

## A LEVEL

*Examiners' report*

# PHYSICS A

**H556**

For first teaching in 2015

## **H556/03 Summer 2018 series**

Version 1

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## Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates. The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. The reports will also explain aspects which caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report. A full copy of the question paper can be downloaded from OCR.

## Paper H566/03 series overview

H556/03 is one of the three examination components for the new revised A Level examination for GCE Physics A. It assesses all areas of the course mainly through examples of real practical and experimental situations. To gain good marks in this paper, candidates need to be able to apply their knowledge and understanding to unfamiliar contexts such as question 2 and analyse and interpret experimental data as in question 4.

To do well in this paper candidates are expected to be able to

- perform and layout calculations logically showing clear working in questions such as 1(b), 2(c) and 3(a) (ii) and (iii).
- produce clear and concise responses to the Level of Response questions: 1(a) and 5(b) and to short answer explanations such as 2(b), 3(a)(i) and 6(a)(ii).
- process and interpret data from an experiment to reach conclusions as in 4
- be able to read, interpret and use all of the information given in the text of the question.

There are ten examples of candidates' answers included below to illustrate points made in the report.

There was little evidence that candidates had difficulty in completing the paper in the time allowed. There were few scripts where there was no response to the final part or parts of the last question or of blank sections within the paper.

## Question 1 (a)

1 This question is about a resistance wire made of nichrome.

(a)\* It is suggested that the resistance  $R$  of a length of nichrome wire varies with temperature  $\theta$  in  $^{\circ}\text{C}$  according to the equation

$$R = R_0 (1 + k\theta)$$

where  $R_0$  is the resistance of the wire at  $0^{\circ}\text{C}$  and  $k$  is a constant for the wire.

Fig. 1.1 shows a diagram of the arrangement of apparatus in an experiment to test the relationship between  $R$  and  $\theta$  and to determine the value of  $k$ .

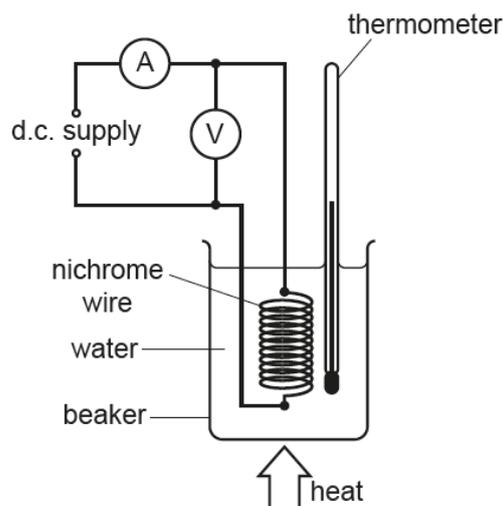


Fig. 1.1

The resistance wire is coiled and placed in a water bath.

Describe how you would carry out the experiment, analyse the data to verify the relationship between  $R$  and  $\theta$  and determine a value for  $k$ .

In your description, state any precautions that you would take to improve the accuracy and precision of the measurements.

.....  
 .....  
 ..... [6]

This question proved to be a suitable starter as almost all wrote a full page answer or even completed it on one of the spare pages at the back of the examination booklet.

The majority of candidates described the basic procedure to perform the experiment. There was a small group who did not appreciate that  $R_0$  referred to  $0^{\circ}\text{C}$  but took it to be their initial room temperature. Some of these contradicted themselves once they reached the analysis of data section of their answer. Some started with ice water whilst others just found  $R_0$  by extrapolation from the graph. A few good candidates compared both methods as a check on the reliability of their experiment. The example (exemplar 1) of an L3 answer shown here implies this check without stating it clearly.

## Exemplar 1

At a variety of temperatures, record from  $0-100^{\circ}$  in  $10^{\circ}\text{C}$  intervals record the current & voltage of the wire. Do this when you do keep the temperature constant and the wire is also at this temperature. i.e hold it at the temperature for 2 mins before taking results. Also stir the water to ensure it is all the same temperature. Once you have results for all temperatures. Repeat twice more and take averages. Work out the resistance for each temperature using  $\frac{V}{I} = R$ . Plot a graph of  $\frac{R}{R_0}$  against  $\theta$  where  $R_0$  is the value you got for  $0^{\circ}\text{C}$  or as close to this temperature you could get. Plot a line of best fit & work out the gradient. If it is a straight line then the relationship is true. The gradient should be  $k$  and the y intercept 1. This graph  $k$  gives the value for  $k$ . To improve accuracy you should repeat the experiment a multiple times and take an average gradient to give a more accurate result. You should also get your water & this wire to  $0^{\circ}\text{C}$ , or as close possible, to give a more precise value for  $R_0$ .

About half of the candidates remembered to stir the heating water. Only a minority allowed time for thermal equilibrium to be reached with the heating removed before taking measurements. Many did not state how they heated the water which was important because a group described using the given nichrome wire and supply for this purpose. Many wanted to take the unnecessary precaution of lagging the beaker or using a lid to avoid heat loss. One sensible improvement suggested was to use a digital thermometer in place of the one in the diagram. The advantages of this change were not always explained.

The candidates were able to explain how to process the data to obtain a value for  $k$ . Only a very few did not draw a graph. As in question 5b many are not clear about the difference between a linear and a

proportional relationship. A good exposition describing a suitable graph with a  $y$ -intercept of  $R_0$  could be ruined by the statement that the graph showed that  $R$  was proportional to  $\theta$ .

### Question 1 (b) (i)

- (b) A student is investigating a 230V, 1.0kW heating element. The heating element is shown in Fig. 1.2.

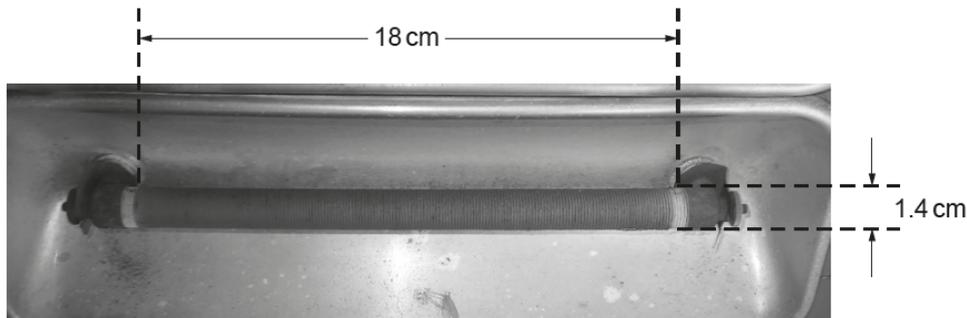


Fig. 1.2

A length of nichrome wire is wound in a spiral groove along 18 cm of a ceramic cylinder of diameter 1.4 cm. The distance between the centres of adjacent turns of the wire is 1.5 mm.

The numbers labelling the reels of loose wire on the laboratory shelf are the *imperial standard wire gauge* (swg). The student wishes to find out which reel holds the same wire as that wound on the heating element of Fig. 1.2.

The book of data gives the following information:

resistivity of nichrome at operating temperature =  $1.1 \times 10^{-6} \Omega \text{ m}$

<b>swg</b>	24	26	28	30	32
<b>diameter of wire / <math>10^{-3} \text{ m}</math></b>	0.56	0.46	0.38	0.32	0.27
<b>cross-sectional area / <math>10^{-6} \text{ m}^2</math></b>	0.25	0.16	0.11	0.08	0.06

- (i) Show that the resistance of the nichrome wire wound on the ceramic cylinder is  $53 \Omega$ .

[2]

## Question 1 (b) (ii)

(ii) Show that the length of wire wound on the heating element is 5.3 m.

[2]

## Question 1 (b) (iii)

(iii) Use the information given in (i) and (ii) to determine the swg number of the wire used as the heating element.

swg number = ..... [3]

The purpose of this question was to challenge the candidates to use their knowledge to solve a laboratory based practical problem. The majority approached part (i) correctly by considering the power data for the fire element. A significant minority were drawn to the formula relating resistance and resistivity. Many of these realised that this approach was incorrect and changed to the correct approach. Here is a typical example (exemplar 2) of a script where the candidate continued to complete the whole question correctly. The rest remained at a loss and did not gain any marks for parts (ii) and (iii).

## Exemplar 2

$$R = \frac{\rho l}{A} = \frac{1.1 \times 10^{-6} \times 0.18 \times \pi \times 0.014}{\pi \times \left(\frac{0.014}{2}\right)^2}$$

$$P = \frac{V^2}{R} \quad R = \frac{V^2}{P} = \frac{230^2}{1000} = 52.9 \Omega \approx 53 \Omega \quad [2]$$

In part (ii) a minority again tried the resistivity formula rather than an approach using geometry.

Finally in part (iii) the resistivity formula was applied with success. The question overall proved to be a good discriminator of ability and understanding.

## Question 2 (a)

- 2 The 500 m tall Taipei 101 tower is shown in Fig. 2.1. The tower has a massive sphere suspended across five floors near the top of the building to dampen down movement of the tower in high winds and earthquakes. The sphere is connected to pistons (not shown) which drive oil through small holes providing damping. The vibration energy of the sphere is converted to thermal energy.

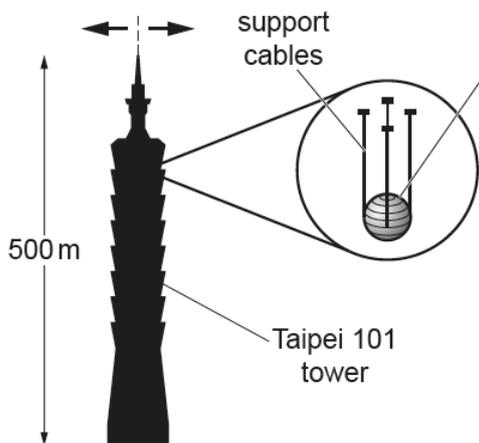


Fig. 2.1

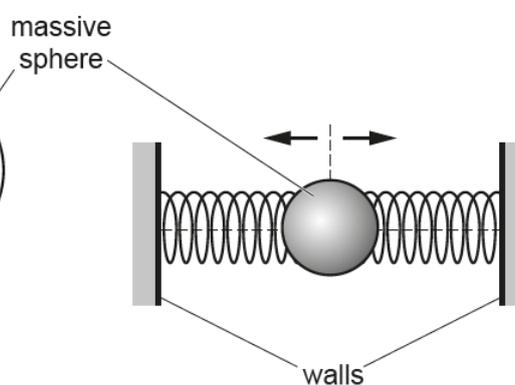


Fig. 2.2

Fig. 2.2 models the damper system as the sphere held between two springs. The movement of the walls of the tower forces the sphere to oscillate in **simple harmonic motion**.

In the strongest wind, the natural frequency of the oscillations of the tower is 0.15 Hz and the maximum acceleration of the sphere is  $0.050 \text{ m s}^{-2}$ .

- (a) Calculate the maximum displacement of the sphere in the strongest wind.

maximum displacement = ..... m [3]

The words *simple harmonic motion* in the text pointed almost all candidates to use the correct formula. The angular frequency was calculated correctly. Two common errors were to forget to square the value or to give the final answer to only one significant figure rather than a minimum of two.

## Question 2 (b)

(b) Explain why the natural frequency of the damper system must be about 0.15 Hz.

.....

.....

.....

..... [2]

The answers gave a clear indication as to how well the candidates understood a resonance situation. Many omitted to explain which of the three oscillating elements were acting as drivers and which were driven. The candidate who wrote the answer (exemplar 3) shown here has some understanding of the situation but has failed to communicate it clearly to the reader.

## Exemplar 3

because the maximum amplitude is  
 produced when the system is resonant ✓  
 which is when the natural frequency is  
 equal to the driving frequency and the natural  
 frequency is 0.25 Hz so resonant when driving freq = 0.15 Hz [2]

The ball was often quoted as just acting against the tower to reduce the amplitude rather than using the clue at the end of the initial paragraph about the energy drawn from the tower being absorbed by the dampers. Hence the requirement for the ball to be given a large amplitude or absorb the maximum amount of energy.

## Question 2 (c) (i)

- (c) The acceleration  $a$  of the sphere is given by the equation

$$a = -\left(\frac{k}{m}\right)x$$

where  $k$  is the force constant of the spring combination,  $x$  is the displacement of the sphere and  $m$  is the mass of the sphere.

The mass of the sphere is  $6.6 \times 10^5$  kg. The natural frequency of the oscillations of the sphere is 0.15 Hz.

- (i) Show that the force constant  $k$  of the spring combination is about  $6 \times 10^5 \text{ N m}^{-1}$ .

[3]

## Question 2 (c) (ii)

- (ii) The S-wave of an earthquake causes a sudden movement of the building displacing the sphere 0.71 m from its equilibrium position relative to the building.

Use your answer in (i) to calculate the energy transferred to the springs of the damper system.

energy transferred = ..... J [2]

The exercise in this section completed successfully by most candidates was to perform standard calculations stating correct formulae and showing clear working to determine the required quantities. The example (exemplar 4) shown here is of a typical neat script.

The most common error was to forget to square quantities in part (ii) or to use the amplitude calculated part (a) rather than the figure given in the stem of this part.

## Exemplar 4

$$a = -\frac{k}{m}x \quad \frac{0.05}{0.056} \times (6.6 \times 10^5) = k$$

$$0.05 = -\frac{k}{(6.6 \times 10^5)} (0.056)$$

$$k = 5.89 \times 10^5$$

$$k \approx 6 \times 10^5 \text{ Nm}^{-1}$$

[3]

$$\omega = 2\pi f \quad \frac{0.050}{(0.30\pi)^2} = x$$

$$\omega = 0.30\pi \quad x = 0.056$$

$$a = -\omega^2 x$$

maximum displacement = ..... 0.056 ..... m [3]

(b) Explain why the natural frequency of the damped system must be about 0.45 Hz.  
Second variant for M1 given with evidence of working.

$$E = \frac{1}{2} k x^2 \quad \swarrow \text{my value of } k$$

$$E = \frac{1}{2} (5.89 \times 10^5) (0.71)^2$$

$$E = 148529.46$$

$$E = 1.49 \times 10^5 \quad \text{energy transferred} = \dots 1.49 \times 10^5 \dots \text{ J [2]}$$

## Question 3 (a) (i)

3 A binary star is a pair of stars which move in circular orbits around their common centre of mass.

In this question consider the stars to be point masses situated at their centres.

(a) Fig. 3.1 shows a binary star where the mass of each star is  $m$ . The stars move in the same circular orbit.

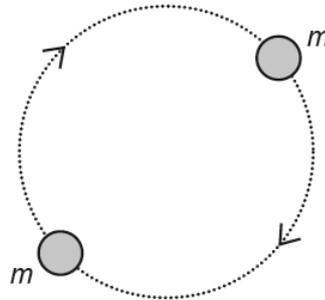


Fig. 3.1

(i) Explain why the stars of equal mass must always be diametrically opposite as they travel in the circular orbit.

.....

.....

.....

.....

..... [2]

Only a minority of candidates related the gravitational force between the stars to the centripetal force required for circular motion to occur. This candidate has written the perfect answer (exemplar 5).

There were two popular insufficient answers; that if the stars were not diametrically opposite they would collide and that the centre of mass of the system had to be at the centre of the orbit.

## Exemplar 5

\* Their gravitational force to each other acts as the centripetal force. ✓

\* Gravitational force is directly towards their centers which means the centripetal force is on the same line of the gravitational force so the center of orbit must be ~~on~~ on the line of their centers as the diameter. ✓ [2]

## Question 3 (a) (ii)

- (ii) The centres of the two stars are separated by a distance of  $2R$  equal to  $3.6 \times 10^{10}$  m, where  $R$  is the radius of the orbit. The stars have an orbital period  $T$  of 20.5 days. The mass of each star is given by the equation

$$m = \frac{16\pi^2 R^3}{GT^2}$$

where  $G$  is the gravitational constant.

Calculate the mass  $m$  of each star in terms of the mass  $M_{\odot}$  of the Sun.

$$\begin{aligned} 1 \text{ day} &= 86400 \text{ s} \\ M_{\odot} &= 2.0 \times 10^{30} \text{ kg} \end{aligned}$$

$$m = \dots\dots\dots M_{\odot} \text{ [3]}$$

This question tested the candidates' ability to interpret and substitute data into an elaborate formula and then evaluate it. The most common error was to write the formula with the correct substitutions but then to omit the square symbol against  $T$ . Candidates should be encouraged to consider whether their answers are reasonable before moving on to the next question. In the calculation (exemplar 6) shown here, is it possible that these stars could be four million times the mass of the Sun? The correct answer of 2.2 Sun masses seems very plausible and should give candidates confidence.

## Exemplar 6

Calculate the mass  $m$  of each star in terms of the mass  $M_{\odot}$  of the Sun.

$$\begin{aligned} 1 \text{ day} &= 86400 \text{ s} \\ M_{\odot} &= 2.0 \times 10^{30} \text{ kg} \end{aligned}$$

$$\begin{aligned} m &= \frac{16\pi^2 \times (1.8 \times 10^{10})^3}{6.67 \times 10^{-11} \times (20.5 \times 8.64 \times 10^4)^2} \\ &= 7.795 \dots \times 10^{36} \text{ kg} \end{aligned}$$

$$\frac{\text{Ans}}{2 \times 10^{30}} = 3.8977 \dots \times 10^6$$

$$m = \dots 3.9 \times 10^6 \dots M_{\odot} \text{ [3]}$$

## Question 3 (a) (iii)

- (iii) The stars are viewed from Earth in the plane of rotation. The stars are observed using light that has wavelength of 656 nm in the laboratory. The observed light from the stars is Doppler shifted.

Calculate the maximum change in the observed wavelength  $\Delta\lambda$  of this light from the orbiting stars. Give your answer in nm.

$\Delta\lambda = \dots\dots\dots$  nm [2]

Most of the higher performing candidates completed this problem successfully. Two common errors among the remainder were to equate the formula for central force gravitational potential energy ( $GMm/r$ ) to kinetic energy to find a value for the speed of the stars and to rewrite incorrectly metres in powers of 10 in nanometres.

## Question 3 (b) (i)

(b) Fig. 3.2 shows a binary star where the masses of the stars are  $4m$  and  $m$ .

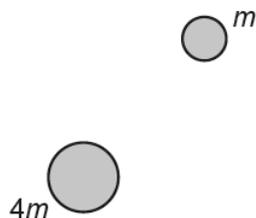


Fig. 3.2

- (i) The centre of mass of the binary star lies at the surface of the star of mass  $4m$ . Draw on Fig. 3.2 two circles to represent the orbits of **both** stars. [1]

## Question 3 (b) (ii)

- (ii) Explain why the smaller mass star travels faster in its orbit than the larger mass star.

.....

.....

.....

.....

..... [2]

Candidates should be encouraged to draw diagrams such as part (i) as accurately as they can. Some had drawing instruments and drew accurate circles. Many drew shapes which were very far from circular, making it difficult in some examples to judge whether the candidate knew the correct path.

A secondary purpose of this part was to reinforce the idea that the stars remain diametrically opposite as in part (a) (i). Many did not respond to this trigger having Kepler's laws or centripetal force requirements central in their minds. The rest stated clearly that the orbital period for the two stars had to be the same and consequently were credited both marks.

## Question 4 (a)

4 Fig. 4.1 shows an arrangement used by a student to determine the acceleration of free fall.

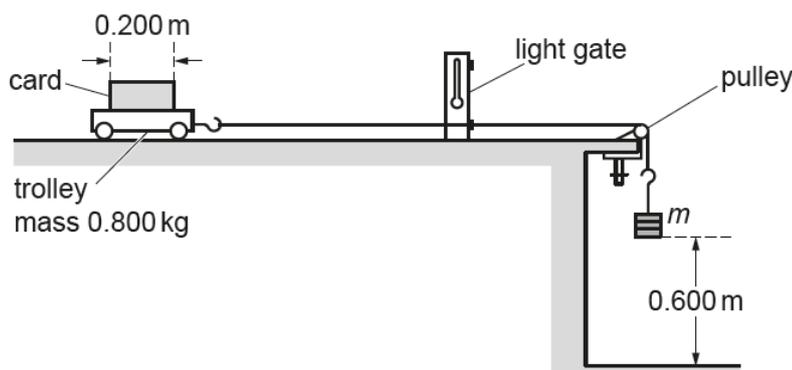


Fig. 4.1

A trolley is attached to a variable mass  $m$  by a string which passes over a pulley.

The mass  $m$  is released from rest and falls through a fixed height of 0.600 m accelerating the trolley of mass 0.800 kg. When the mass  $m$  hits the floor, the trolley then continues to move at a **constant** velocity  $v$ .

This constant velocity  $v$  is determined by measuring the time  $t$  for the card of length 0.200 m to pass fully through a light gate connected to a timer.

Frictional forces on the trolley and the falling mass  $m$  are negligible.

(a) Show that the relationship between  $v$  and  $m$  is

$$v^2 = \frac{1.20mg}{(m + 0.800)}$$

where  $g$  is the acceleration of free fall.

[2]

The challenge to candidates in answering this *show that* question was to produce a convincing proof. More chose to use constant acceleration equations and  $F = ma$  rather than loss of potential energy equates to gain in kinetic energy. The difficulty in the former method was justifying the statement  $F = mg = (m + 0.800) a$ . Most just quoted that  $a = mg / (m + 0.800)$  which immediately gave the relationship shown in the question. The difficulty with the second method was that most candidates wrote  $mgh = \pm \frac{1}{2}mv^2$  as the first line of their answer. In the next line one  $m$  became  $(m + 0.800)$  without explanation to give the required relationship. Only candidates who gave more explanation were credited the marks.

The candidate who wrote this perfect answer (exemplar 7) solved the problem in the first method of solution by introducing the tension in the string (labelled  $T$  on Fig. 4.1).

## Exemplar 7

- (a) Show that the relationship between
- $v$
- and
- $m$
- is

$$v^2 = \frac{1.20mg}{(m + 0.800)}$$

where  $g$  is the acceleration of free fall.

$$T = 0.800a$$

$$mg - T = ma$$

$$mg = a(0.800 + m)$$

$$s = 0.600$$

$$v = ?$$

$$a = ?$$

$$t = ?$$

$$v^2 = u^2 + 2as$$

$$v^2 = 2(0.600)a$$

$$v^2 = \frac{1.20mg}{(0.800 + m)}$$

[2]

## Question 4 (b) (i)

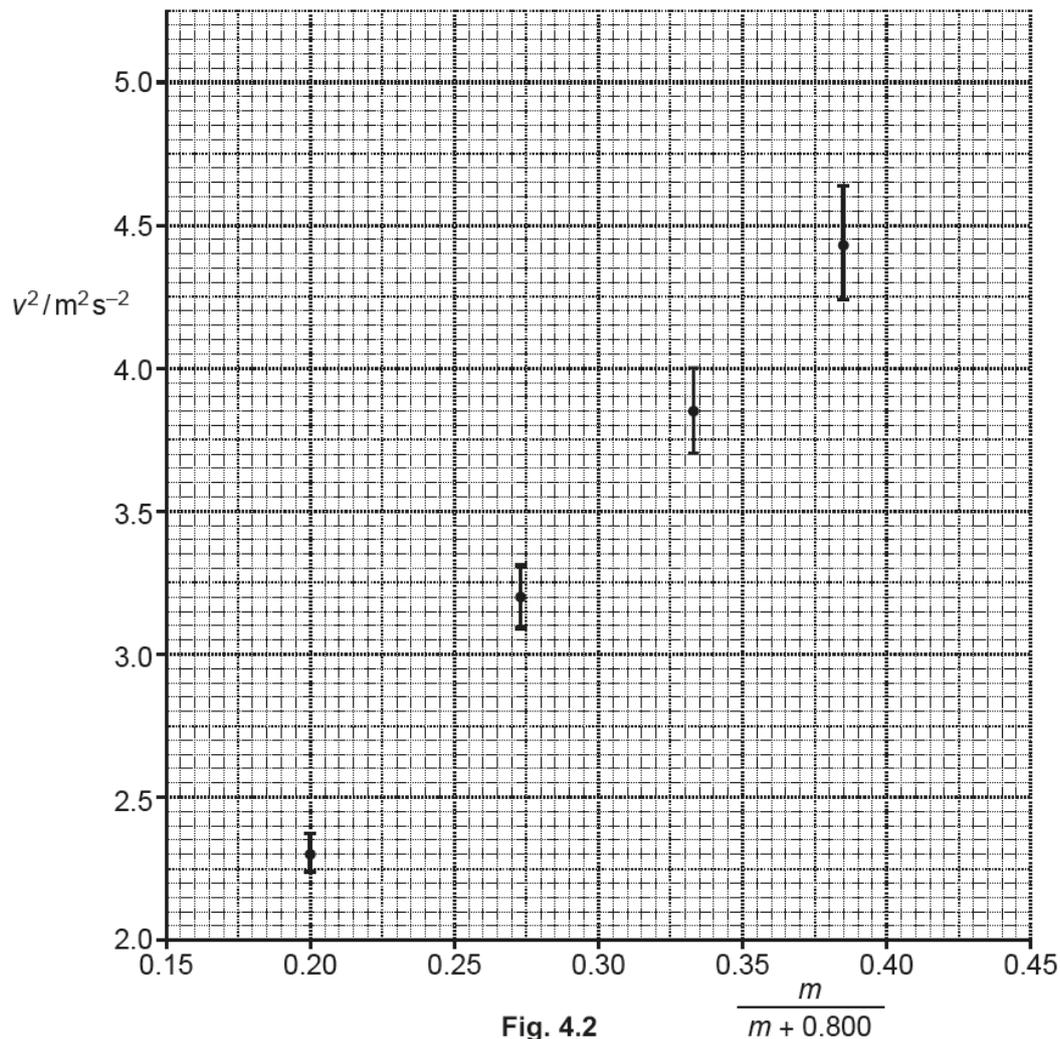
- (b) The student records the information from the experiment in a table. The column headings and just the last row for
- $m = 0.600$
- kg from this table are shown below.

$m/\text{kg}$	$t/10^{-3}\text{s}$	$\frac{m}{(m + 0.800)}$	$v/\text{ms}^{-1}$	$v^2/\text{m}^2\text{s}^{-2}$
0.600	$90 \pm 2$	0.429	$2.22 \pm 0.05$	

- (i) Complete the missing value of
- $v^2$
- in the table including the absolute uncertainty. [2]

## Question 4 (b) (ii)

- (ii) Fig. 4.2 shows some of the data points plotted by the student. Plot the missing data for  $m = 0.600\text{ kg}$  on Fig. 4.2 and draw the straight line of best fit. [2]



Most candidates calculated the value of  $v^2$  to two decimal places successfully. Fewer were successful in giving the absolute uncertainty as  $\pm 0.22$ . A popular distractor was  $\pm 0.10$ . On the graph of Fig. 4.2 only the correct position of the point was required to gain the mark. The length of the uncertainty bar was ignored. A significant number of candidates forgot to draw the line of best fit on the graph.

## Question 4 (c) (i)

- (c) (i) Use the equation given in (a) to show that the gradient of the graph of  $v^2$  against  $\frac{m}{(m+0.800)}$  is equal to  $1.20g$ .

[1]

The common successful method employed by the majority was to compare the given equation with standard form for a straight line  $y = mx + c$ . A simple rearrangement of the relationship without any explanation was not considered to be adequate.



Exemplar 8

The time taken ~~to~~ is increased. ✗

SO constant velocity  $v$  decreases. ✓ ECF

$v \propto \frac{m}{m + 0.800} \cdot 1.20g$  ECF

Gradient would be smaller, therefore, the experimental value of  $g$  would be smaller. ✓ ECF

Question 5 (a) (i)

- 5 (a) A magnet rotates inside a shaped soft iron core. A coil is wrapped around the iron core as shown in Fig. 5.1. The coil is connected to an oscilloscope.

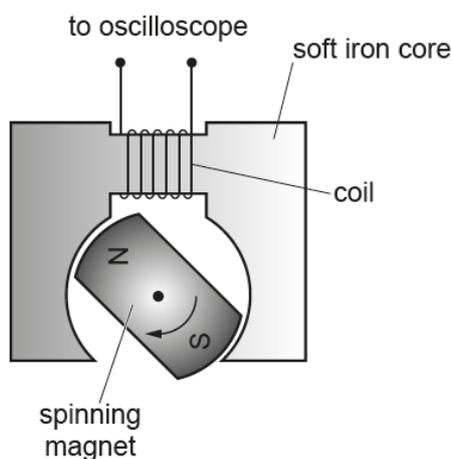


Fig. 5.1

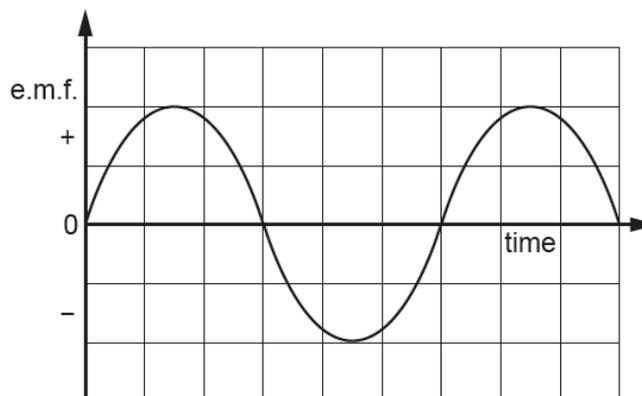


Fig. 5.2

The spinning magnet induces an e.m.f. in the coil. A graph of the e.m.f. displayed on the oscilloscope screen is shown in Fig. 5.2.

- (i) Explain the shape of the graph in terms of the magnetic flux linking the coil.

.....

.....

.....

.....

[2]

## Question 5 (a) (ii)

- (ii) On Fig. 5.3 sketch a graph of the magnetic flux linkage of the coil against time. The variation of the induced e.m.f. across the coil is shown as a dotted line. [1]

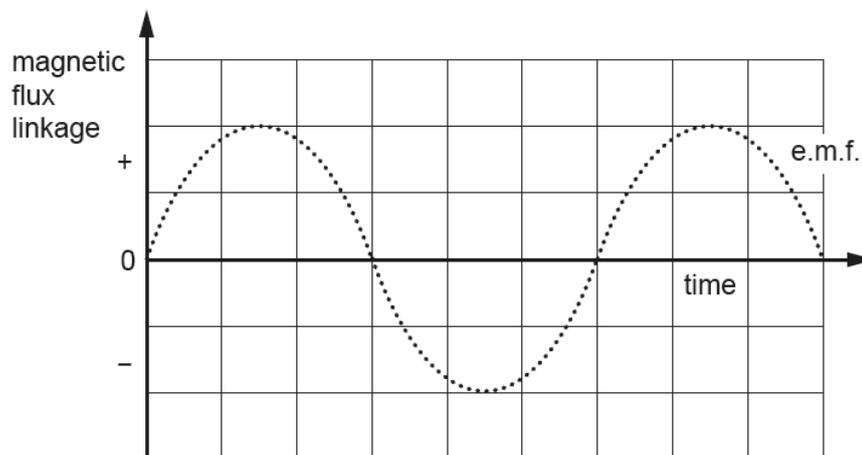


Fig. 5.3

In part (i) many of the candidates described the phase shift that they drew in the sketch graph of part (ii) by stating either the magnitude or the rate of change of the flux linkage when the induced e.m.f. was zero or a maximum. The majority quoted Faraday's law either in words or as a mathematical equation. Some candidates introduced current and Lenz's law not appreciating that an oscilloscope is effectively a voltmeter. Few described the whole picture of a steadily rotating magnetic field sweeping through a coil creating a changing flux linkage.

## Question 5 (a) (iii)

- (iii) The coil shown in Fig. 5.1 has 150 turns. The maximum induced e.m.f.  $V_0$  across the coil is 1.2V when the magnet is rotating at 24 revolutions per second.

Calculate the maximum **magnetic flux** through the coil using the equation

$$V_0 = 2\pi \times (\text{frequency}) \times (\text{maximum magnetic flux linkage})$$

Give a unit with your answer.

maximum flux = ..... unit ..... [2]

## Question 5 (b)

(b)\* A student is given a transformer with coils **X** and **Y**, as shown in Fig. 5.4.

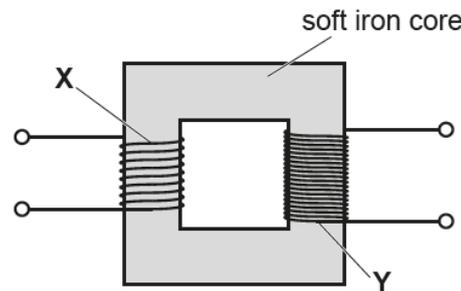


Fig. 5.4

The student is intending to investigate how the maximum induced e.m.f.  $V_0$  in coil **Y** depends on the frequency  $f$  of the alternating current in coil **X**.

The changing magnetic flux density in coil **X** induces an e.m.f. in coil **Y**. Faraday's law indicates that the maximum induced e.m.f.  $V_0$  should be directly proportional to  $f$ .

Describe how you would investigate the suggested relationship between  $V_0$  and  $f$  in the laboratory using these coils. In your description include all of the equipment used and how you would analyse the data collected.

Use the space below to draw a suitable diagram.

.....

.....

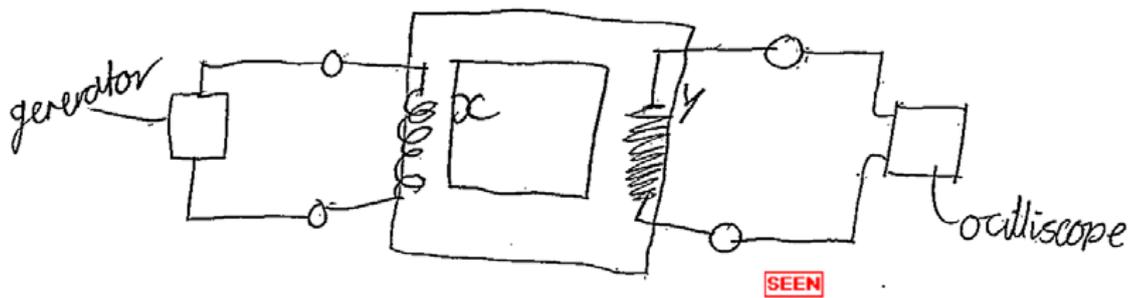
.....

..... [6]

From the proposed arrangements for the investigation, it was apparent that most of the candidates were unfamiliar with the most suitable equipment for this experiment, namely a signal generator. Many improvised by using an ac supply with a variable frequency. A minority of these believed that by increasing the voltage of their power supply it would alter the frequency. Most drew a cell or battery symbol for the ac supply. Others improvised by using the rotating magnet from part (a) but had not realised the significance of the calculation in part (a)(iii) which indicated that at 24 revolutions per second the output voltage was 1.2 V. This made the suggested method of using a stop watch to find the period of rotation impracticable. Few realised that the oscilloscope as a voltmeter could measure both the output voltage and the period of the ac. The instrument was often connected in series in the primary circuit. No one realised that the input current has to be constant to provide a constant flux. Despite all of these difficulties most candidates managed to write sensible statements worthy of credit but rarely full marks.

The author of the example shown (exemplar 9) has used the rotating magnet as the ac source and continued with the clues from part (a) to produce an L3 quality answer.

## Exemplar 9



Using some form of signal generator alternating current generator with variable frequency set connected to X and an oscilloscope connected to Y Vary frequency  $f$  from the generator either by increasing rpm rotation of motor magnet or using a built in frequency adjustment from the oscilloscope measure  $V$  by the ~~dis~~ height of the peaks X voltage base setting and frequency ~~by~~ distance by measuring some period as distance between peaks ~~on X~~ fine base setting and  $f = \frac{1}{T}$  as  $\frac{V_x}{V_y} = \frac{N_x}{N_y}$  and  $N_x$  and  $N_y$  (number of turns in X and Y) are constant  $V_x \propto V_y$  so as  $V_x$  should be ~~directly~~  $V_y \propto f$  so  $V_y \propto$  frequency so plotting a graph of  $V_y$  and  $f$  against  $f$  for varying frequencies should be a straight line through the origin if the relationship is correct.

L3

## Question 6 (a) (i)

- 6 Fig. 6.1 shows a single photomultiplier tube and its internal components. The tube can detect gamma photons in high-energy physics experiments. A single gamma photon incident on the scintillator crystal generates many photons of blue light. These visible light photons travel to the photocathode where they are converted into photoelectrons. The number of electrons is then multiplied in the photomultiplier tube with the help of electrodes called dynodes. A short pulse of electric current is produced at the output end of the photomultiplier tube.

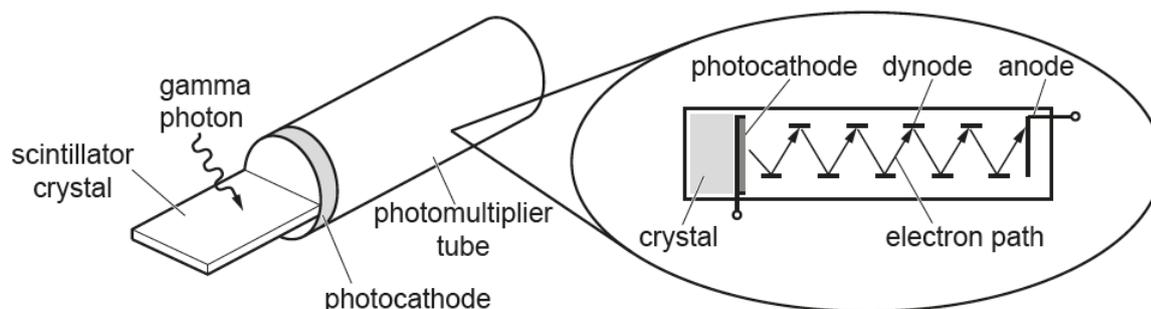


Fig. 6.1

- (a) Fig. 6.2 shows a section through the scintillator crystal in air.

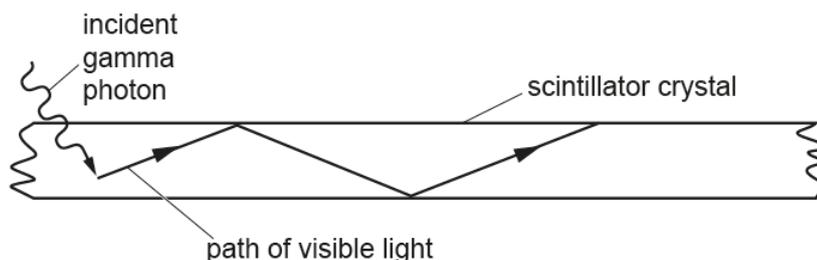


Fig. 6.2

- (i) The refractive index of the scintillator crystal for visible light is 1.69. The refractive index of air is 1.00. Calculate the critical angle  $C$  for this crystal.

$$C = \dots\dots\dots^\circ \quad [2]$$

## Question 6 (a) (ii)

- (ii) Explain why the visible light inside the scintillator crystal follows the path shown in Fig. 6.2.

.....

.....

.....

..... [2]

Almost all of the candidates managed to calculate the critical angle correctly. The explanation in part (ii) was not so successful. The majority gained the mark for total internal reflection but most omitted the crucial words *of incidence* to qualify which angle must be greater than the critical angle.

The example here (exemplar 10) shows the perfect succinct answer.

## Exemplar 10

the crystal has a higher refractive index  
 than air and the angle of incidence is  
 greater than the critical angle, so the  
 light undergoes total internal reflection. [2]

## Question 6 (b)

- (b) A high energy gamma photon passing through the scintillator crystal converts some of its energy into visible light photons of mean wavelength 450 nm.

Show that the energy of a single photon of wavelength 450 nm is less than 3 eV.

[3]

## Question 6 (c) (i)

- (c) The photocathode is coated with potassium which has a work function of 2.3 eV. Each emitted photoelectron is accelerated by a potential difference of 100 V between the photocathode and a metal plate, called the first dynode.
- (i) Show that the maximum kinetic energy of an emitted electron at the photocathode is very small compared to its kinetic energy of 100 eV at the first dynode.

[1]

## Question 6 (c) (ii)

- (ii) 2000 photoelectrons are released from the photocathode. Each photoelectron has enough energy to release four electrons from the first dynode at the collision. These four electrons are then accelerated to the next dynode where the process is repeated. There are 9 dynodes in the photomultiplier tube. The total number of electrons collected at the anode for each photoelectron is  $4^9$ .

The pulse of electrons at the anode lasts for a time of  $2.5 \times 10^{-9}$  s.

Calculate the average current due to this pulse.

average current = ..... A [3]

Almost all of the candidates attempted this last section of the paper with some success. In part (i) most candidates showed that they understood the theory behind the question and subtracted the appropriate two numbers from part (b) to gain the mark. Part (ii) was done well with a significant number obtaining the correct answer. Another large group forgot that 2000 electrons were released and performed the calculation for only a single electron being multiplied up and so forfeited the final mark.

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