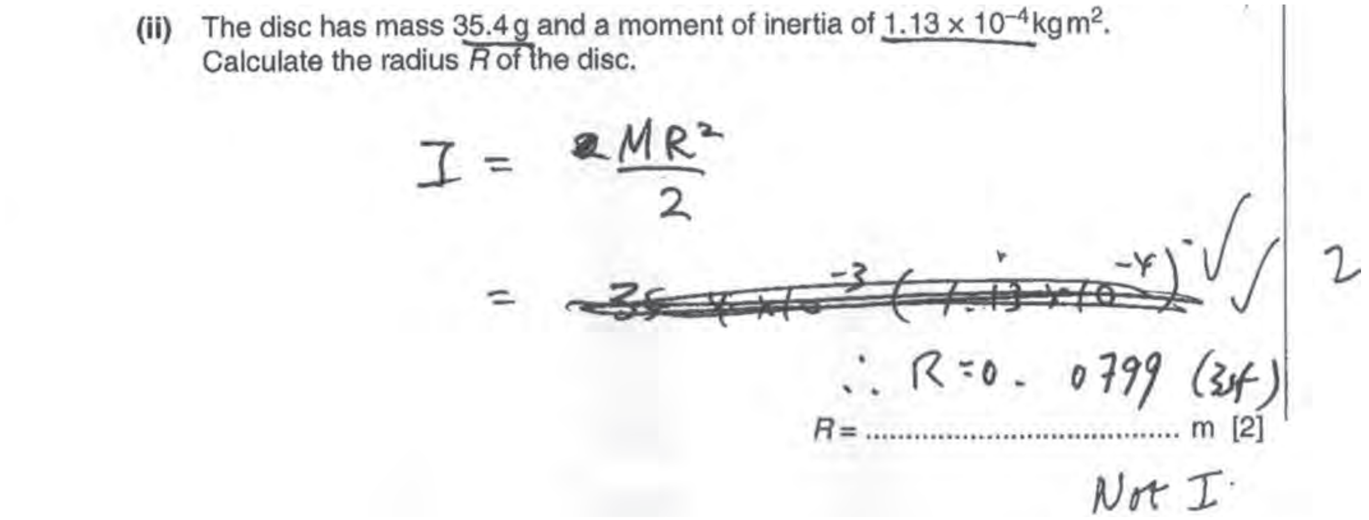
$$I = \frac{\cancel{2}MR^2}{2}$$

$= $ ~~$35.4 \times 10^{-3} (1.13 \times 10^{-4})$~~ ✓ ✓ 2

$\therefore R = 0.0799$ (3sf)

R = ... m [2]

Not I.



(ii) The disc has mass 35.4 g and a moment of inertia of 1.13 x 10^{-4} kg m^2.
Calculate the radius *R* of the disc.

$$I = \frac{\cancel{2}MR^2}{2}$$

$= $ ~~$35.4 \times 10^{-3} (1.13 \times 10^{-4})$~~ ✓ ✓ 2

$\therefore R = 0.0799$ (3sf)

R = ... m [2]

Not I.

Examiner Comment

This candidate completed a nearly flawless answer to the question. All of parts **(a)** – **(d)** gained full marks and the layout of the integration was immaculate in **(e) (i)**. The candidate correctly calculated the radius of the disc in **(e) (ii)** but unfortunately used the numerical value of the radius as if it were the moment of inertia when making his calculation in **(e) (iii)**.

Example Candidate Response – Merit

7 Diamonds sparkle because light entering the diamond undergoes numerous internal reflections before emerging.

Fig. 7.1 shows the path of a ray of light through a diamond.

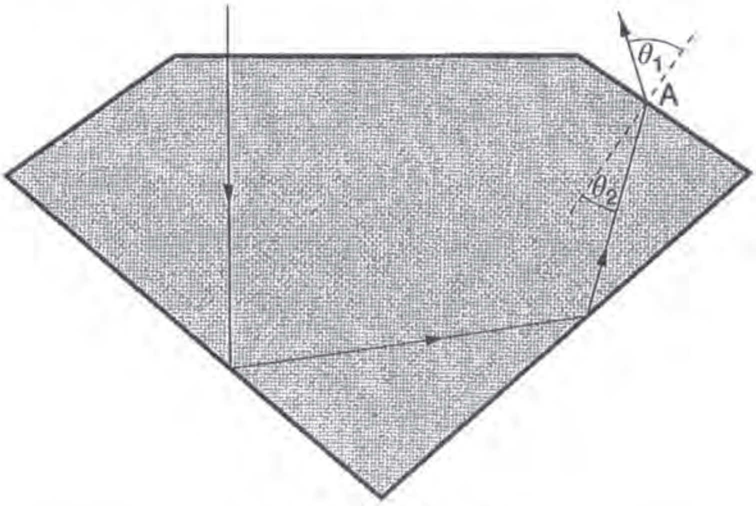


Fig. 7.1 (not to scale)

(a) The critical angle of light in diamond is 24°. Calculate the refractive index n of diamond to 2 decimal places.

$$n = \frac{1}{\sin\theta}$$

$$n = 2.46$$

✓✓ 2

n = 2.46 [2]

(b) The ray finally emerges at the point labelled A. The angle of incidence θ_2 within the diamond is 19.0°.

(i) Calculate the angle of refraction θ_1 in air.

$\theta_1 = 53.2°$

$$n = \frac{\sin\theta_1}{\sin\theta_2}$$

$$2.46 = \frac{\sin\theta_1}{\sin 19}$$

$$2.46 \sin 19 = \sin\theta_1$$

✓ 1

θ_1 = 53.2° [1]

(ii) Place ticks in the table below to identify the effect on waves of light as they refract from diamond into air at A.

wave property of the light	**effect**			
	increase	unchanged	decrease	
speed	✓			✓
wavelength		✓		✗
frequency	✓			✗

[3] 1

(c) A very thin phosphor-bronze disc is used to saw through rough uncut diamonds. The disc rotates about a horizontal axis at 4000 revolutions each minute.

(i) Calculate the angular speed ω of the disc.

$\omega = 2\pi f$ $\frac{4000}{60} \times 2\pi = 418{\cdot}9$ ✓

✓ 2

$\omega =$ 418·9 rad s^{-1} [2]

(ii) The rim of the disc is initially impregnated with diamond dust, which is replenished as the diamond is cut. Without this dust, the disc would fail to cut through the diamond. What does this tell us about the relative hardness of diamond and phosphor-bronze?

diamond is harder than phosphor - ✓ 1

bronze [1]

(d) Laws of rotational motion can be deduced by comparison with Newton's laws of linear motion.
Complete the table below by stating the equivalent formulae, in words, for rotational motion.

linear motion	rotational motion
work = force × displacement	work = torque × angular ~~$I\theta$~~ displacement ✓
momentum = mass × velocity	rotational momentum = moment of inertia ✓ ~~$L = I\omega$~~ × angular velocity

2

[2]

(e) Fig. 7.2a and Fig. 7.2b show a phosphor-bronze cutting disc of mass M and thickness t with radius R. The uniform density of the disc is ρ.

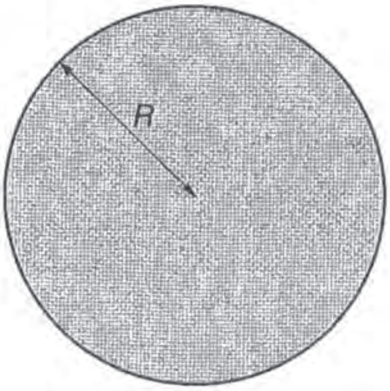


Fig. 7.2a (front view)

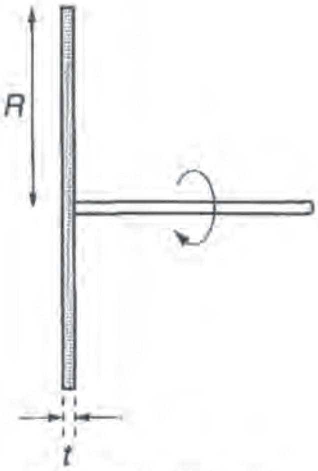
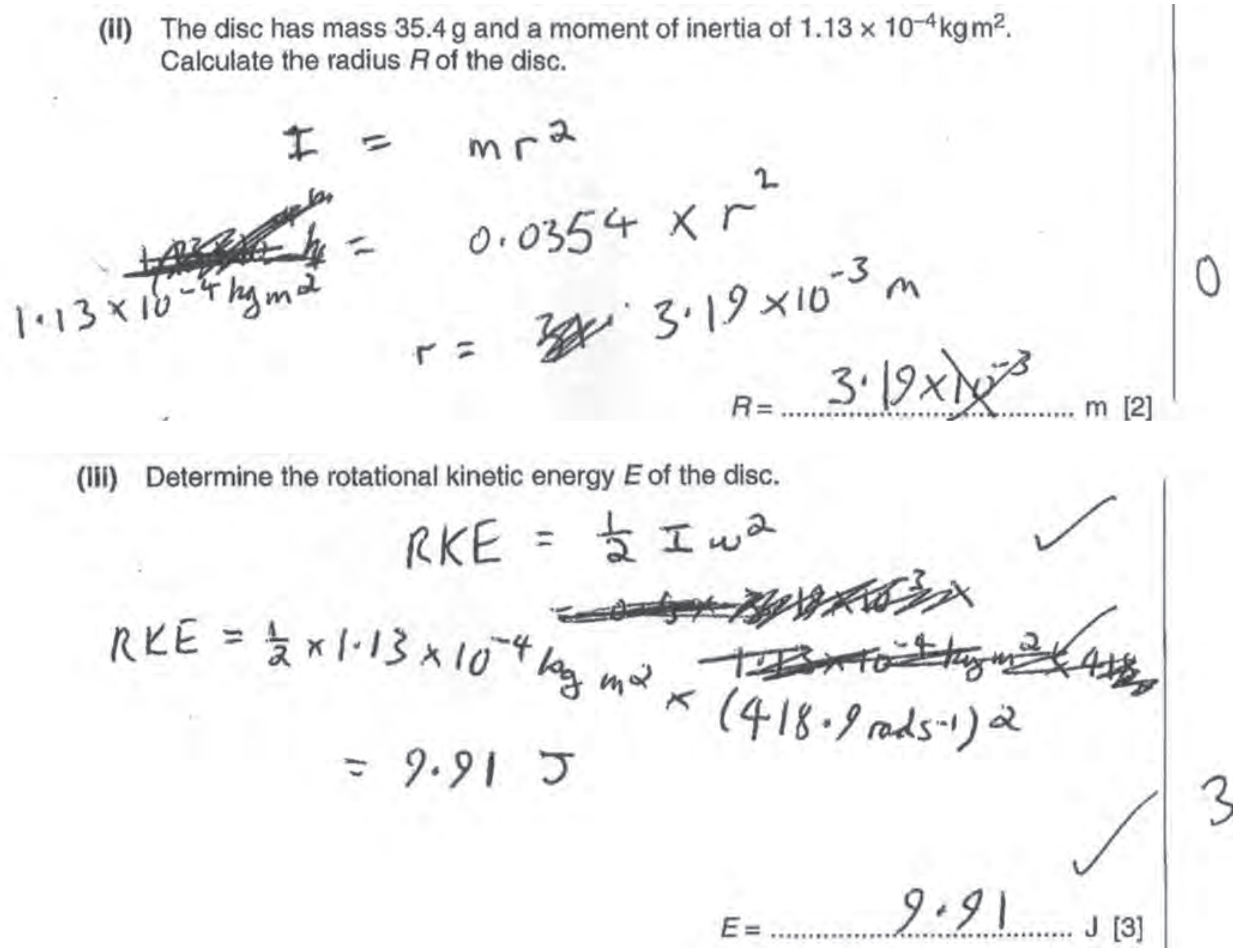


Fig. 7.2b (side view)

(i) Use integration to derive an expression for the moment of inertia I of the disc.
You may draw on Fig. 7.2a to help illustrate your working.

$t\pi R^2\rho = M$



(ii) The disc has mass 35.4 g and a moment of inertia of 1.13×10^{-4} kg m^2. Calculate the radius R of the disc.

$I = mr^2$

~~1.13×10^-4 kg~~ 1.13×10^{-4} kgm^2 $= 0.0354 \times r^2$

$r =$ ~~3.19~~ 3.19×10^{-3} m

$R =$ 3.19×10^-3 m [2]

0

(iii) Determine the rotational kinetic energy E of the disc.

$RKE = \frac{1}{2} I \omega^2$ ✓

~~= 0.5 × 3.19×10^-3 ×~~

$RKE = \frac{1}{2} \times 1.13 \times 10^{-4}$ kg m^2 ~~1.13×10^-4 kg m^2 × 418~~ ✓ $\times (418.9 \text{ rads}^{-1})^2$

$= 9.91$ J

✓

$E =$ 9.91 J [3]

3

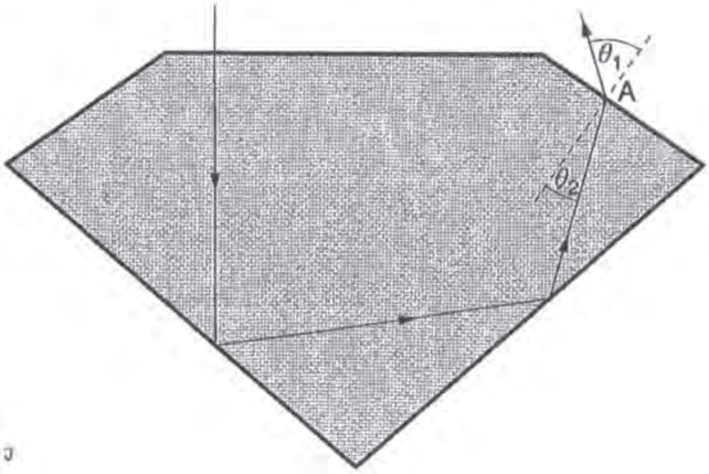
Examiner Comment

This candidate started well and completed parts **(a)** to **(d)** with the loss of only 2 marks. Part **(b)** **(ii)** was where he dropped marks. Most candidates knew that the speed of light in diamond is less than the speed in air, so the 'increase' box needed ticking for light emerging from diamond into air. Few knew that the wavelength increased but that the frequency is constant throughout. A particularly good part of this candidate's response was in part **(d)** where he accurately named the quantities involved. Expressions such as rotational work, couple, angle, angular speed and mass x velocity x radius were common. The mark scheme wanted "work = torque x angular displacement" and "angular momentum = moment of inertia x angular velocity". The candidate did not attempt the integration and just used $I = mR^2$ in part **(b)** **(ii)**. He forgot to take the square root of his value for R^2. However he worked through part **(b)** **(iii)** correctly.

Example Candidate Response – Pass

7 Diamonds sparkle because light entering the diamond undergoes numerous internal reflections before emerging.

Fig. 7.1 shows the path of a ray of light through a diamond.



$n_1 \sin i = n_2 \sin r$

~~$n \sin 90$~~

$n_1 \sin i = n_2$

$n_1 =$

$n_1 \sin c = n_2 \sin r$

$\sin c = \frac{n_2 \sin r\ 90}{n_1}$

Fig. 7.1 (not to scale)

(a) The critical angle of light in diamond is 24°. Calculate the refractive index *n* of diamond to 2 decimal places.

$\frac{n_1}{n_2} = \frac{\sin i}{\sin r}$

~~$\sin c = 24$~~

$r.i. = \frac{\sin c}{4}$ ~~$= 2.46$~~

$r.i. = \frac{1}{\sin c} = 2.4$ ✓ ✓ 2

$n =$ ~~2.46~~ 2.4 [2]

(b) The ray finally emerges at the point labelled A. The angle of incidence θ_2 within the diamond is 19.0°.

(i) Calculate the angle of refraction θ_1 in air.

$n_1 \sin i = n_2 \sin r$

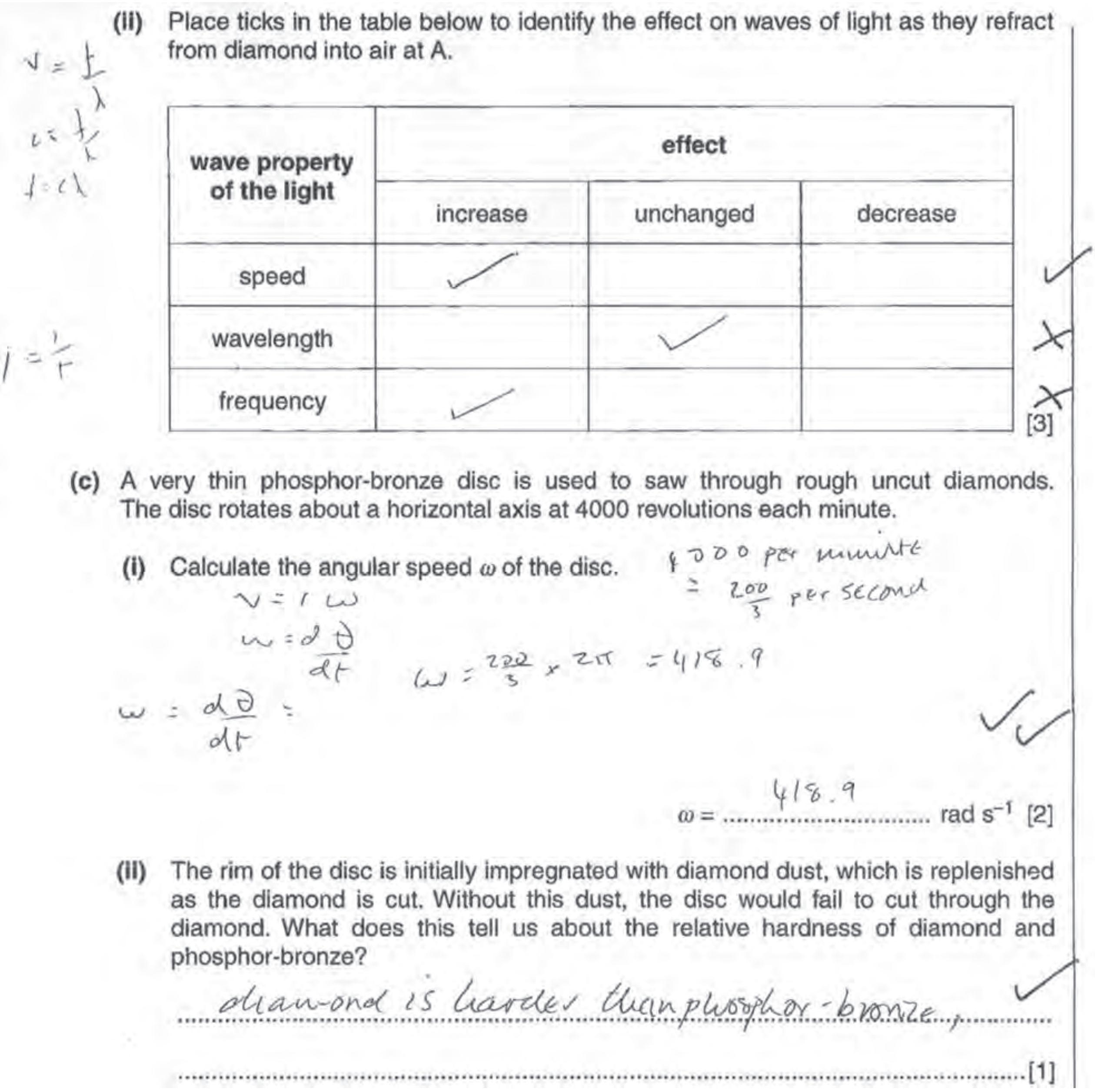
~~$\frac{n_1}{n_2} = \frac{\sin i}{\sin r}$~~

~~0.4~~ 2.4 $\sin 19 = 1 \times \sin r$

$\sin r =$ ~~[illegible]~~ 0.78

$\sin^{-1} 0.78 =$ ~~[illegible]~~ 51.4 ✓ 1

$\theta_1 =$ 51.4 [1]



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

$c = \frac{f}{\lambda}$

$f = c\lambda$

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

(ii) Place ticks in the table below to identify the effect on waves of light as they refract from diamond into air at A.

wave property of the light	**effect**			
	increase	unchanged	decrease	
speed	✓			✓
wavelength		✓		✗
frequency	✓			✗

[3] 1

(c) A very thin phosphor-bronze disc is used to saw through rough uncut diamonds. The disc rotates about a horizontal axis at 4000 revolutions each minute.

(i) Calculate the angular speed ω of the disc.

4000 per minute

$= \frac{200}{3}$ per second

$v = r\omega$

$\omega = \frac{d\theta}{dt}$

$\omega = \frac{200}{3} \times 2\pi = 418.9$

$\omega = \frac{d\theta}{dt} =$

✓✓ 2

$\omega =$ 418.9 rad s^{-1} [2]

(ii) The rim of the disc is initially impregnated with diamond dust, which is replenished as the diamond is cut. Without this dust, the disc would fail to cut through the diamond. What does this tell us about the relative hardness of diamond and phosphor-bronze?

diamond is harder than phosphor-bronze. ✓ 1

.... [1]

(d) Laws of rotational motion can be deduced by comparison with Newton's laws of linear motion.
Complete the table below by stating the equivalent formulae, in words, for rotational motion.

linear motion	rotational motion
work = force × displacement	Torque = moment of Inertia × angular sp~~eed~~
momentum = mass × velocity	~~torque~~ ~~[illegible]~~ ~~[illegible]~~ = moment of Inertia × angular sp~~eed~~

$x = I\omega$ [2]

0

(e) Fig. 7.2a and Fig. 7.2b show a phosphor-bronze cutting disc of mass M and thickness t with radius R. The uniform density of the disc is ρ.

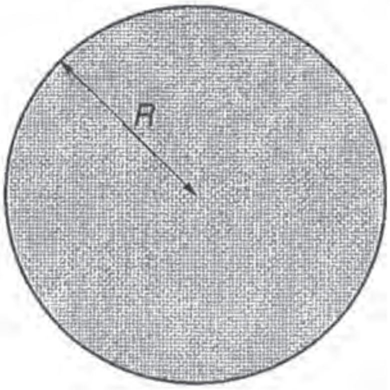


Fig. 7.2a (front view)

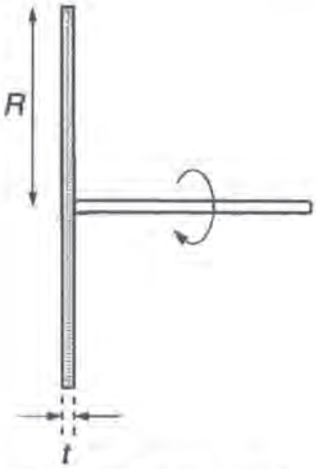
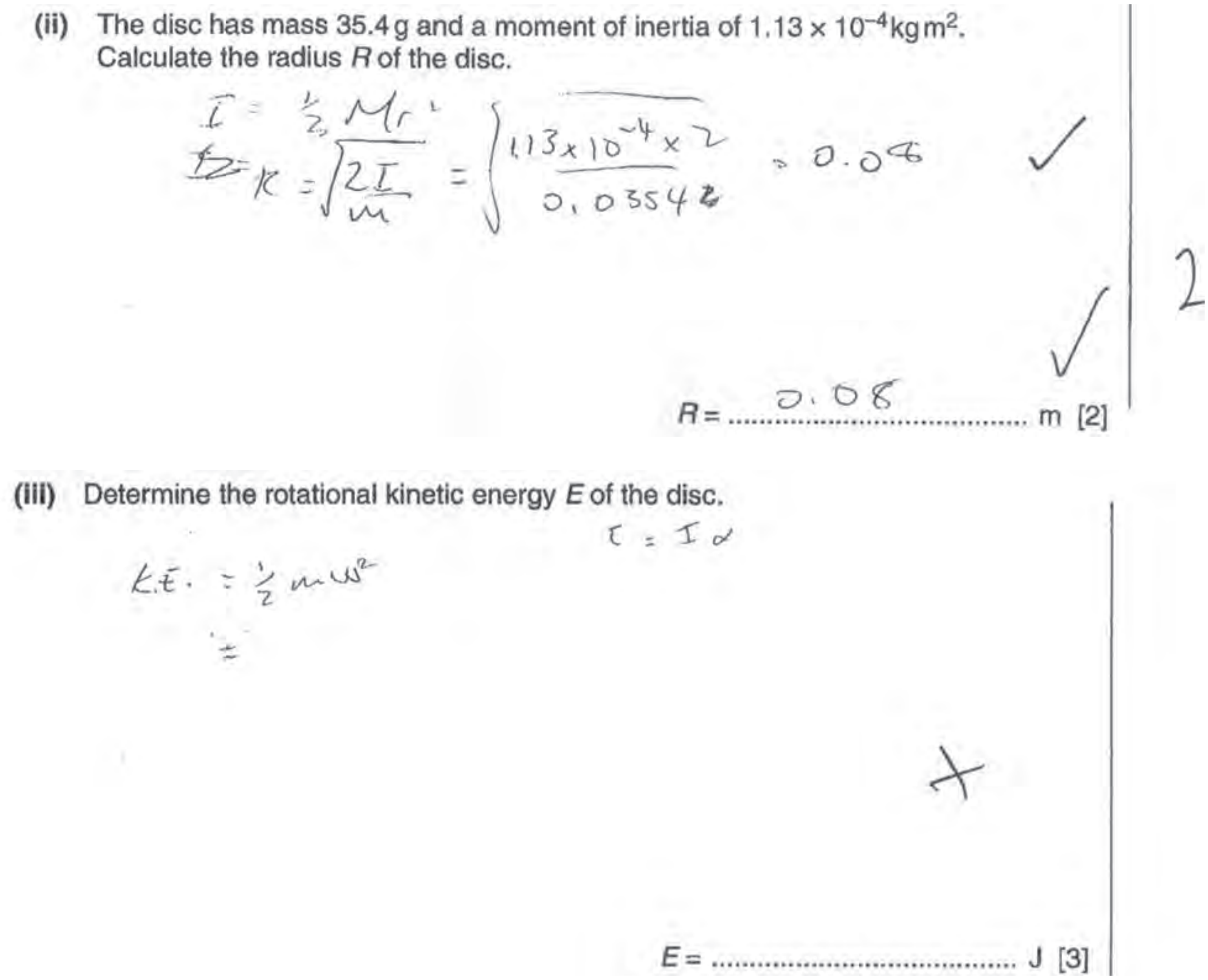


Fig. 7.2b (side view)

(i) Use integration to derive an expression for the moment of inertia I of the disc.
You may draw on Fig. 7.2a to help illustrate your working.

$\Sigma m_i r_i$

[4]



(ii) The disc has mass 35.4 g and a moment of inertia of 1.13×10^{-4} kg m^2.
Calculate the radius R of the disc.

$I = \frac{1}{2} Mr^2$

~~R~~ $R = \sqrt{\frac{2I}{m}} = \sqrt{\frac{1.13 \times 10^{-4} \times 2}{0.03542}} = 0.08$ ✓

✓ 2

$R =$ ....0.08.... m [2]

(iii) Determine the rotational kinetic energy E of the disc.

$\tau = I\alpha$

$K.E. = \frac{1}{2} m\omega^2$

$=$

✗

$E =$ .... J [3]

Examiner Comment

This candidate dealt with the refraction part of the question well. This candidate did not realise that frequency is unchanged on refraction. In part **(d)** angular speed was used twice, once in place of angular displacement and once where angular velocity was required. Parts **(e)** **(i)** and **(iii)** were not attempted but using a known equation for moment of inertial part **(e)** **(ii)** was answered correctly.

Question 8 Mark Scheme

(a) See both $^{207}_{82}\text{Pb}$ and $^{0}_{-1}\text{e}$ [1]

(b)

$\int_{N_0}^{N}\frac{dN}{N} = -\lambda\int_{0}^{t} dt$	Rearrangement	(1)
$[\ln N]_{N_0}^{N} = -\lambda t$	Integration	(1)
$\ln N - \ln N_0 = -\lambda t$ $\ln N = -\lambda t + \ln N_0$ $(N = N_0 e^{-\lambda t})$	Either line	(1) [3]

(c) **(i)** Do not penalise unit errors or omissions

Either For 2 or more values of the ratio A_1/A_2 at fixed time intervals (1)
A values must be ≥ 1 Ms apart (1.70 / 1.60 = 1.60 / 1.51 = 1.51 / 1.42) (1)
Shown to be about the same (1.062 = 1.059 = 1.063 i.e. 1.06) (1)
{similar method could be used to find t values for fixed ratio – unlikely}

Or Use $A = dN / dt = A_0 e^{-\lambda t}$ and find 2 values of λ (1)
A values to be ≥ 1 Ms apart (1)
Shown to be about equal (1)

Or Do first stage (1)
Assume exponantial decay and substitute to predict (1)
Second value of A {or t} (1) [3]

(ii) Use of $\lambda t_{1/2} = \ln 2$ to find $t_{1/2}$ (1)
Conversion between seconds and days i.e. either way (1)

$$t_{1/2} = \frac{\ln 2}{5.94 \times 10^{-8}} = 11.67 \times 10^{6}\,\text{s} = \frac{11.67 \times 10^{6}}{60 \times 60 \times 24}\ \text{days}$$

See $\frac{A_0}{4}$ i.e. realisation that 270 days = $2t_{1/2}$ (1) [3]

Or

3 marks for correct answer: activity = 0.425×10^{14} (Bq)

$$\text{Activity} = \frac{A_0}{4} = \frac{1.70 \times 10^{14}}{4} = 0.425 \times 10^{14}\ \text{(Bq)}$$

(d)	**(i)**	(A region or area in which there is...) the same force per unit charge / point charge	 (1) (1)	 [2]
	(ii)	A minimum of 5 reasonably parallel vertical lines A downwards arrow on a field line	(1) (1)	 [2]
(e)	**(i)**	Substitution [ignoring powers of 10] $W = \frac{4}{3}\pi\,(7.80 \times 10^{-7})^3(920)(9.81)$ (N) $W = 1.79 \times 10^{-14}$ (N)	(1) (1)	 [2]
	(ii)	Recall $F = EQ$ and $E = V/d$ Establish that $Q = Wd/V$ and substitute $Q = \dfrac{(1.79 \times 10^{-14})(20 \times 10^{-3})}{746}$ $Q = 4.8 \times 10^{-19}$ (C)	(1) (1) (1)	 [3]
	(iii)	3 times the fundamental charge i.e. $3 \times 1.6 \times 10^{-19}$ (C) Or Answer is an integral multiple of the fundamental charge		 [1]

[Total: 20]

Example Candidate Response – Distinction

8 A nucleus of $^{207}_{81}\text{T}l$, an isotope of thallium, decays to a nucleus of lead by beta-minus emission.

(a) Complete the nuclear equation for this decay.

$$^{207}_{81}\text{T}l \longrightarrow {}^{207}_{82}\text{Pb} + {}^{0}_{-1}\beta$$ ✓ [1]

(b) The activity $-\frac{dN}{dt}$ of a radioactive source is proportional to the number N of nuclei present. Hence,

$$\frac{dN}{dt} = -\lambda N$$

where λ is the decay constant.
Show by integration that $N = N_0 e^{-\lambda t}$ is a solution to this equation when $N = N_0$ at time $t = 0$ s.

$$\frac{dN}{dt} = -\lambda N$$

$$\int \frac{1}{N} dN = \int -\lambda \, dt$$ ✓

$$\ln N = -\lambda t + C$$ ✓

when [illegible] a[illegible] $t = 0$, $N = N_0 : \ln N_0 = C$

$$\therefore \ln N = -\lambda t + \ln N_0$$

$$N = e^{-\lambda t + \ln N_0} \Rightarrow N = (e^{\ln N_0})(e^{-\lambda t})$$ ✓

$$N = N_0 e^{-\lambda t}$$ ✓

[3]

(c) Fig. 8.1 shows the activity of $^{207}_{81}Tl$ over a period of about 120 days.

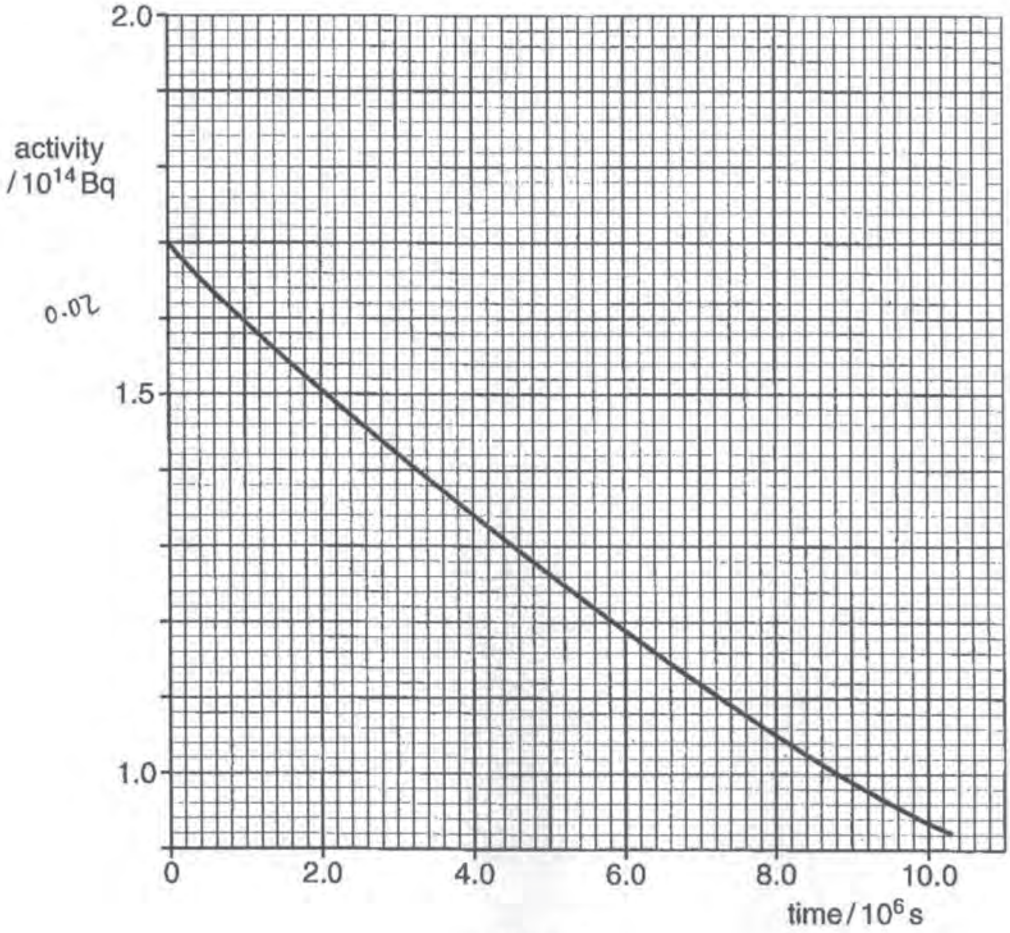


Fig. 8.1

(i) Show that the graph is an exponential decay curve.

Let the graph have eqt'n $A = ke^{-xt}$

When, $t=0$, $A = 1.7 \times 10^{14}$:

$1.7 \times 10^{14} = ke^{0}$

$k \doteq 1.7 \times 10^{14}$ ✓

when $t = 8 \times 10^6$, $A = 1.05 \times 10^{14}$:

$1.05 \times 10^{14} = 1.7 \times 10^{14} e^{-x(8 \times 10^6)}$

$x \doteq 6.03 \times 10^{-8}$ ✓

∴ The eqt'n : $A = (1.7 \times 10^{14}) e^{-6.03 \times 10^{-8} t}$

Sub $t = 6 \times 10^6$: $A = 1.14 \times 10^{14}$ from graph: $A = 1.17 \times 10^{14}$ ∴ The graph fits into an exponential curve. ✓ [3]

3

(ii) The decay constant of $^{207}_{81}Tl$ is 5.94 × $10^{-8}s^{-1}$. Determine the activity of $^{207}_{81}Tl$ after 270 days.

$A = A_0 e^{-\lambda t}$ ✓

$A_0 = 1.7 \times 10^{14}$, $t = 270 \times 24 \times 60 \times 60$

$= 23328000$ ✓

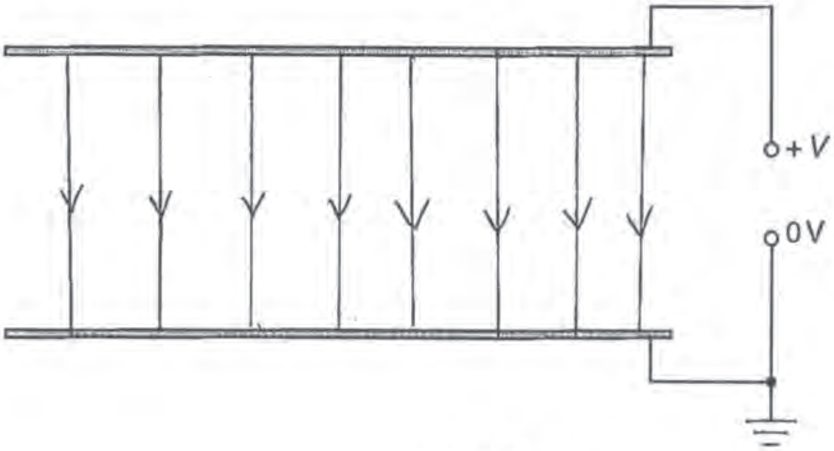
$A = (1.7 \times 10^{14})\ e^{(-5.94 \times 10^{-8})(23328000)}$

$= 4.25 \times 10^{13}$ (3 s.f.) ✓

activity = 4.25×10^{13} (3sf) Bq [3]

3

(d) Fig. 8.2 shows two horizontal parallel metal plates. A voltage is applied across them to produce a uniform electric field between them.



✓✓

Fig. 8.2

(i) Explain what is meant by a *uniform electric field*.

the electric field at any point between the plates are the same. ✓ A [2]

(ii) On Fig. 8.2, draw lines to represent the uniform field between the plates. [2]

2

(e) A very small droplet of oil is introduced between plates that are 20 mm apart. The droplet is given a charge Q using a beta radioactive source. It is held stationary when the voltage is adjusted to 746 volts. Fig. 8.3 shows the main forces acting on the droplet.

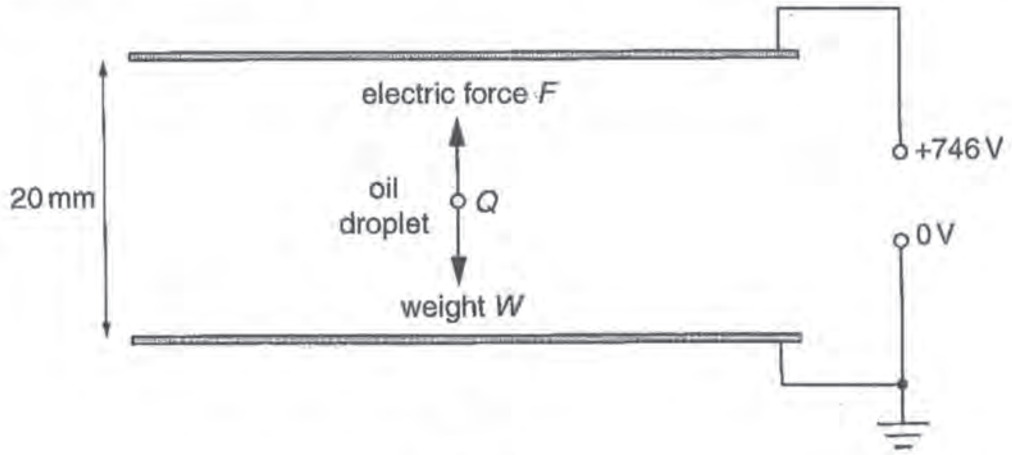


Fig. 8.3

The density of the oil is 920 kg m^{-3}. The average radius of the droplet is 7.8×10^{-7} m.

(i) The volume of a sphere V is given by $V = \frac{4\pi r^3}{3}$. Use this expression to calculate the weight W of the droplet.

$$V = \frac{4\pi(7.8\times10^{-7})^3}{3}$$

$$= 1.987799 \times 10^{-18}$$

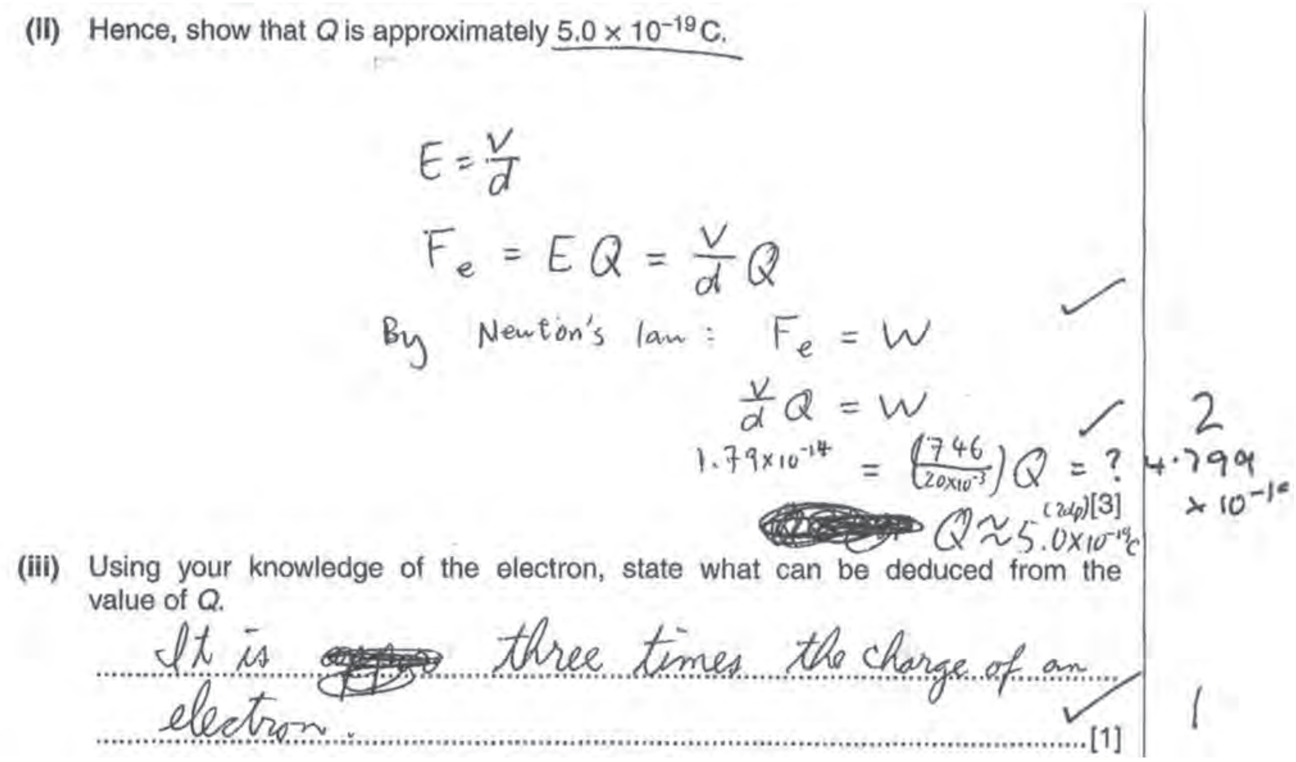
$$\text{Weight} = (1.987799\times10^{-18})(920)(9.81)$$

$$= 1.79\times10^{-14}$$

(3sf) ✓ ✓

W = 1.79x10^{-14} (3sf) N [2]

2



(II) Hence, show that Q is approximately 5.0×10^{-19} C.

$E = \frac{V}{d}$

$F_e = EQ = \frac{V}{d}Q$

By Newton's law : $F_e = W$

$\frac{V}{d}Q = W$

$1.79\times10^{-14} = \left(\frac{746}{20\times10^{-3}}\right)Q = ?$

$Q \approx 5.0\times10^{-19}$ C (2dp)

[3]

2

4.799×10^{-19}

(iii) Using your knowledge of the electron, state what can be deduced from the value of Q.

It is three times the charge of an electron.

[1]

1

Examiner Comment

Distinction grade candidates were able to show their ability on this question by getting full marks from answers to parts **(a)**,**(b)** and **(c)**. This candidate did just that. Several approaches were allowed for part **(c) (i)**, either using the exponential equation or working with ratios for two equal time intervals. This candidate lost a mark in not saying that the force per unit charge is the same at all points in **(d)** and also made a small arithmetical error in **(e) (iii)**.

Example Candidate Response – Merit

8 A nucleus of $^{207}_{81}\text{T}l$, an isotope of thallium, decays to a nucleus of lead by beta-minus emission.

(a) Complete the nuclear equation for this decay.

6? not a 7

$$^{207}_{81}\text{T}l \longrightarrow \, ^{208}_{82}\text{Pb} + \, ^{0}_{-1}e^{-}$$

[1]

0

(b) The activity $-\frac{dN}{dt}$ of a radioactive source is proportional to the number N of nuclei present. Hence,

$$\frac{dN}{dt} = -\lambda N$$

where λ is the decay constant.
Show by integration that $N = N_0 e^{-\lambda t}$ is a solution to this equation when $N = N_0$ at time $t = 0$ s.

$$dN = -\lambda N \, dt$$

$$dN = \frac{\ln 2}{t} \, \textcircled{N} \, dx$$

$$N = \int_0^\infty \frac{\ln 2}{t} \, N \, dt$$

$$N = N_0 \int_0^\infty \frac{\ln 2}{t}$$

X

$$N = N_0 e^{-\lambda t}$$

$$\Rightarrow N = N_0 e^{-\lambda t}$$

[3]

0

(c) Fig. 8.1 shows the activity of $^{207}_{81}\text{T}l$ over a period of about 120 days.

(i) Show that the graph is an exponential decay curve.

$$A = A_0 e^{-\lambda t}$$

~~$1 \times 10^{14} = 1.6 \times 10^{14} \times e^{-\lambda(8.8 \times 10^{6})}$~~

~~$0.625 = e^{-\lambda(8.8 \times 10^{6})}$~~

- curve follows the pattern so is exponential. X

[3]

(ii) The decay constant of $^{207}_{81}\text{T}l$ is $5.94 \times 10^{-8}\,\text{s}^{-1}$. Determine the activity of $^{207}_{81}\text{T}l$ after 270 days.

270

$$A = A_0 e^{-\lambda t}$$

$$A = \boxed{1.6} \times 10^{14} \times e^{-(5.98 \times 10^{-8})(2.3 \times 10^{7})} \quad \overset{2.33}{} \checkmark$$

1.7

$$A = 1.6 \times 10^{14} \times e^{-(1.376)}$$

TE

✓

activity = 4.07× 10^{13} Bq [3]

2

(d) Fig. 8.2 shows two horizontal parallel metal plates. A voltage is applied across them to produce a uniform electric field between them.

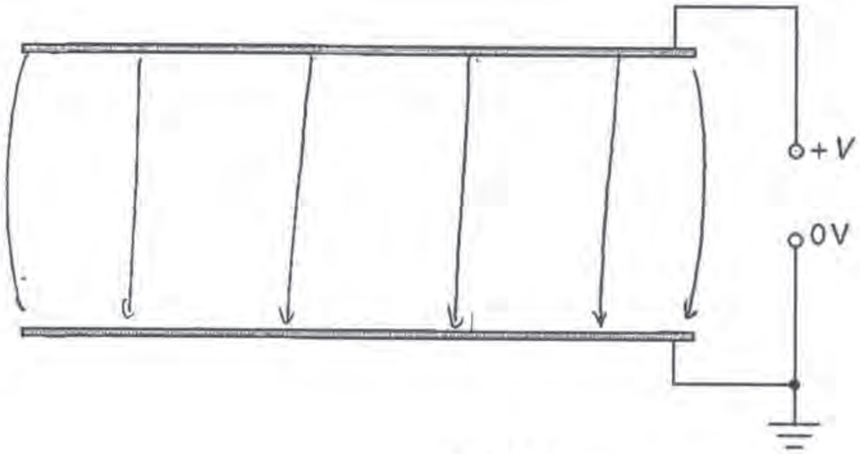


Fig. 8.2

(i) Explain what is meant by a *uniform electric field.*

An electric field that has a uniform / slope in which the potential ~~is the~~ decreases uniformly ✓ [2]

1

(ii) On Fig. 8.2, draw lines to represent the uniform field between the plates. ✓ ^ [2]

1

(e) A very small droplet of oil is introduced between plates that are 20 mm apart. The droplet is given a charge Q using a beta radioactive source. It is held stationary when the voltage is adjusted to 746 volts. Fig. 8.3 shows the main forces acting on the droplet.

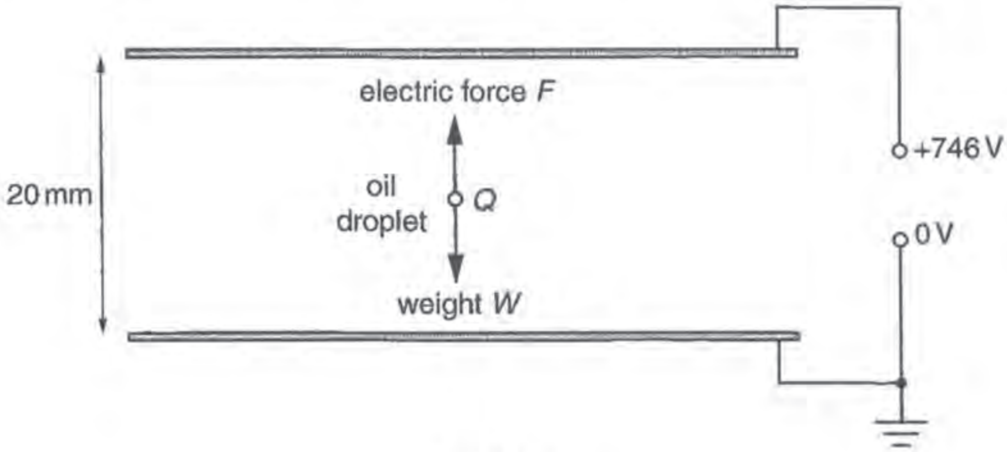


Fig. 8.3

The density of the oil is 920 kg m^{-3}. The average radius of the droplet is 7.8×10^{-7} m.

(i) The volume of a sphere V is given by $V = \frac{4\pi r^3}{3}$. Use this expression to calculate the weight W of the droplet.

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

$m = \rho V$

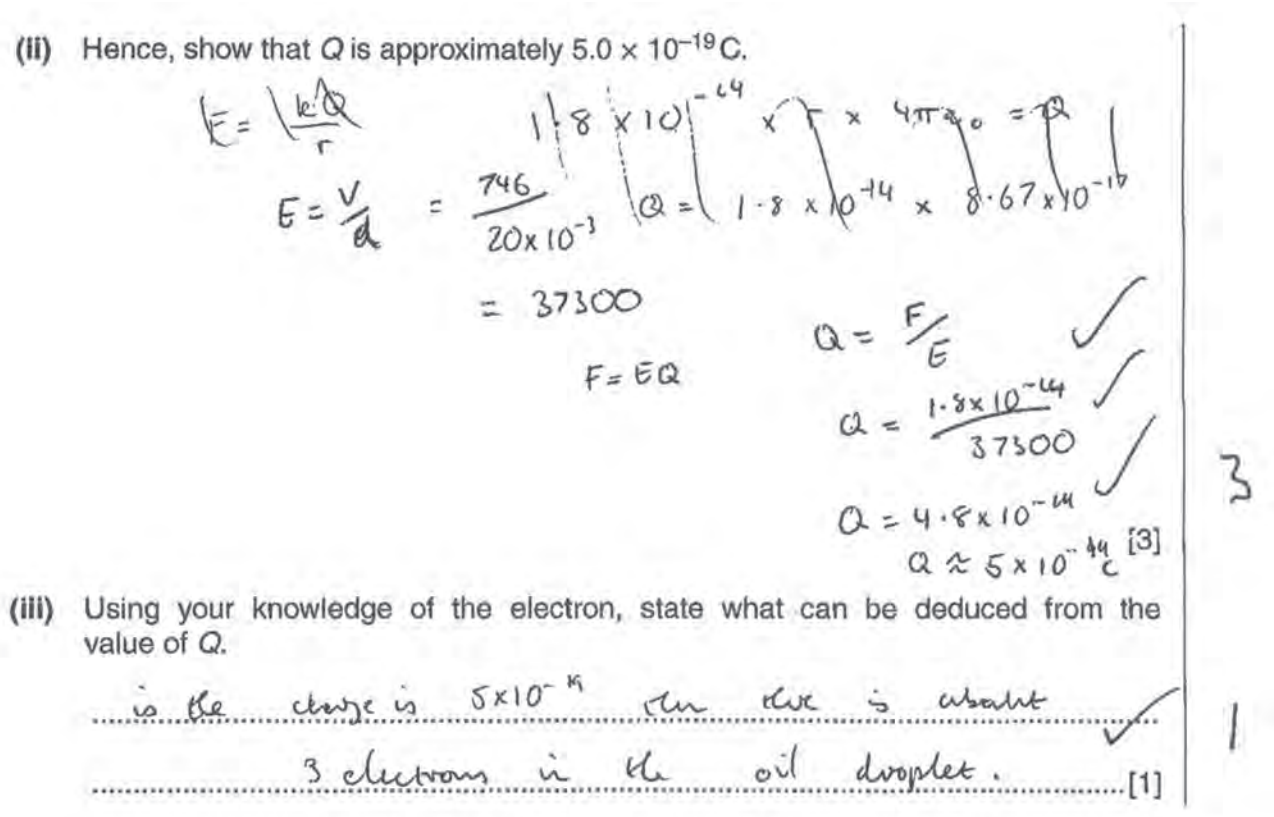
$m = 920 \left(\frac{4\pi (7.8 \times 10^{-7})^3}{3} \right)$

$m = 1.8287 \times 10^{-15}$ ✓

$W = 1.79 \times 10^{-14}$ ✓

2

$W =$ ......1.8×10^{-14}...... N [2]



(ii) Hence, show that *Q* is approximately 5.0×10^{-19} C.

~~$E = \frac{kQ}{r}$~~

$E = \frac{V}{d} = \frac{746}{20 \times 10^{-3}}$

~~$1.8 \times 10^{-14} \times r \times 4\pi\varepsilon_0 = Q$~~

~~$Q = 1.8 \times 10^{-14} \times 8.67 \times 10^{-16}$~~

$= 37300$

$F = EQ$

$Q = F/E$ ✓

$Q = \frac{1.8 \times 10^{-14}}{37300}$ ✓

$Q = 4.8 \times 10^{-14}$ ✓

$Q \approx 5 \times 10^{-14}$ C [3]

3

(iii) Using your knowledge of the electron, state what can be deduced from the value of *Q*.

as the charge is 5×10^{-19} then there is about 3 electrons in the oil droplet. ✓ [1]

1

Examiner Comment

In contrast with the Distinction candidate, this candidate made mistakes with parts **(a)**,**(b)** and **(c)** but went on to score full marks with part **(e)**. In part **(a)** the numbers did not seem to add up and there was no attempt to integrate in **(b)**. Part **(c) (i)** was not really attempted and **(c) (ii)** started with an incorrect reading taken from the graph. This mistake is a common one; candidates would be advised to put extra numbers on the axes of graphs before taking a reading from them. A transferred error, such as this, resulted in 1 of the 3 marks being lost. In part **(d)** there was not enough on the diagram to convince that the field was uniform.

Example Candidate Response – Pass

8 A nucleus of ${}^{207}_{81}\mathrm{T}l$, an isotope of thallium, decays to a nucleus of lead by beta-minus emission.

(a) Complete the nuclear equation for this decay.

$${}^{207}_{81}\mathrm{T}l \longrightarrow {}^{207}_{82}\mathrm{Pb} + {}^{0}\beta$$

no – sign visible. [1]

0

(b) The activity $-\frac{dN}{dt}$ of a radioactive source is proportional to the number N of nuclei present. Hence,

$$\frac{dN}{dt} = -\lambda N$$

where λ is the decay constant.
Show by integration that $N = N_0e^{-\lambda t}$ is a solution to this equation when $N = N_0$ at time $t = 0$ s.

[3]

(c) Fig. 8.1 shows the activity of ${}^{207}_{81}\mathrm{T}l$ over a period of about 120 days.

(i) Show that the graph is an exponential decay curve.

$\frac{\text{activity}}{\text{time}}$ — $\frac{1.5}{2} = 0.75$ $\frac{1}{8.8} = 0.11$

X

∴ as ~~a~~ time increases activity decreases ~~depending~~ at an exponential rate

~~another~~ the chances of decay decrease the fewer active particles there are as time goes on

M

0

[3]

(ii) The decay constant of $^{207}_{81}\mathrm{T}l$ is $5.94 \times 10^{-8}\,\mathrm{s}^{-1}$. Determine the activity of $^{207}_{81}\mathrm{T}l$ after 270 days.

$N = N_0 e^{-\lambda t}$

270 days
≃ 23328000 seconds

$A = A_0 e^{-\lambda t}$ ✓

$A = \frac{1.7}{10^{14}} e^{-5.94\times10^{-8} \times 23328000}$ ✓

$A = \frac{1.7}{10^{14}} \times 0.25$ ✓

$= 4.25 \times 10^{-15}$ Bq

activity = 4.25×10^{-15} Bq [3]

3

(d) Fig. 8.2 shows two horizontal parallel metal plates. A voltage is applied across them to produce a uniform electric field between them.

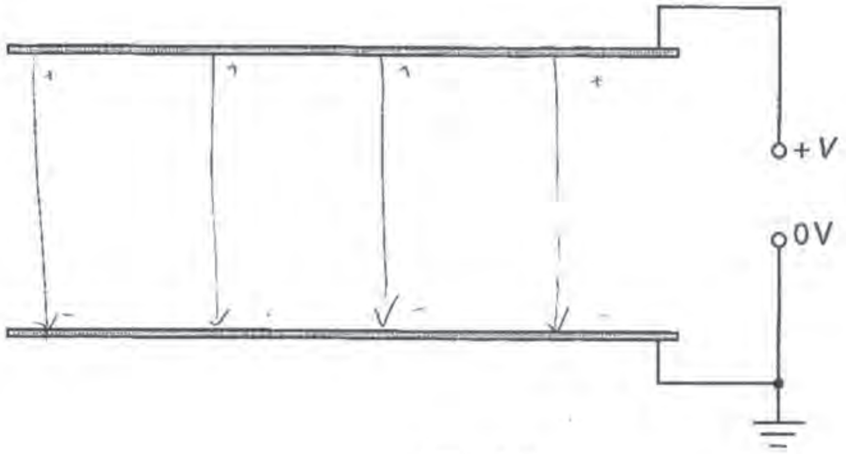


Fig. 8.2

(i) Explain what is meant by a *uniform electric field*.

Field travels from positive to negative ✗

[2]

0

(ii) On Fig. 8.2, draw lines to represent the uniform field between the plates. ^ [2]

1

(e) A very small droplet of oil is introduced between plates that are 20 mm apart. The droplet is given a charge *Q* using a beta radioactive source. It is held stationary when the voltage is adjusted to 746 volts. Fig. 8.3 shows the main forces acting on the droplet.

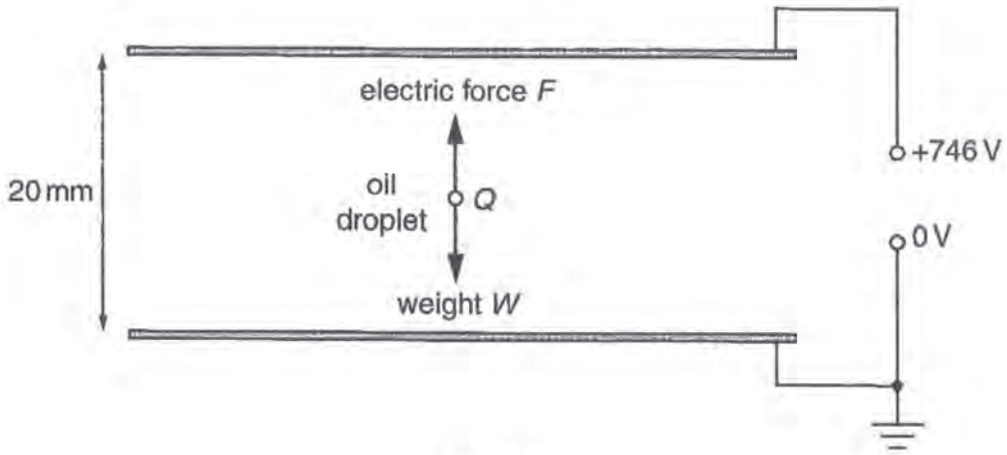


Fig. 8.3

The density of the oil is 920 kg m^{-3}. The average radius of the droplet is 7.8×10^{-7} m.

(i) The volume of a sphere *V* is given by $V = \frac{4\pi r^3}{3}$. Use this expression to calculate the weight *W* of the droplet.

density = $\frac{m}{v}$ mass = 3.767 × 920 = 3×10^{-3} kg ✗

$V = \frac{4\pi\, 7.8 \times 10^{-7}}{3} = 3.2672...$

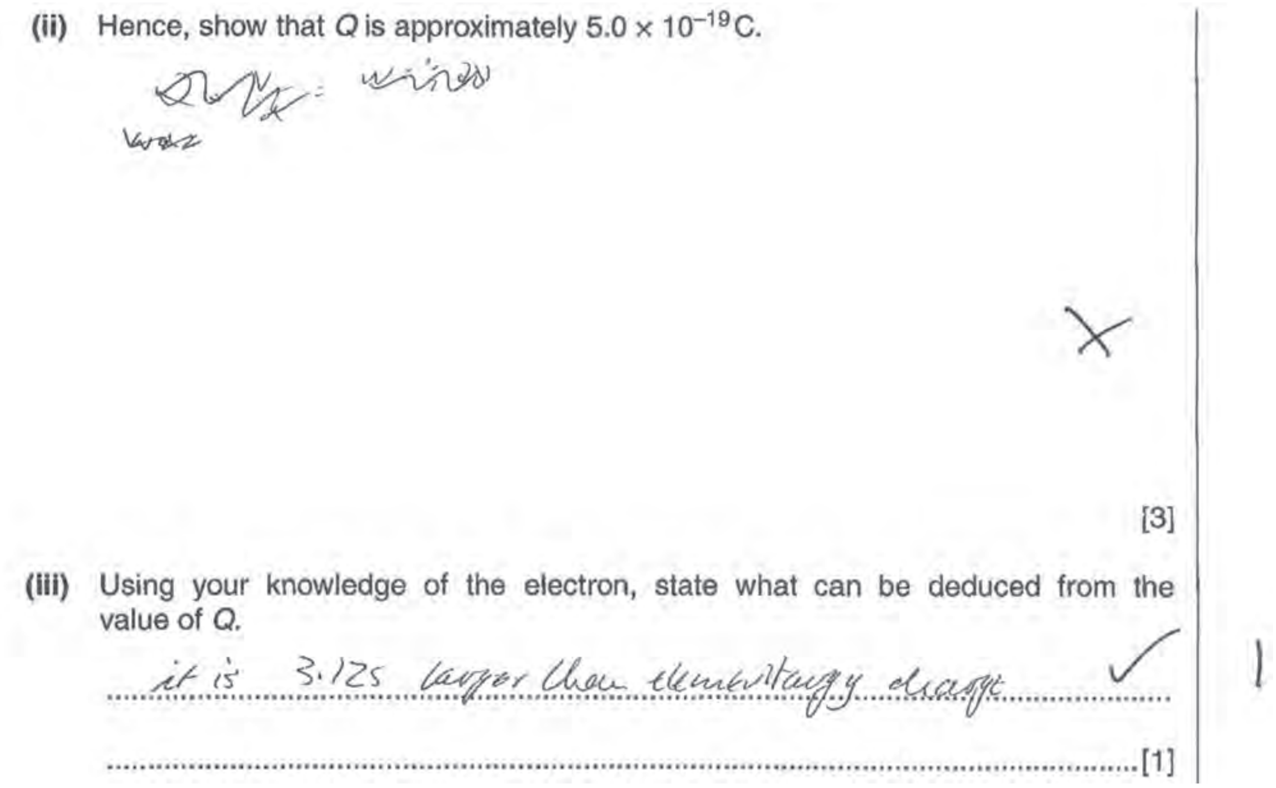
W = mg

= $3 \times 10^{-7} \times 9.81 = 0.03$

✗

0

W = ...0.03...... N [2]



(ii) Hence, show that Q is approximately 5.0×10^{-19} C.

[illegible] = [illegible]

[illegible]

✗

[3]

(iii) Using your knowledge of the electron, state what can be deduced from the value of Q.

it is 3.125 larger than elementary charge ✓

[1]

1

Examiner Comment

In **(a)** no minus sign was given for the charge on the electron, in **(b)** no attempt was made to answer and in **(c) (i)** odd numbers were given without any connection being made between them. It often helps a candidate's thought processes to use *words* when starting a line of working rather than putting down a series of numbers and symbols. Part **(c) (ii)** was done correctly. Part **(d)** included the statement that 'field flowed'. Poor technique in **(e) (i)** resulted in powers of 10 being omitted and the omission of the cube of the radius. No answer to **(e) (ii)** could be given but he was able to gain a mark for **(e) (iii)** using the information supplied in the earlier part.

Question 9 Mark Scheme

(a) **(i)** Small displacement / small angle [1]

(ii) $T = 2\pi\sqrt{\dfrac{0.54}{9.81}} = 1.47(\text{s})$

$T = \underline{1.47}(\text{s})$ [1]

(b) Recall $\omega = \dfrac{2\pi}{T}$ (1)

Use to give $\dfrac{d^2x}{dt^2} = -\dfrac{g}{l}x$

statement alone scores both marks (1) [2]

(c) Taking logs gives $\ln T = ½ \ln l + ½ \ln(4\pi^2/g)$

Show or state in working that intercept is $½ \ln(4\pi^2/g)$ (1)

Attempt to use intercept value $\ln T = 0.70$ from graph (1)

$g = 9.73 / 9.7$ (m s^{-2}) (1) [3]

(d) **(i)** 1st differentiation $\dfrac{dx}{dt} = -A\omega\sin(\omega t)$

Negative sign (1)

Multiplication by ω (1)

2nd differentiation $\dfrac{d^2x}{dt^2} = -A\omega^2\cos(\omega t)$

Correctly done (1) [3]

(ii) Substitution (ignoring any errors in powers of 10) (1)

$x = A\cos(\omega t) = 3.0\cos\left(\dfrac{2\pi}{1.47}0.50\right) = -1.61$ (cm)

Correct answer only, to include the minus sign (1) [2]

(e) Idea that Total energy = Maximum KE

Or that Total energy = $½ mv_{max}^2$ (1)

Substitution of $v_{max} = A\omega$ into KE = $½ mv^2$ (1) [2]

(f) **(i)** Correct substitution (1)

$$-\frac{d\Phi}{dt} = \frac{0.025}{200} = 1.25 \times 10^{-4}\ \text{Wb s}^{-1}$$

Correct value (–)1.25×10^{-4} (1)

Correct unit Wb s^{-1} or equivalent (1) [3]

(ii) Some relevant reference to energy (1)

- e.g. Energy of pendulum is used to do work or to create current in the coil

Plus any other two points:

- Reference to 'Lenz's law'
- Change in flux linkage produces induced e.m.f. in coil
- There is an induced current in the coil
- A magnetic field is created around the coil
- The motion of the magnet is damped by the interaction of the two magnetic fields.
- Amplitude decreases so less flux linkage in same time interval (max 2) [3]

[Total: 20]

Example Candidate Response – Distinction

9 Fig. 9.1 shows a simple pendulum, which consists of a small mass suspended by a thread. The equilibrium position of the small mass is O. When the mass is given a displacement *x* and released, the pendulum oscillates with simple harmonic motion (s.h.m.).

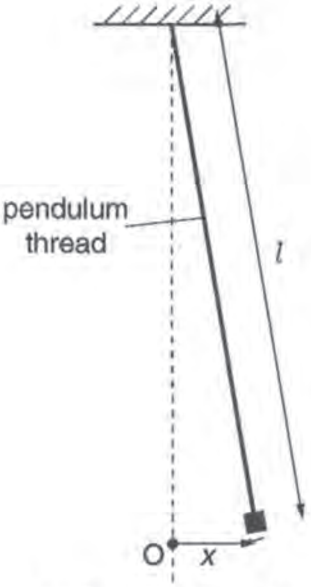


Fig. 9.1 (not to scale)

(a) The period *T* of the pendulum is related to its length *l* by the equation

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where *g* is the acceleration of free fall.

(i) State an assumption made for this equation to be valid.

No air resistance. ✓ [1]

(ii) Show that a pendulum of length 54 cm has a period of approximately 1.5 s.

$$T = 2\pi\sqrt{\frac{0.54\text{m}}{9.81\text{N/kg}}} = 1.47\text{ s.}$$

$$\simeq 1.5\text{s.}$$ ✓

1

[1]

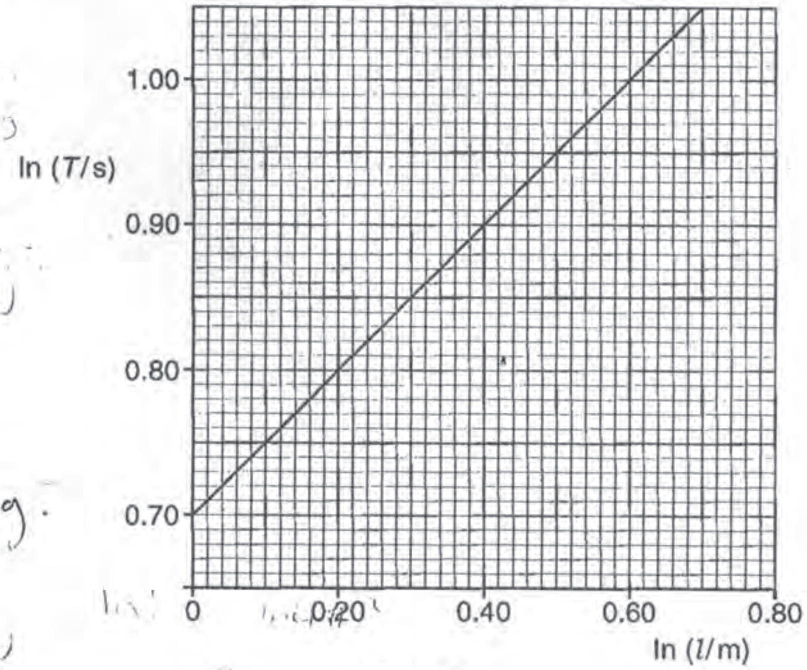
(b) Write an expression for the instantaneous acceleration $\frac{d^2x}{dt^2}$ of the pendulum from O in terms of x, l and g.

$$\frac{d^2x}{dt^2} = \cancel{\sqrt{\frac{g}{l}}x} \, . \; -\frac{g}{l}x$$

✓ ✓ 2

[2]

(c) Fig. 9.2 is a graph of $\ln T$ against $\ln l$ for different lengths of the pendulum.



$\frac{0.35}{0.7}$

Fig. 9.2

$.0.7 =$

Use the equation for the period of a pendulum and data from the graph in Fig. 9.2 to determine a value for g.

$$T = 2\pi\sqrt{\frac{l}{g}} .$$

$$T^2 = \frac{4\pi^2 l}{g} . \quad \therefore g ~~T^2 = 4\pi^2 l~~ .$$

$$2\ln T = \ln l + \ln\left(\frac{4\pi^2}{g}\right)$$

$$\therefore \ln T = \frac{1}{2}\ln l + \frac{1}{2}\ln\left(\frac{4\pi^2}{g}\right)$$

y intercept = 0.7.

$$\therefore 0.7 = \frac{1}{2}\ln\left(\frac{4\pi^2}{g}\right)$$

$$e^{1.4} = \frac{4\pi^2}{g}$$

$$\therefore g = \frac{4\pi^2}{e^{1.4}}$$

✓ ✓ ✓ 3

g = 9.735 ms^{-2} [3]

(d) **(i)** Show that $x = A\cos(\omega t)$ is a solution to the equation $\frac{d^2x}{dt^2} = -\omega^2 x$

where A is the amplitude of oscillation and ω is the angular frequency.

$x = A\cos\omega t.$ ✓

$\frac{dx}{dt} = -\omega A\sin\omega t.$ ✓

$\frac{d^2x}{dt^2} = -\omega^2 A\cos\omega t.$ ✓

$-\omega^2 x = -\omega^2(A\cos\omega t) = \frac{d^2x}{dt^2}.$

[3]

3

(ii) At time $t = 0$ the pendulum in **(a)(ii)** is released from an initial displacement of 3.0 cm.
Calculate its displacement after 0.5 s.

$A = 3 \quad \omega = \sqrt{\frac{g}{L}} = \sqrt{\frac{9.81}{0.54}} = 4.26\,\text{rads s}^{-1}.$

$\therefore x = \overset{0.03}{\cancel{3}}\cos(4.26\,\text{rads s}^{-1} \times t)$ ✓

$x = \overset{0.03}{\cancel{3}}\cos(4.26 \times 0.5) = \overset{-0.0159\text{m}}{\cancel{-1.59\text{m}}}$

✓

displacement = −1.59cm cm [2]

2

(e) Show that the total energy E of an undamped oscillating pendulum of mass m is given by $E = \frac{1}{2}mA^2\omega^2$.

TE = PE + KE

Therefore, Total energy is equal to maximum kinetic energy as potential energy = 0 here. ✓

$\therefore$ max $v = A\omega$ (from $v = -A\omega\sin\omega t$) ✓

$\therefore$ Max KE $= \frac{1}{2}mv^2 = \frac{1}{2}mA^2\omega^2.$

[2]

2

(f) The pendulum mass is a small magnet. It swings inside a horizontal coil, which is connected to a sensitive voltmeter, data-logger and computer, as shown in Fig. 9.3.

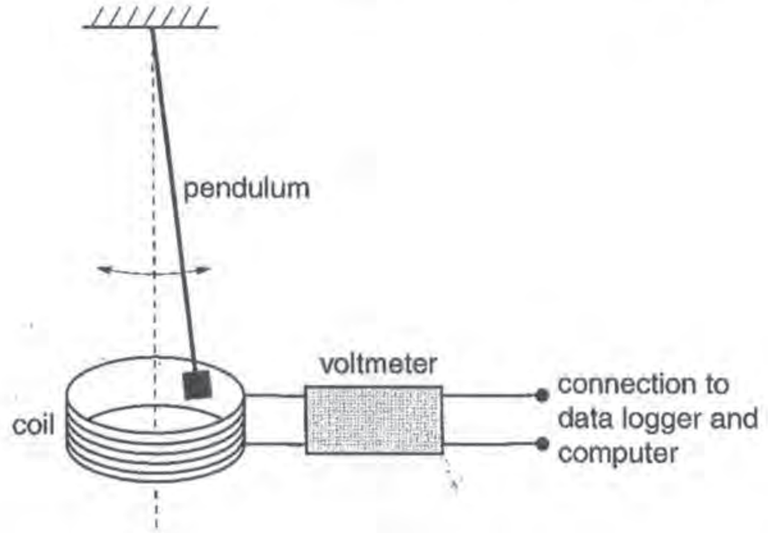


Fig. 9.3 (not to scale)

The maximum induced e.m.f. recorded by the data-logger is 25 mV. The coil has 200 turns.

(i) Calculate the maximum rate of change of flux through the coil. Include units with your answer.

$$E.M.F = \frac{N d(\Phi)}{dt} \quad \therefore \quad 25mV = 200 \frac{d(\Phi)}{dt}$$

✓

rate of change of flux = 1.25×10^{-4} V ✓ ✓ [3]

3

(ii) When the terminals of the coil are connected together, the oscillations of the pendulum are damped. The coil gains internal energy. as the total mechanical energy of the pendulum gradually decreases with time.
Explain how the energy transfer takes place.

As the magnetic swings from side to side it induces a current in the wire. ✓ This current induces an magnetic field which works against the pendulum. This is why the pendulum becomes damped and decreases with time. The energy transfer is therefore the kinetic energy of the pendulum transferring to electric energy in the coil. [3]

✗ 1

Examiner Comment

This Distinction candidate tackled the question very well and only lost a few marks on part **(f) (ii)**. His working throughout was clear and accurate and he knew how to handle electromagnetic induction.

Example Candidate Response – Merit

9 **(a)** The period T of the pendulum is related to its length l by the equation

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where g is the acceleration of free fall.

(i) State an assumption made for this equation to be valid.

The only forces acting on the mass are from gravity and the thread. [1]

0

(ii) Show that a pendulum of length 54 cm has a period of approximately 1.5 s.

$T = 2\pi\sqrt{0.0551} = 1.47$ secs $\approx$ 1.5 secs ✓

1

[1]

(b) Write an expression for the instantaneous acceleration $\frac{d^2x}{dt^2}$ of the pendulum from O in terms of x, l and g.

$a = \frac{1}{\sqrt{\frac{l}{g}}} \times \cos x$ ✗

0

[2]

(c) Fig. 9.2 is a graph of $\ln T$ against $\ln l$ for different lengths of the pendulum.

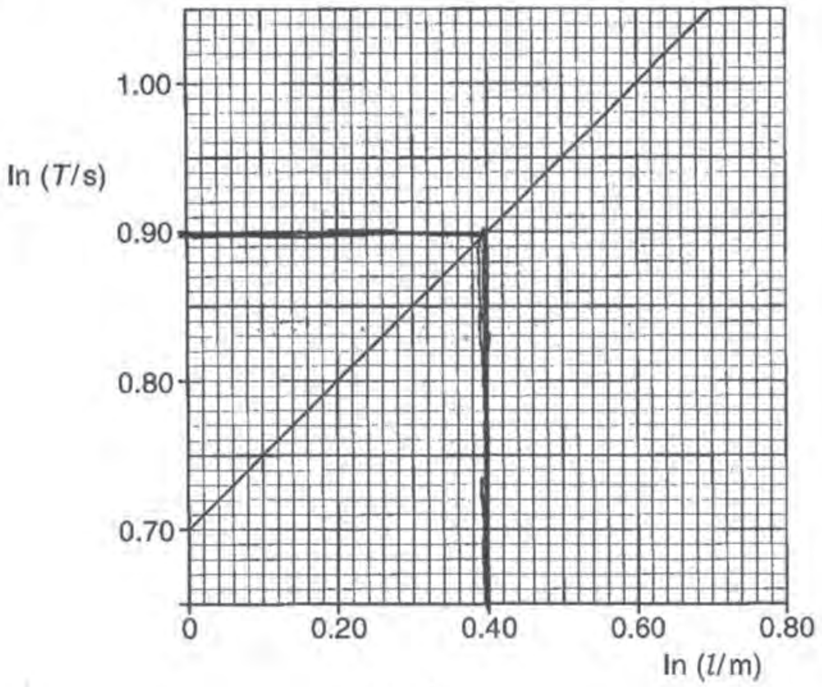


Fig. 9.2

Use the equation for the period of a pendulum and data from the graph in Fig. 9.2 to determine a value for g.

~~$T = 2\pi\sqrt{\frac{L}{g}}$~~

~~$2\ln T = \ln 2 + \pi + L - g$~~

~~$2\ln T = \ln 2 + \pi - g \times \ln L$~~

~~$2 \times 0.9 = \ln 2 + \pi - g \times 0.4$~~

~~$1.8 = 0.69 \times 1.14 \times 0.4 - \ln g$~~

~~$\ln g = 0.67$~~

~~$L = e^{0.4} = 1.49$~~

~~$T = e^{0.9} = 2.46$~~

~~$T = 2\pi\sqrt{\frac{L}{g}}$~~

~~$\ln T = \ln 2 \times \ln \pi \times \frac{1}{2}(\ln L - g)$~~

~~$0.9 = 0.69 \times 1.14 \times \frac{1}{2}(\ln L - \ln g)$~~

~~$1.14 = \frac{1}{2}(0.4 - \ln g)$~~

~~$1.14 = 0.2 - \frac{1}{2}\ln g$~~

~~$\frac{1}{2}\ln g = \frac{0.2}{1.14}$~~

~~$\ln g =$~~

~~$L = 1.49$~~

~~$T = 2.46$~~

$L = e^{0.4} = 1.49$

$T = e^{0.9} = 2.46$

$2.46 = 2\pi\sqrt{\frac{1.49}{g}}$

$0.153 = \frac{1.49}{g}$

$g = \frac{1.49}{0.153} = 9.72$ ✓

$g =$ 9.72 ✓ ms^{-2} [3] ✓

3

(d) **(i)** Show that $x = A\cos(\omega t)$ is a solution to the equation $\frac{d^2x}{dt^2} = -\omega^2 x$

where A is the amplitude of oscillation and ω is the angular frequency.

λ

[3]

(ii) At time $t = 0$ the pendulum in **(a)(ii)** is released from an initial displacement of 3.0 cm.
Calculate its displacement after 0.5 s.

$x = A\cos(\omega t)$

$\omega = \frac{2\pi}{T} = 4.19$

$x = 3 \times \cos(\omega t)$

$x = 3 \times \cos(4.19 \times 0.5) = -1.5$cm

correct in rad.

✓ ✓

displacement = −1.5 cm [2]

2

(e) Show that the total energy E of an undamped oscillating pendulum of mass m is given by $E = \frac{1}{2}mA^2\omega^2$.

$E = \frac{1}{2}mv^2$

$v^2 = A^2\omega^2$ ✓

$E = \frac{1}{2}mA^2\omega^2$ ✓

2

[2]

(f) The pendulum mass is a small magnet. It swings inside a horizontal coil, which is connected to a sensitive voltmeter, data-logger and computer, as shown in Fig. 9.3.

(i) Calculate the maximum rate of change of flux through the coil. Include units with your answer.

~~F = BANE 0.025N~~

$$\frac{0.025}{200} \cancel{\times 200} \times \frac{1}{T} = 8.33 \times 10^{-5}$$

rate of change of flux = 8.33×10^{-5} T ✗ [3] 0

(ii) When the terminals of the coil are connected together, the oscillations of the pendulum are damped. The coil gains internal energy as the total mechanical energy of the pendulum gradually decreases with time.
Explain how the energy transfer takes place.

The energy gained by the coil is gained through the magnet providing a ✓ change in magnetic flux causing an e.m.f. ✓ This provides a force counteracting the ✗ restoring force of the SHM which takes away some of the kinetic [3] energy of the pendulum.

2

Examiner Comment

This candidate produced an answer with many bits correct but much that was below par as well. Part **(c)** was answered correctly. It was accepted that an approach from just using one point on the graph was valid, if not desirable. Part **(d) (ii)** was correct throughout. The candidate correctly used his calculator set in radians and his rounded answer for the period from **(a) (ii)**. Part **(e)** was answered correctly but rate of change of flux was not understood. He gained marks by writing about changes in magnetic flux causing an e.m.f. in part **(f)**.

Example Candidate Response – Pass

9 **(a)** The period T of the pendulum is related to its length l by the equation

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where g is the acceleration of free fall.

(i) State an assumption made for this equation to be valid.

no air resistance ∧ .... [1]   0

(ii) Show that a pendulum of length 54 cm has a period of approximately 1.5 s.

$$T = 2\pi\sqrt{\frac{0.54}{9.81}} = 1.47 \approx 1.5\,s$$ ✓

[1]   1

(b) Write an expression for the instantaneous acceleration $\frac{d^2x}{dt^2}$ of the pendulum from O in terms of x, l and g.

$$-xg^2 \cos(g \cdot 2\pi\sqrt{\tfrac{l}{g}})$$ ✗

[2]   0

(c) Fig. 9.2 is a graph of $\ln T$ against $\ln l$ for different lengths of the pendulum.

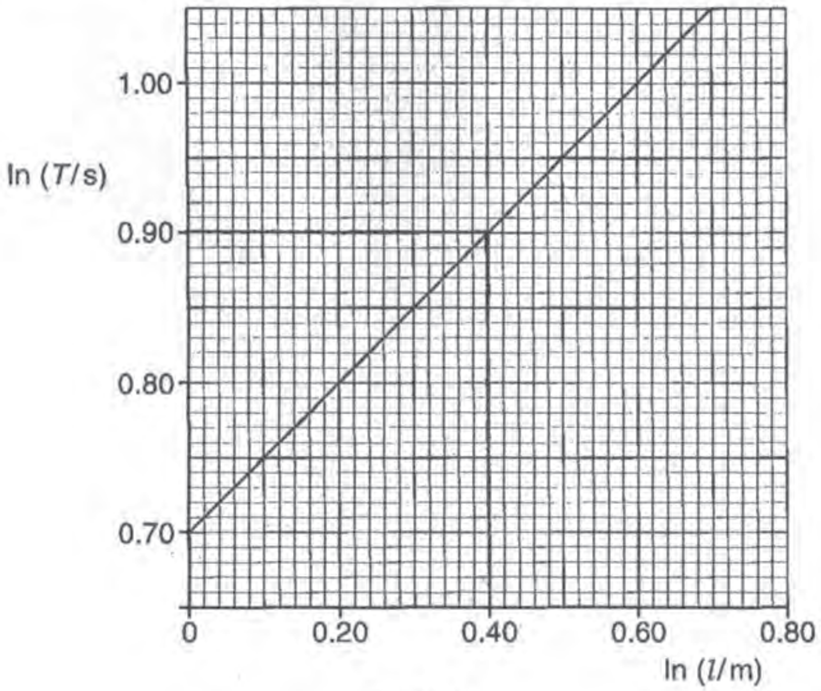


Fig. 9.2

Use the equation for the period of a pendulum and data from the graph in Fig. 9.2 to determine a value for g.

$\ln T = 0.9$

$\ln l = 0.4$

$\Rightarrow 2.46 = 2\pi\sqrt{\frac{1.49}{g}}$ ✓

$\left(\frac{2.46}{2\pi}\right)^2 = \frac{1.49}{g}$ ✓

$g = 9.72$ ✓

3

$g =$ 9.72 ms^{-2} [3]

(d) **(i)** Show that $x = A\cos(\omega t)$ is a solution to the equation $\dfrac{d^2x}{dt^2} = -\omega^2 x$

where A is the amplitude of oscillation and ω is the angular frequency.

$$\frac{d^2x}{dt^2} = -\omega^2 A\cos(\omega t)$$ ✓

Λ

[3] 1

(ii) At time $t = 0$ the pendulum in **(a)(ii)** is released from an initial displacement of 3.0 cm.
Calculate its displacement after 0.5 s.

$$3 = \overset{A}{\cancel{0.54}}\cos(\omega \times 0)$$

$A = 3$

⇒

✗ 0

displacement = ... cm [2]

(e) Show that the total energy E of an undamped oscillating pendulum of mass m is given by $E = \frac{1}{2}mA^2\omega^2$.

$E = \frac{1}{2}mv^2$ $v = \omega r$ $r = A$ ✓

$v = \omega A$

$v^2 = \omega^2 A^2$

$\Rightarrow E = \frac{1}{2}mA^2\omega^2$ ✓

2

[2]

(f) The pendulum mass is a small magnet. It swings inside a horizontal coil, which is connected to a sensitive voltmeter, data-logger and computer, as shown in Fig. 9.3.

(i) Calculate the maximum rate of change of flux through the coil. Include units with your answer.

$V = 25 \times 10^{-3}$

$N = 200$

∧

T X

rate of change of flux = ... [3]

(ii) When the terminals of the coil are connected together, the oscillations of the pendulum are damped. The coil gains internal energy as the total mechanical energy of the pendulum gradually decreases with time.
Explain how the energy transfer takes place.

.... X

....

....

....

....

.... [3]

Examiner Comment

After calculating the period correctly this candidate could not answer **(b)**. He found *g* using one value from the graph in part **(c)** but could not differentiate the cosine equation or substitute in it in part **(d)**. Part **(e)** was answered correctly and was given 2 marks.

Question 10 Mark Scheme

(a) **(i)** Description of main features of de Broglie's model – 3 marks max.

Wavelength associated with electrons (1)

Wavelength inversely proportional to momentum (or equation $\lambda = \frac{h}{p}$) (1)

Wave amplitude/intensity related to probability of locating the electron (1) [3]

(ii) Explanation of spreading using wave model – 2 marks max.

Diffraction mentioned. (1)
Amount of spread related to wavelength λ and slit width *w* correctly
(i.e. angular spread related to ratio of wavelength to slit width)* (1) [2]
*They must refer to both λ *and* slit width *w* for this mark.

(b) The detection/counting of electrons. (1)
Electrons are detected/counted discretely. (1) [2]

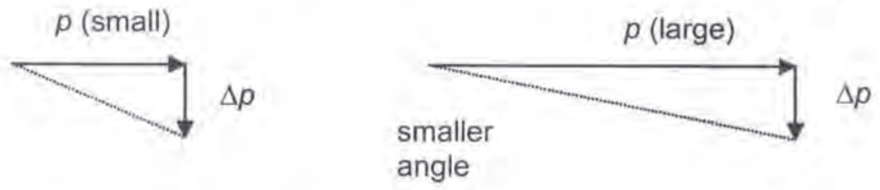
(c) **(i)** Δy is uncertainty in position (1)
Linked to slit width (1) [2]

(ii) Δp is uncertainty in momentum (1)
In the *y*-direction. (1) [2]

(d) **(i)** The uncertainty in *y*-momentum gives each electron a momentum (velocity) perpendicular to the original direction. (1)
The process is random so the beam spreads out with some electrons going to $+y$ and some to $-y$. (1) [2]

(ii) If *w* is smaller then Δy is smaller. (1)
Δp is therefore larger (1)
so more electrons scatter through larger angles. (1) [3]

(iii) Uncertainty in *y*-momentum is still the same. (1)
momentum in original direction is larger. (1)
Use of vector diagram to show that this results in smaller deflection angles:



(2) [4]

Accept equivalent written explanations.
Do not award marks for explanations based on wave theory that do not refer to HUP.

Example Candidate Response – Distinction

10 A beam of electrons is directed along a normal towards a barrier, as shown in Fig. 10.1.

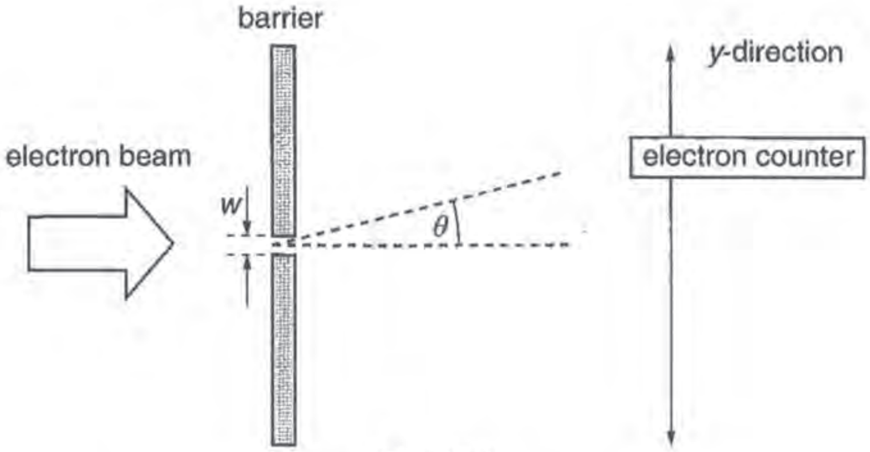


Fig. 10.1

The barrier contains a single slit of width *w*. Beyond the slit there is a detector that counts electrons. This can be moved in the *y*-direction to compare the rate of arrival of electrons at different values of the angle *θ* from the original direction of the beam.

(a) (i) Louis de Broglie suggested that some aspects of the behaviour of electrons can be explained using a wave model. Describe the main features of de Broglie's model of the electron.

Broglie's electron was a wave rather than point particle, and its wave length ~~λ~~ is related to its momentum by the equation ✓ ✓ ✓

$\lambda = \frac{h}{p}$ [3]

3

(ii) Use the wave model to explain how the electron beam spreads out beyond the slit.

The electron beam spreads out beyond the slit, because it can be described as a wave which diffracts since its wavelength is close ~~than~~ to that of the slit. ✓ [2]

1

(b) State and explain one aspect of this experiment that cannot be explained using the wave model.

The electron counter counts individual electrons, ✓ which would require a particle model to explain their ✓ discrete nature, – a wave does not have discrete parts. [2]

2

(c) Werner Heisenberg used a different approach involving what is now known as the uncertainty principle. This can also be used to explain why the electron beam spreads out after passing through the slit. One version of this involves the equation

$$\Delta p \Delta y \geqslant \frac{h}{2\pi}.$$

Explain how the terms below apply to electrons **as they pass through** the slit.

(i) Δy

The position of the electron is uncertain to a degree, ✓ so if its initial position is unknown, it may hit a range of areas beyond the slit and therefore the beam spreads out. [2]

1

(ii) Δp

✓ Because of the uncertainty in an electron's momentum, it may move in a range of different directions, making the ✓ beam spread out. [2]

2

(d) Hence use the uncertainty principle to explain why

(i) the beam spreads out,

Because the initial positions of the electrons, and their directions can only be known to a certain degree of accuracy, there is a range of ✓ places they may go to, when detected by the electron counter - the beam spreads out. [2]

1

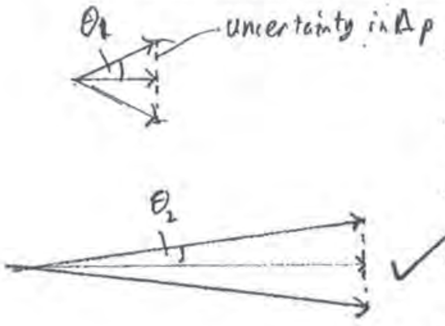
(ii) the beam is spread out more when the slit is narrower (smaller w),

the value of Δy is smaller when w is smaller, increasing the value of Δp, ✓ and so the electrons can have a greater range of different momenta, ✓ and therefore travel in different directions, spreading out further. ✓ [3]

by implication

3

(iii) the beam is spread out less when the incoming electrons have greater linear momentum. (You might find it helpful to include a vector diagram.)



When the electrons have greater linear momentum, the value of Δp relative to p is much smaller, so the effect of uncertainty on their direction is much smaller.

$\theta_1 >> \theta_2$

[4]

4

(17)

Examiner Comment

This candidate's answer showed good understanding throughout. In part **(a)** he stated all that was needed about de Broglie's model but lost a mark by stating that diffraction only occurs when the slit width is close to the wavelength. Part **(b)** was answered correctly and a good use of uncertainty was made in **(c)**. Part **(d)** was almost completely correct with good sketch diagrams indicating the uncertainties in **(iii)**.

Example Candidate Response – Merit

10 A beam of electrons is directed along a normal towards a barrier, as shown in Fig. 10.1.

(a) **(i)** Louis de Broglie suggested that some aspects of the behaviour of electrons can be explained using a wave model. Describe the main features of de Broglie's model of the electron.

$\lambda = \frac{h}{p}$. The electron can be a particle and a wave at the same time. It is a wave when an electon beam if diffracted and a particle when it collides with ~~a~~ other particles ✓ ✓ ✓ [3]

3

(ii) Use the wave model to explain how the electron beam spreads out beyond the slit.

The wave model says that waves will diffract when the slit is smaller than the ~~wavelength~~ amplitude. When the electron be is diffracted it is a wave. ✓ ^ [2]

1

(b) State and explain one aspect of this experiment that cannot be explained using the wave model.

the electron counter reads peaks of intensities at certain ~~total~~ point, but will count electrons due to it's particle ✓ property of bring "packets" of energy, it each particle instead of a constant Wave of energy, it peaks and drops. ^ [2]

1

(c) Werner Heisenberg used a different approach involving what is now known as the uncertainty principle. This can also be used to explain why the electron beam spreads out after passing through the slit. One version of this involves the equation

$$\Delta p \Delta y \geqslant \frac{h}{2\pi}.$$

Explain how the terms below apply to electrons **as they pass through** the slit.

(i) Δy

their position changes ✓ by $\geqslant \frac{h}{2\pi}$ due to their wave property ~~mass~~ they get diffracted [2] 1

(ii) Δp

~~p~~ their momentum change by $\geqslant \frac{h}{2\pi}$ due to their particle property mv p their speed decreases [2]

(d) Hence use the uncertainty principle to explain why

(i) the beam spreads out,

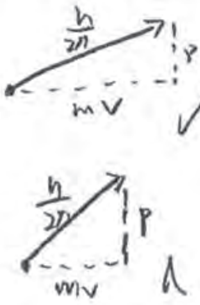
as they pass through there's a change in momentum as mv decreases change in position increases ✓ hence spreads out.

[2] 1

(ii) the beam is spread out more when the slit is narrower (smaller w),

[3]

(iii) the beam is spread out less when the incoming electrons have greater linear momentum. (You might find it helpful to include a vector diagram.)



✓

$\uparrow mv \downarrow y = \frac{h}{2\pi}$

if momentum increase change in ✓ position decreases so that $\Delta mv \Delta p = \frac{h}{2\pi}$

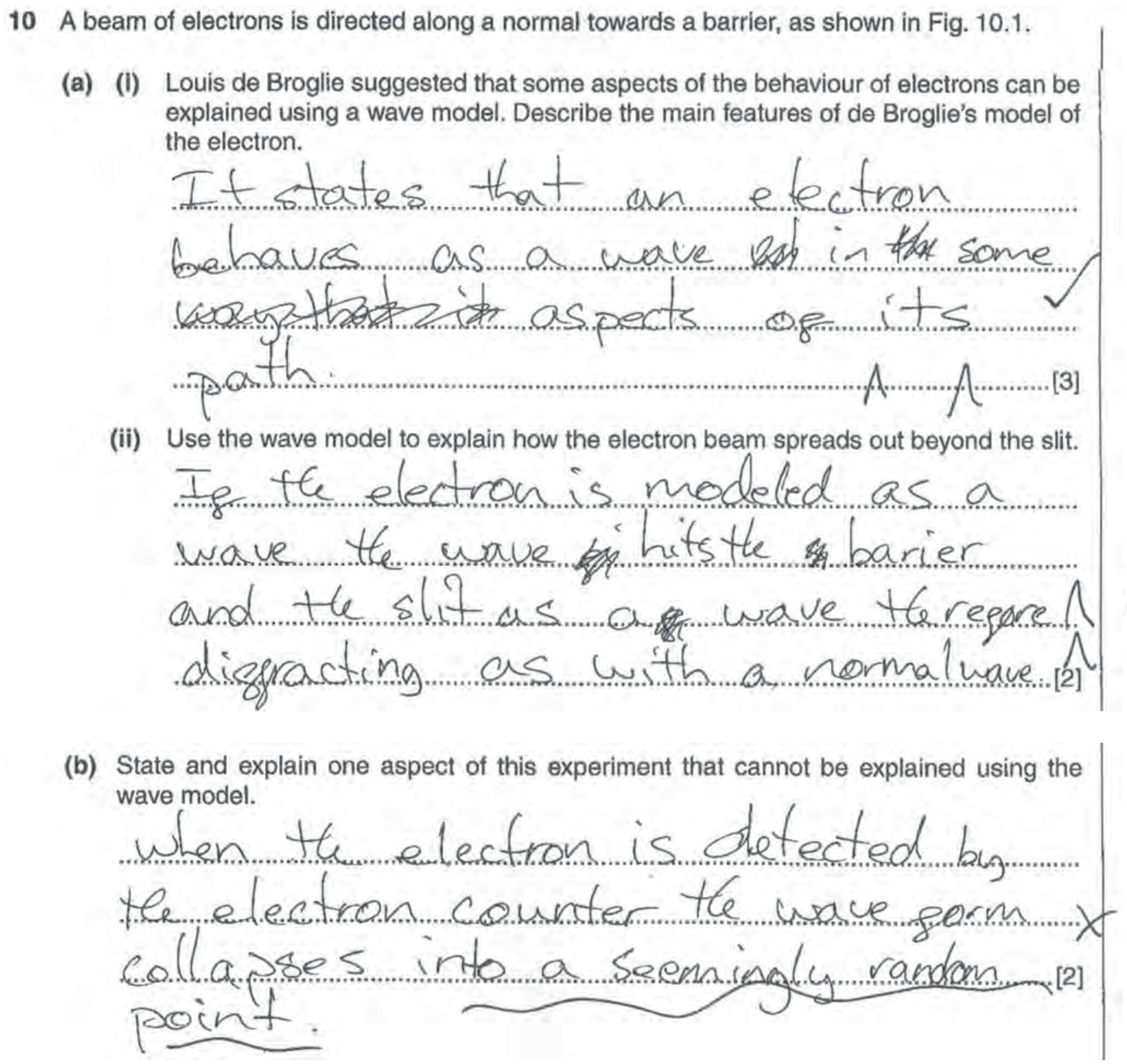
[4]

2

Examiner Comment

This candidate's answer started well with a full mark answer to **(a) (i)**, but in answering **(a) (ii)** he mentioned diffraction but then stated that the slit needed to be smaller than the amplitude of the wave. He wrote about counting electrons in **(b)** but did not mention their discrete property. Answers to **(c)** had some credit but were not helped by the statement that 'their position changes by *h*/2π'. No mention was made of the fact that Δ*y* is the uncertainty in position and Δ*p* is the uncertainty in momentum, which the question implied needed to be stated. In **(d) (i)** the change in momentum was credited but there was no mention of this being a random process and so could result in deflection being either positive or negative. Part **(d) (ii)** was omitted and in **(d) (iii)** two vector diagrams were sketched but unfortunately Δ*p* was simply labelled *p* and did not have the same value on both diagrams.

Example Candidate Response – Pass



10 A beam of electrons is directed along a normal towards a barrier, as shown in Fig. 10.1.

(a) **(i)** Louis de Broglie suggested that some aspects of the behaviour of electrons can be explained using a wave model. Describe the main features of de Broglie's model of the electron.

It states that an electron behaves as a wave ~~[illegible]~~ in ~~the~~ some ~~way that it~~ aspects of its path. ✓ ^ ^ [3] 1

(ii) Use the wave model to explain how the electron beam spreads out beyond the slit.

If the electron is modeled as a wave the wave ~~[illegible]~~ hits the ~~[illegible]~~ barier and the slit as a ~~[illegible]~~ wave therefore ^ difracting as with a normal wave. ^ [2] 0

(b) State and explain one aspect of this experiment that cannot be explained using the wave model.

when the electron is detected by the electron counter the wave form collapses into a seemingly random point. ✗ [2] 0

(c) Werner Heisenberg used a different approach involving what is now known as the uncertainty principle. This can also be used to explain why the electron beam spreads out after passing through the slit. One version of this involves the equation

$$\Delta p \Delta y \geqslant \frac{h}{2\pi}.$$

Explain how the terms below apply to electrons **as they pass through** the slit.

(i) Δy

this the position ✓ of the electrona in the ~~sli~~ slit. ^ [2] 1

(ii) Δp

This is the momentum of the ✓ electron in the slit. [2] 1

(d) Hence use the uncertainty principle to explain why

(i) the beam spreads out,

this is because you cannot know both the position and momentum of the electron at one time, ✓ this uncertainty of eith of them explains why it ~~w~~ would modeled as the beam spreading out. [2] 1

(ii) the beam is spread out more when the slit is narrower (smaller w),

there is a smaller gap therefore less area in which to locate the ✓ electron which causes an increase in the diffraction of the beam. [3] 1

(iii) the beam is spread out less when the incoming electrons have greater linear momentum. (You might find it helpful to include a vector diagram.)

If the electrons have
greater linear momentum
they are less likely
to be affected by the
slit therefore the beam
spreads out less.

..........[4]

0

Examiner Comment

The answer from this candidate contained too many generalisations and too few concrete facts. For example 'an electron behaves as a wave in some aspects of its path' does not give much more than question **(a) (i)** itself. This candidate did not mention the fact that Δy is the uncertainty in position and Δp is the uncertainty in momentum. The candidate had little appreciation of the Δ terms and did not treat them as *uncertainties.* He states that Δy is the *position* of the electron in the slit. In **(d) (iii)** the candidate states that 'if the electrons have greater momentum they are less likely to be affected by the slit...', but no vector diagram is given.

Question 11 Mark Scheme

(a) Candidates **do not** need to derive the time dilation equation in order to gain full marks on this question, although a clear derivation could gain full marks.

Key marking points:
relevant reference to the Principle of Relativity – e.g. The speed of light is the same for all (uniformly moving) observers, (1)
use of this principle (e.g. with light clocks) to show that clocks in relative motion 'tick' at different rates, (2)
convincing demonstration that the satellite clock ('moving' clock) **runs slow** when observed from the Earth clock. (1) [4]

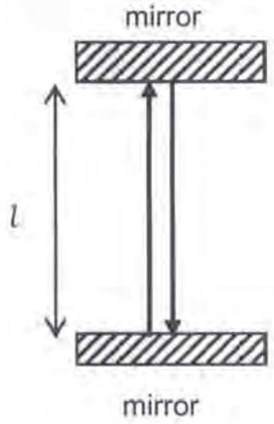
Note: examples of *possible* approaches to this question given underneath.

1. Example based on light clocks:

Diagrams could be used to compare a light clock 'at rest' with a moving light clock.

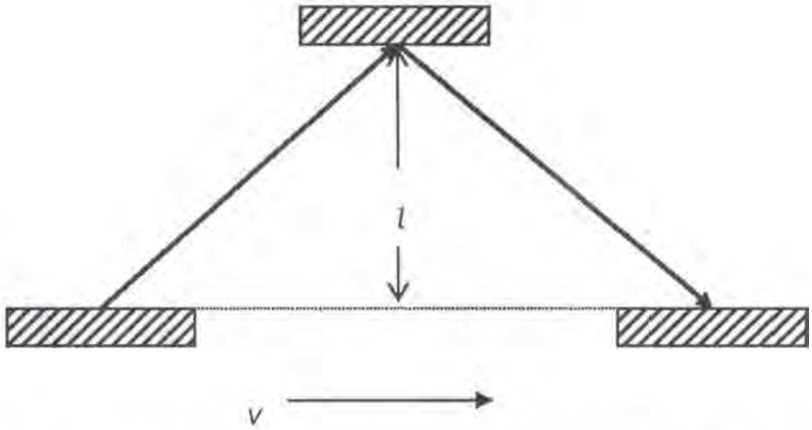
The key ideas (which can be gained from a labelled diagram) are:
- the speed of light relative to the observer is the same in both cases
- the light path in the 'moving' clock is longer
- the time between 'ticks' on the moving clock is longer so it runs slow

Light path
in 'rest' or
Earth-based
clock



l = separation of mirrors in the light clock
v = relative velocity of satellite clock

Extended
light path
in moving
or satellite
clock



Candidates may go on to compare the light path lengths and derive the equation for time dilation, but this is not required for the marks.

2. Example based on the Lorentz transformation (this is not expected, and goes further than is required by the question, but some candidates may use it).

The key ideas are:
the Lorentz transformation follows from the principle of relativity,
the Lorentz transformation can be used to compare time measurements for observers in relative motion:

$$t = \gamma\left(t' + \frac{vx'}{c^2}\right)$$

where t is the time elapsed on the Earth clock while a time t' is observed (from Earth) to elapse on the moving clock onboard the satellite.
If the moving clock is at the origin of the moving reference frame then $x' = 0$ and:

$$t = \gamma t'$$

where $\gamma = \dfrac{1}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ which is greater than 1

so $t > t'$ meaning that more time passes on the Earth clock and therefore the moving clock on the satellite appears to run slow.

(b) **(i)** Substitution of $v = 3.5 \times 10^3$ ms^{-1} and $c = 3.0 \times 10^8$ ms^{-1} in the equation:

$$t' = \frac{t}{\sqrt{1 - \dfrac{v^2}{c^2}}} \approx t\left(1 + \frac{1}{2}\left(\frac{v^2}{c^2}\right)\right) \qquad (1)$$

t' identified as time on the moving (satellite) clock as measured by the clock on Earth and t as time on the stationary (handset) clock* (1)
*This equation can be interpreted in different ways – the essential point is that the candidate recognises that it compares clock rates between the two reference frames.
Calculation of $(t' - t) = 6.8 \times 10^{-11}$ s (1) [3]

(ii) $60 \times 6.8 \times 10^{-11} = 4.1 \times 10^{-9}$ s ≈ 4 ns [1]

(c) The error will change with time (becoming larger with a greater time between measurements). (1)
This will lead to a different value for distance from the reference satellite so the two measurements will differ. (1) [2]

(d) **(i)** Difference used (e.g. 30 – 4 = 26 ns per minute). (1)
260 ns (1) [2]
Allow one mark for (34 × 10 = 340 ns)

(ii) Distance = $260 \times 10^{-9} \times 3.0 \times 10^{8} = 78$ m [1]

(iii) The error can be large and significant (1)
One good practical example: (1) [2]
E.g. sat. nav. giving wrong information leading to a ship hitting a reef at sea

(e) Newtonian view (2 marks max.).
Idea of absolute time explained. (2)
E.g.
All observers have the same time regardless of position or movement.
Time progresses at the same rate for everyone.
Time is independent of motion or gravity.

Einsteinian view (2 marks max.).
Idea of relativistic time explained. (2)
E.g.
The laws of physics are the same for all observers so time and space measurements are not.
Time passes at different rates for observers in relative motion.
The 'present moment' for one observer might lie in the future or past for another.
The rate at which time passes depends on the gravitational field.

Use of one relevant example (or GPS) – (must show relevance). (1) [5]
E.g. in a Newtonian universe we would not have to apply corrections to clocks onboard GPS satellites.

Example Candidate Response – Distinction

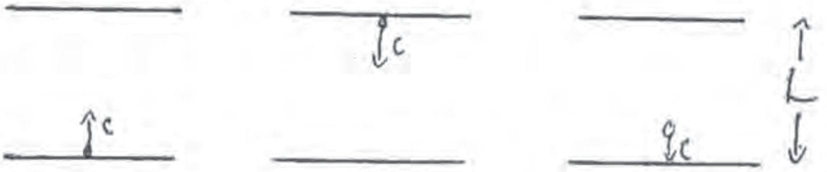
11 The GPS (Global Positioning System) is used in satellite navigation systems in cars. The receivers pick up and compare time signals from orbiting satellites and use them to calculate positions relative to a particular satellite. For this system to work accurately, the time signals have to be corrected for two relativistic effects that affect the rate of the onboard atomic clocks.

The first of these effects is due to the satellite's relative velocity with respect to the receiver.

The first of these effects is due to the satellite's relative velocity with respect to the receiver.

(a) Explain why a 'moving' clock runs slow compared to a clock at rest beside the observer. Ignore the effects of gravity. (You may wish to use a diagram.)

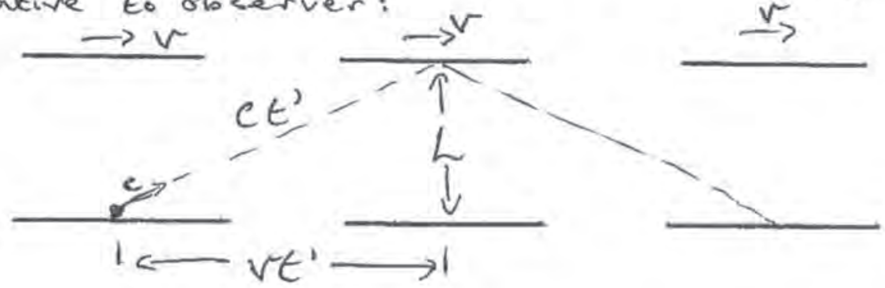
Following diagram shows light clock at rest beside the observer:



✓

Time for photon to move L : $t = \frac{L}{c}$ ①

Following diagram show light clock moving at v relative to observer:



✓

$L = \sqrt{(ct')^2 - (vt')^2} = ct'\sqrt{1 - v^2/c^2}$ ②

Substitute ② in ①:

$t = \frac{\cancel{c}t'\sqrt{1 - v^2/c^2}}{\cancel{c}}$ ✓

$\Rightarrow t' = \frac{t}{\sqrt{1 - v^2/c^2}}$

Since v must be smaller than c, t' will alway be larger than t so a moving clock will run slower. ✓

[4]

4

(b) **(i)** The satellite's relative velocity is typically about $3.5 \times 10^3\,\mathrm{m\,s^{-1}}$. Show that an atomic clock on a satellite moving at about $3.5 \times 10^3\,\mathrm{m\,s^{-1}}$ relative to the receiver loses about 6.8×10^{-11} s every second.

You can use the approximation: $\dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}} \approx 1 + \dfrac{1}{2}\left(\dfrac{v^2}{c^2}\right)$ when $\left(\dfrac{v^2}{c^2}\right)$ is small.

$\dfrac{V^2}{C^2} = 1.36 \times 10^{-10}$ => when $t = 1$:

$t' = \dfrac{1}{\sqrt{1-(1.36\times10^{-10})}} = 1 + \frac{1}{2}(1.36\times10^{-10})$ ✓

$= 1 + 6.8 \times 10^{-11}$ ✓

=> The clock loses 6.8×10^{-11}s every second ✓ [3] 3

(ii) Show that this results in a time error of about 4 ns per minute.

every minute clock loses $6.8\times10^{-11} \times 60$s

$6.8\times10^{-11}\times60 = 4.08\times10^{-9}$ s ✓

~ 4ns [1] 1

(c) A GPS receiver is used to make two position measurements at different times from the same location.
Explain why these measurements will be different unless a correction for the motion of the satellite is made.

Since the satellite's time dilates by about 4ns every minute, ✓ in the time between taking the two measurement, the satellites clock may have dilated significantly [2] so the position measurements will differ. ✓ 2

(d) The second relativistic effect is due to gravitational time dilation. This makes the clock on a typical GPS satellite run **fast** by about 30 ns per minute relative to a clock at rest beside the receiver.

(i) Calculate the total time error due to both relativistic effects for two measurements of position made 10 minutes apart from the same point on Earth.

$(30 \times 10) - (4 \times 10) = \underline{\underline{260\ ns}}$ ✓

✓ $(260 \times 10^{-9} s)$

[2]

2

(ii) Calculate the corresponding error in distance between the receiver and the satellite.

$d = V \times t = \overset{3 \times 10^{8}}{\cancel{3.5 \times 10^{3}}} \times 260 \times 10^{-9}$

$= \underline{\underline{9.1 \times 10^{-4}}}\ m$ ✗

[1]

0

(iii) Hence explain why it is important to correct for relativistic effects, and give a practical example of a navigation problem that might otherwise arise.

In a short time (10 minutes) the distance error is already significant and will ✓ become more significant over more time. This would become a problem if the error became very large (eg. 1km) [2] as the GPS would ~~tead~~ give the position of a location as 1km from its actual position.

∧

1

(e) Explain the difference between Newton's concept of absolute time and the concept of time in Einstein's theory of relativity. State how this makes a practical difference in the case of GPS.

Newton's concept of absolute time states that time is the same when measured by any observer independent of their motion. ✓ Einstein's theory of relativity leads to the fact that at relativistic speeds close to the speed of light, time dilates for an observer. ✓ In everyday life, Newton's concept of absolute time is mostly used because nothing is moving fast enough for time to dilate significantly. ✓ [5]

However, in the case of the GPS, Einstein's theory must be taken into account as the satellite is moving fast ✓ enough to cause significant time dilation that could potentially cause the GPS to become useless.

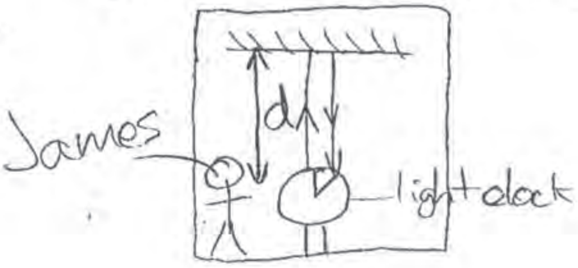
4

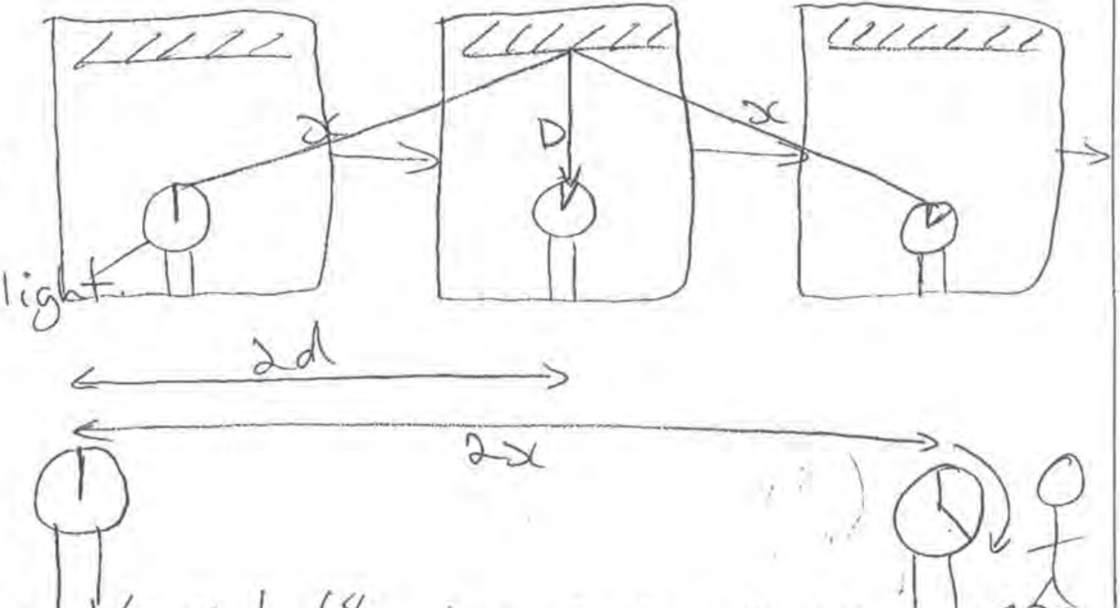
Examiner Comment

This was a very good answer from a Distinction candidate. His answer to part **(a)** went well beyond what was necessary for full marks and his mathematical work in part **(b)** was flawless. Full marks were given for parts **(c)** and **(d) (i)**. In part **(d) (ii)** he used the speed of the satellite rather than the speed of light for his calculation so his answer to part **(d) (iii)** was meaningless. A well constructed argument was given in his answer to part **(e)** but he might have added to his statement that '..time is independent of motion...' and gravity.

Example Candidate Response – Merit

(a) Explain why a 'moving' clock runs slow compared to a clock at rest beside the observer. Ignore the effects of gravity. (You may wish to use a diagram.)





On the satelite James measures ✓ the time the light take to travel a distance 2d this time is the proper time, however gary times it from the ground and so the light from the light clock does not travel 2d it travels ✓ 2x instead this takes a longer time therefore the gps must take into account this difference. ✓ [4]

3

(b) **(i)** The satellite's relative velocity is typically about $3.5 \times 10^3\,\mathrm{m\,s^{-1}}$. Show that an atomic clock on a satellite moving at about $3.5 \times 10^3\,\mathrm{m\,s^{-1}}$ relative to the receiver loses about 6.8×10^{-11} s every second.

You can use the approximation: $\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \approx 1 + \frac{1}{2}\left(\frac{v^2}{c^2}\right)$ when $\left(\frac{v^2}{c^2}\right)$ is small.

$\frac{v^2}{c^2} = \frac{(3.5\times10^3)^2}{(3\times10^8)^2} = 1.36\times10^{-10}$ this is very small ~~than~~ therefore ✓

~~$1+\frac{1}{2}\left(\frac{v^2}{c^2}\right) =$ Thus~~ ^

$\frac{1}{2}\ 1.36\times10^{-10} = 6.8\times10^{-11}$ s ✓ 2

∴ Time lost $= \frac{1}{2}\left(\frac{v^2}{c^2}\right)$ [3]

(ii) Show that this results in a time error of about 4 ns per minute.

$6.8\times10^{-11} \times 60 = 4.08\times10^{-9}$

$= \underline{4\ \mathrm{ns}}$ ✓ 1

[1]

(c) A GPS receiver is used to make two position measurements at different times from the same location.
Explain why these measurements will be different unless a correction for the motion of the satellite is made.

the GPS satelite is at a different point ^ due to it's orbit ~~area~~ around the earth ∴ the correction must be used in order to get accurate ✓[2] 1 measurements. This changes due the relative further distance that the observer see's therefore there is a time difference.

(d) The second relativistic effect is due to gravitational time dilation. This makes the clock on a typical GPS satellite run **fast** by about 30 ns per minute relative to a clock at rest beside the receiver.

(i) Calculate the total time error due to both relativistic effects for two measurements of position made 10 minutes apart from the same point on Earth.

minutes

~~time~~ $\cancel{30}\times10^{-9}\times10 = 3\times10^{-7}$ ✗ [2] 0

(ii) Calculate the corresponding error in distance between the receiver and the satellite.

$3.5\times10^{3} = \frac{D}{600 - 3\times10^{-7}}$ 2100000 − 2099999

$D = 3.5\times10^{3}\times(600 - 3\times10^{-7}) =$ ~~[illegible]~~ 1.05×10^{3} m [1]

(iii) Hence explain why it is important to correct for relativistic effects, and give a practical example of a navigation problem that might otherwise arise.

it is important to get accuracy when finding position therefore the relativistic effects have to be taken into account. I.e a boat ✓ [2] only takes it's position once every 6 hours it ~~[illegible]~~ could ~~[illegible]~~ be a significant distance off course when it takes its next gps reading. ✓ 1

(e) Explain the difference between Newton's concept of absolute time and the concept of time in Einstein's theory of relativity. State how this makes a practical difference in the case of GPS.

According newton's ideas time ~~must be constant~~ velocity and distance must ~~all~~ be constant in ✓ all frames of referance, however einstein~~ed~~ proved that this was not allways the case with objects moving close to the speed of light or at the speed of light. therefore when einstein presented his ideas of Special relativity, not only [5] did he prove that the speed of light was a constant but also that time can change depending ~~of~~ on the frame of reference. he also dissproved the ~~idea~~ idea of the aether ✓ as a medium for em waves. If we use only newtonin concepts in the travel of signals between ✓ gps and reciever we will get an ~~err~~ erron in the measurements. but if we take into account einstiens laws of special relativity we can correct this inaccuracy.

3

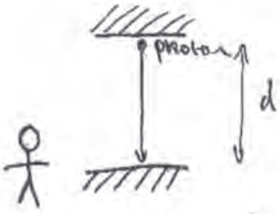
Examiner Comment

This candidate's answer starts with part **(a)** where he gives a good account. Part **(b)** has the numerical work done correctly and part **(c)** has only a minor omission. Part **(d)** is poor. The time used was 10 minutes rather than 26 ns resulting in an incorrect answer for **(d) (ii)** and therefore difficulties in answering part **(d) (iii)**. His answer for part **(e)** made no mention of general relativity and the ideas expressed were repetitious but well worth the 3 marks gained here.

Example Candidate Response – Pass

(a) Explain why a 'moving' clock runs slow compared to a clock at rest beside the observer. Ignore the effects of gravity. (You may wish to use a diagram.)

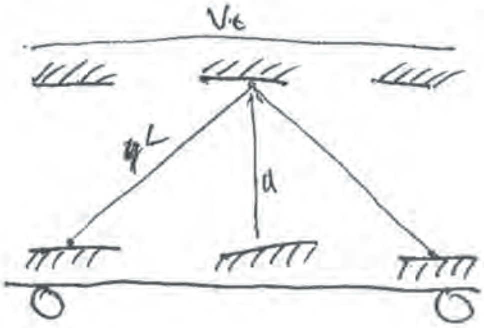
$s = \frac{d}{T}$



$2d = cT.$

light clock in observers reference frame.

✓✓



~~4~~ $L^2 = d^2 + (\frac{1}{2}(vt))^2.$

$4L^2 = 4d^2 + v^2t^2.$

✓

$\rightarrow 0.99c.$

observer not in same reference phrame as clock

in the ~~eta~~ ~~light clock~~ reference phrame inwhich ~~I~~ im in the same one as the clock the photon only traves 2d where as in the light clock in which the light clock is in a diffrent refference frame to the clock the the distance is 2L and so for the moving clock the tick time is longer then the tick time for the stationy clock. ✓ ✓ ✓ [4]

4

(b) **(i)** The satellite's relative velocity is typically about $3.5 \times 10^3\,\text{m}\,\text{s}^{-1}$. Show that an atomic clock on a satellite moving at about $3.5 \times 10^3\,\text{m}\,\text{s}^{-1}$ relative to the receiver loses about 6.8×10^{-11} s every second.

You can use the approximation: $\dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}} \approx 1 + \dfrac{1}{2}\left(\dfrac{v^2}{c^2}\right)$ when $\left(\dfrac{v^2}{c^2}\right)$ is small.

$1 + \frac{1}{2}\left(\frac{3.5\times10^3}{3\times10^8}\right)^2 = 1.000005\cancel{8}33$ seconds time dilated

X

[3]

(ii) Show that this results in a time error of about 4 ns per minute.

^

[1]

(c) A GPS receiver is used to make two position measurements at different times from the same location.
Explain why these measurements will be different unless a correction for the motion of the satellite is made.

as ~~One~~ clock will be one (on) the satlire (satellite) as it is traving (travelling?) fast if they donot corretit (correct) the diskance measured will be out by alot defeating the point of a GPS.

^ [2]

^

0

(d) The second relativistic effect is due to gravitational time dilation. This makes the clock on a typical GPS satellite run **fast** by about 30 ns per minute relative to a clock at rest beside the receiver.

(i) Calculate the total time error due to both relativistic effects for two measurements of position made 10 minutes apart from the same point on Earth.

....

....

....[2]

(ii) Calculate the corresponding error in distance between the receiver and the satellite.

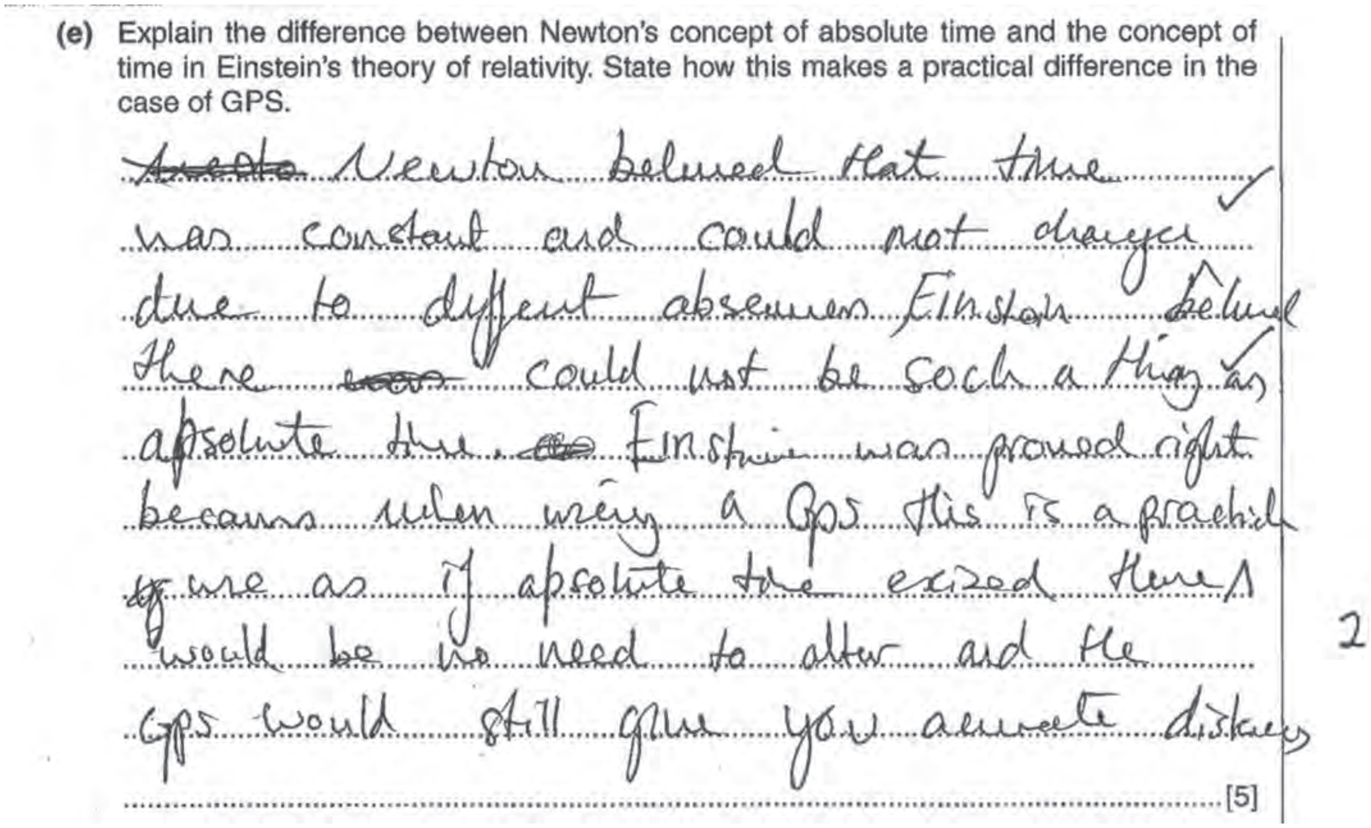
....

....[1]

(iii) Hence explain why it is important to correct for relativistic effects, and give a practical example of a navigation problem that might otherwise arise.

The ~~error~~ errors add up quickly
and as time goes on the error could
be very large so as to send you
to a compleatly diffent county.

....[2]



(e) Explain the difference between Newton's concept of absolute time and the concept of time in Einstein's theory of relativity. State how this makes a practical difference in the case of GPS.

~~[illegible]~~ Newton belived that time ✓
was constant and could not change
due to diffent obsevers Einstein belived
there ~~was~~ could not be such a thing ✓ as
apsolute time. ~~as~~ Einstein was proved right
because when using a Gps this is a practical
~~of~~ use as if apsolute time exised there
would be no need to alter and the
Gps would still give you accurate distances
[5]

2

Examiner Comment

This candidate started well with full marks for the bookwork in part **(a)**. In part **(b)** he got lost with the equation and with use of his calculator so gained no marks. Part **(c)** also gained no marks because he did not say more than 'the distance will be wrong'. Part **(d)** was not really attempted and part **(e)** consisted of stating that Newton believed that time was constant but Einstein believed that there was no such thing as absolute time. The concepts are difficult for weaker candidates but, from an examiner's viewpoint questions such as this do allow a wide range of marks and do discriminate well.

Question 12 Mark Scheme

12 (a) An arrow that points from the past to the future (distinguishes past from future) (1)
Linked to 'one-way' processes (example correctly given) (1) [2]

(b) (i) Newton's first law – still applies. (1)
Example correctly given (1) [2]
E.g. reversing time reverses velocities but does not introduce any new forces, so objects that are moving at constant positive velocity in positive time are moving at constant negative velocity in negative time.

(ii) The first law of thermodynamics still applies. (1)
Example correctly given (1)
E.g. Description of a process in which heat and work done on a system increase internal energy becomes one in which loss of heat and work done by the system decrease internal energy.
Idea that energy is conserved in both directions of time. (1) [3]

(iii) Newton's second law – still applies (1)
Example correctly given (1) [2]
E.g. Reversing time reverses the apparent direction of forces, so that gravity becomes (for example) a repulsion, but $F = ma$ still applies because no additional forces have been introduced.

(iv) The second law of thermodynamics – is violated. (1)
Explanation correctly given
E.g. Entropy / Disorder decreases (1)
Example correctly given
E.g. Mixtures separate spontaneously. (1) [3]

(c) (i) Linking entropy to the distribution of energy or particles amongst states (1)
Quantitative link – e.g. to number of ways
(or to classical equations such as $\Delta S = \dfrac{\Delta Q}{T}$) (1) [2]

(ii) Idea that there are lots of ways of achieving disordered states but only a small number of ways of achieving ordered states. (1)
Link 'order' to low probability (or disorder to high probability). (1) [2]

(d) If the universe were to collapse in the future (1)
Then the direction of entropy increase would be opposite to the direction of expansion. (1) [2]

(e) It had very low entropy (1)
It had a very low probability (1) [2]
Accept answers that explain the idea of low probability – e.g. of all the ways that the universe might have formed the actual distribution of matter and energy was highly unlikely.

Example Candidate Response – Distinction

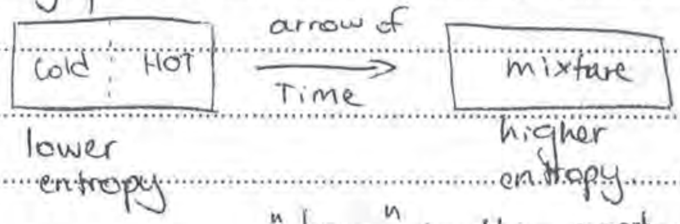
12 Read the extract below, which is taken from Stephen Hawking's book, 'A Brief History of Time'.

'The increase of disorder or entropy with time is one example of what is called an arrow of time, something that distinguishes the past from the future, giving a direction to time. There are at least three different arrows of time. First there is the thermodynamic arrow of time, the direction of time in which disorder or entropy increases. Then, there is the psychological arrow of time. This is the direction in which we feel time passes, the direction in which we remember the past but not the future. Finally, there is the cosmological arrow of time. This is the direction of time in which the universe is expanding rather than contracting.'

Stephen Hawking, 'A Brief History of Time', Bantam Books 1988, p153.

(a) Explain in your own words, with a specific example, what is meant by 'an arrow of time'.

Any process leads to increase in entropy. E.g.



The state of lower entropy in this example with a "box" is the past and higher entropy is the future ✓ ✓ [2]

(b) Imagine you could reverse time and watch everything running backwards from this moment to the start of the universe. For each of the following laws of physics, state the law and, using an example, explain whether the law would also apply in the reverse-time universe.

(i) Newton's first law of motion.

~~F=ma law of~~

Law of inertia: no unbalanced force =

= no acceleration ✓

In reverse time, acceleration would be "causing" the force rather than vice versa. But without acceleration, there would be no force. Therefore, the law holds ✓ in inverse direction (order). [2]

2

(ii) The first law of thermodynamics.

$\Delta Q = \Delta I + \Delta W$

change in heat either causes a change in internal energy or work done on a system, or both.

Again, work done or a change in internal energy or both would be causing a change in heat, so the law holds in reverse order. ✓ ✓ [3]

3

(iii) Newton's second law of motion.

$F = ma \quad F \propto a$ ✓

Force and acceleration would still be directly proportional, so the law holds completely. [2]

1

(iv) The second law of thermodynamics.

Any process causes an increase of entropy in an isolated system. ✓

This law does not hold. Any "reverse process" would be causing ~~a~~ ~~decrease~~ ~~in~~ the entropy to lower. ✓

The new law for the "reverse-universe" "Any process causes ~~a~~ the entropy to lower". [3]

2

(c) In the extract, Hawking uses 'disorder' as a loose description of entropy.

(i) Give a scientific description of the term *entropy*.

Entropy is a measure of disorder or chaos of an isolated system.

$$\Delta S = \frac{\Delta Q}{T}$$ ✓

$$\text{Change in Entropy} = \frac{\text{change in } \cancel{\text{charge}} \text{ heat}}{\text{temperature in Kelvins}}$$ ✓

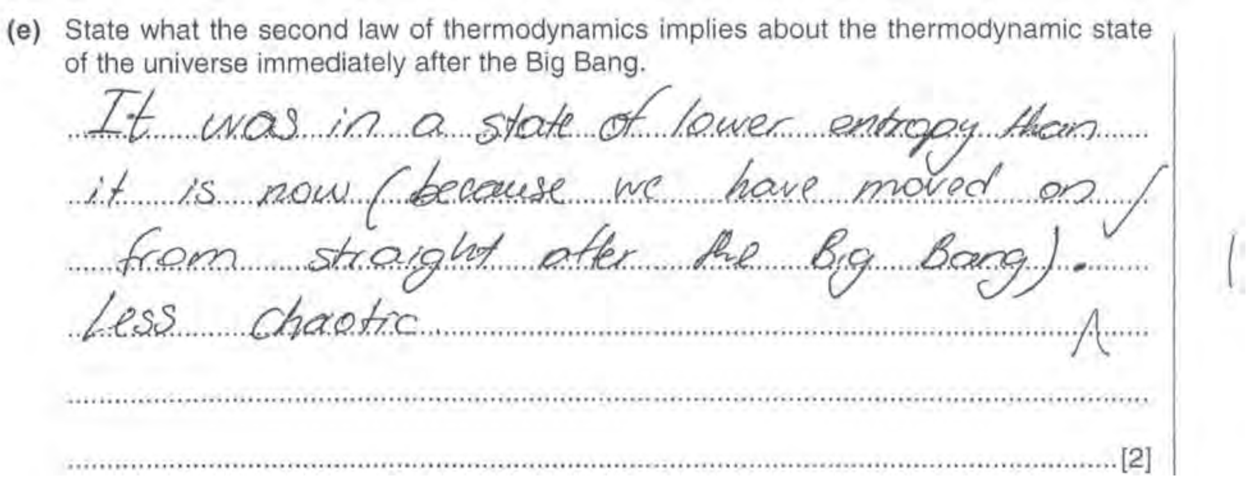
[2] 2

(ii) Explain why 'disorder' and entropy are linked.

The more heat per unit temperature there is, the more entropy there is. A more energetic state of matter is ✓ more chaotic or disorderly. ✓ Heat energy makes objects more energetic, thus increases their ✓ entropy and makes them more disorderly. ✓ [2] 2

(d) Explain a situation in which the cosmological and thermodynamic arrows of time point in different directions.

e.g. Maxwell's Demon situation. Cosmological and psychological arrows agree. But the thermodynamical arrow points ✓ in the opposite direction as the creature only allows ✓ hot particles to one side and cold ones to another, [2] thereby decreasing entropy. 2



(e) State what the second law of thermodynamics implies about the thermodynamic state of the universe immediately after the Big Bang.

It was in a state of lower entropy than it is now (because we have moved on from straight after the Big Bang). ✓
less chaotic

[2] 1

Examiner Comment

This was a very good answer from this Distinction candidate. Part **(a)** was answered in terms of entropy and part **(b)** showed that there was a good understanding of the fundamental laws of physics. The only weak point resulted from stating Newton's second law as just $F = ma$. Parts **(c)** and **(d)** both gained full marks but part **(e)** was answered quite briefly.

Example Candidate Response – Merit

12 **(a)** Explain in your own words, with a specific example, what is meant by 'an arrow of time'.

An arrow of time is something that gives time a direction and proves there is a difference between the past and the future ✓ an example is that ~~[illegible]~~ the entropy of the universe always increases ✓ this is the Thermodynamical arrow of time. [2]

2

(b) Imagine you could reverse time and watch everything running backwards from this moment to the start of the universe. For each of the following laws of physics, state the law and, using an example, explain whether the law would also apply in the reverse-time universe.

(i) Newton's first law of motion.

for every action there is an equal and and opposite reaction. ✗ This would still be true because as im writing the table is ~~[illegible]~~ providing an equal and opposite reaction. Just because i go back in time ✓ does not mean my hand will go though the table

[2]

1

(c) In the extract, Hawking uses 'disorder' as a loose description of entropy.

(i) Give a scientific description of the term *entropy*.

Entropy is a way a mesuring chaos ~~if~~ they are propablitis of random events ^ and the propabliy will always tand to chaos.

0

[2]

(ii) Explain why 'disorder' and entropy are linked.

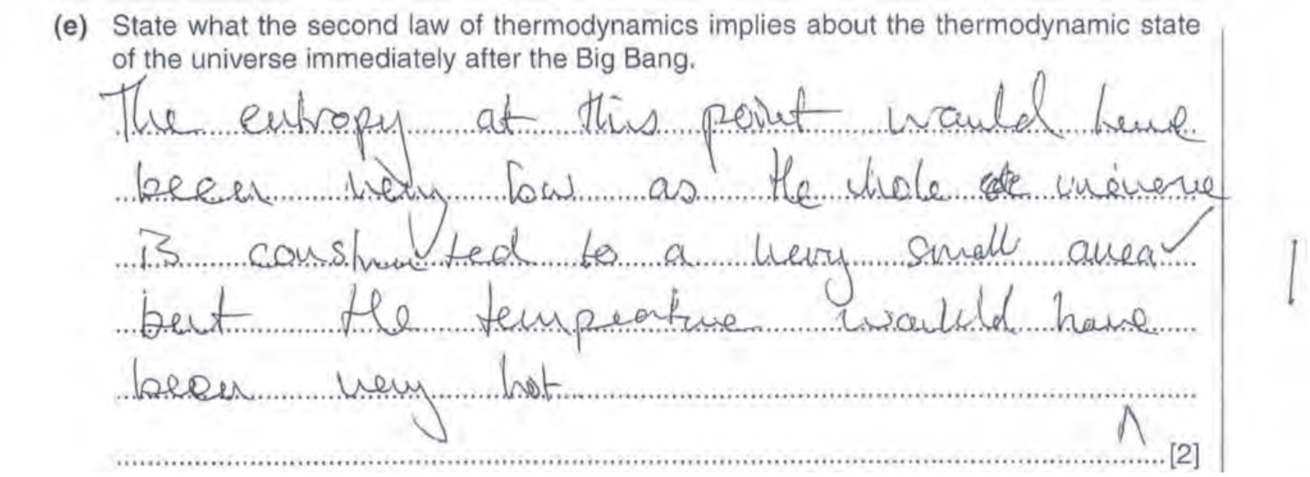
if you have a crystal contaiing 5 Na^+ and 5 Cl^- the entropy would be low but if you replace one Na^+ with a K^+ the entropy would be higher ~~as it~~ as well as the disorder because the probability is that the K^+ could be place anywhere one Na^+ were [2] ∴ entropy and disorder are linked.

✓ ✓ 2

(d) Explain a situation in which the cosmological and thermodynamic arrows of time point in different directions.

the bigbang as the universe increased the entropy got larger but there was X no star system so the cosmological arrow would not have been pointing. ^

[2]



(e) State what the second law of thermodynamics implies about the thermodynamic state of the universe immediately after the Big Bang.

The entropy at this point would have been very low as the whole ~~ole~~ universe Is constricted to a very small area ✓ but the temperature would have been very hot

^ [2]

1

Examiner Comment

This candidate started well but then stated Newton's first law of motion as "action and reaction are equal and opposite", the first law of thermodynamics as "energy cannot be created or destroyed" and Newton's second law as $F = ma$. These incorrect or partial statements limited his overall mark on part **(b)**. In part **(c)** he only stated that entropy is a way of determining probabilities of random events but scored both marks for **(c) (ii)**. In part **(d)** he could only refer to a system where entropy was increasing and in part **(e)** he only stated that at the Big Bang the Universe has a small area (sic) but high temperature.

Example Candidate Response – Pass

(a) Explain in your own words, with a specific example, what is meant by 'an arrow of time'.

An 'arrow of time' is something which allows a clear distinction between past and ✓ future, and allows us to percieve time. An example ~~is~~ could be from our first to ✓ 100th birthday – we percieve time through ✓ [2] the chronological order of events. 2

(b) Imagine you could reverse time and watch everything running backwards from this moment to the start of the universe. For each of the following laws of physics, state the law and, using an example, explain whether the law would also apply in the reverse-time universe.

(i) Newton's first law of motion.

Force is equal to mass x acceleration ✗ (F = ma).

This law would still apply. If I were to 'push' a pen away from me in the reverse-time universe, the ✓ force and acceleration would both be negative, but the equation would ~~st~~ still balance. If no force ~~would~~ [2] was applied, objects would stay still. 1

(ii) The first law of thermodynamics.

For Examiner's Use

Energy flows in the direction of the heat gradient (heat 'flows' from hot place to cold place). ✗

This would not apply in the reverse-time universe - the opposite would be true. For example, a ~~to~~ fridge that ~~be~~ has been ✓ unplugged would become colder. [3]

1

(iii) Newton's second law of motion.

Work done = Force x distance travelled. ✗

This would still apply in a reverse-time universe. If I 'pushed' a box, the force and work done would both be negative, but the distance travelled would ✓ be the same. The equation would balance.

[2]

1

(iv) The second law of thermodynamics.

T = pV (Temperature is proportional ✗ to both pressure and volume). ✗

In a reverse-time universe, this would still apply. The proportionality ✗ relationship in an autoclave, for example, would remain the same, but the changes would be in reverse. [3]

0

(c) In the extract, Hawking uses 'disorder' as a loose description of entropy.

(i) Give a scientific description of the term *entropy*.

All energy in the universe is slowly being homogenised. Eventually, each place in the universe shall have the same energy as each other place. ✓✓

[2]

(ii) Explain why 'disorder' and entropy are linked.

Entropy is a consequence of natural phenomena which by their very nature have no order themselves. ✓
All reactions occur randomly ✓

[2]

(d) Explain a situation in which the cosmological and thermodynamic arrows of time point in different directions.

Directly after the Big Bang the universe will be expanding, but entropy will decrease, as the formation of stars and ✗ galaxies occurs

[2]