Please check the examination details below before entering your candidate information

Candidate surname: StemUp Model Solution

Other names:

Pearson Edexcel Level 3 GCE

Centre Number

Candidate Number

Time 2 hours 30 minutes

Paper reference **9PH0/03**

Physics

Advanced

PAPER 3: General and Practical Principles in Physics

You must have:
Scientific calculator, ruler

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

Information

- The total mark for this paper is 120.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- In questions marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- You are advised to show your working in calculations including units where appropriate.
- Good luck with your examination.

Turn over ▶

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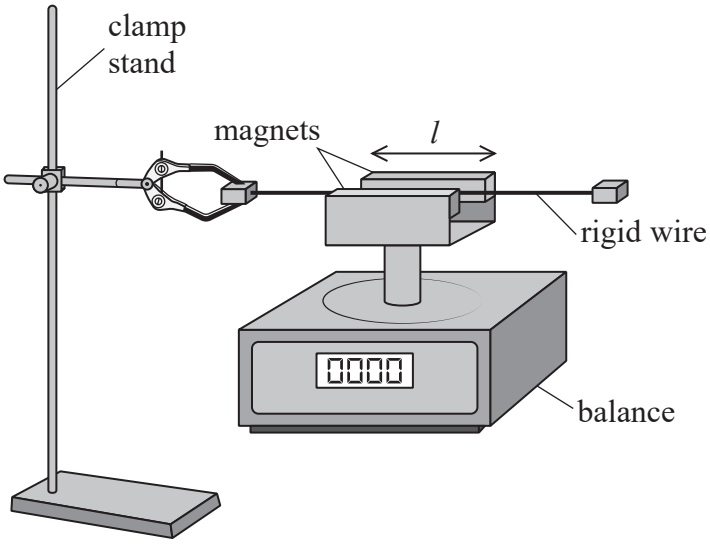
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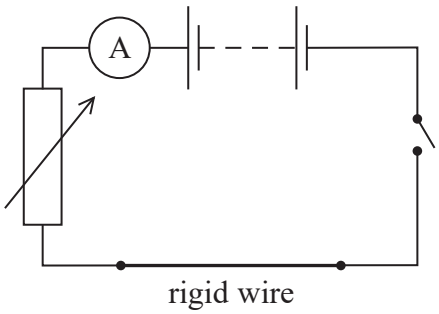
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Pearson

Answer ALL questions in the spaces provided.

1 A student set up the apparatus shown. A length of rigid wire was held horizontally by a clamp in a uniform magnetic field of flux density B.
The circuit connected to the rigid wire is also shown.





With the switch open, the balance was set to zero. When the switch was closed a current I in the circuit was recorded by the ammeter and the reading on the balance increased.

(a) The length l of wire in the magnetic field was 15.5 cm. When the current in the circuit was 4.55 A, the reading on the balance increased by 5.65 g.

Calculate the magnetic flux density B in the region of the rigid wire.

(3)

$F = mg = 5.65 \times 10^{-3}\ kg \times 9.81\ N\ kg^{-1} = 0.0554\ N$

$F = BIl \sin\theta$ with $\theta = 90°$, so $B = F/Il$

$B = 0.0554\ N \div (4.55\ A \times 0.155\ m) = 0.0786\ T$

$B =$ 0.0786 T

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(b) The student wrote the following statement

"The balance could read to the nearest 0.01 g, which makes my values for the magnetic force both accurate and precise."

Comment on this statement.

(3)

High precision means the repeated values have a small spread; high accuracy means the values are close to the true value.

Reading to the nearest 0.01 g is the resolution of the balance, not the accuracy or precision of the values.

A high resolution doesn't guarantee accuracy or precision; the student should have said there is a low uncertainty in the value of the force.

(Total for Question 1 = 6 marks)

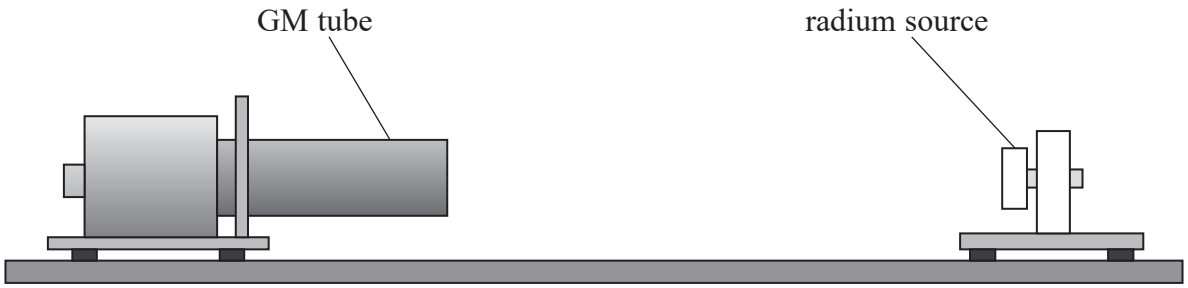
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2 A student used a Geiger-Müller (GM) tube to determine the activity of a radium source. Radium emits α, β, and γ radiation.

He positioned the source 20 cm from the GM tube, as shown, and recorded the count for 1 minute. He repeated the measurement and calculated a mean count.



The student recorded the following results.

Count 1	Count 2	Mean count
183	178	181

(a) Criticise the student's method for determining the count at this position.

(3)

Counting for 1 minute is too short a time: he should count for at least 3 minutes.

He hasn't recorded the background count rate, so he cannot correct for it.

He did take more than one reading and calculate a mean, but he should have taken more than two readings to calculate the mean.

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(b) From his results the student determined that the activity of the source was 3.0 Bq.

Comment on his value for the activity of the source.

(5)

He has calculated the count rate (181 ÷ 60 s = 3.0 counts per second), not the activity of the source.

The counts haven't been corrected for background radiation, so there is a systematic error in his data.

The GM tube is too far away from the source: the α-radiation won't reach the GM tube, as α only has a short range in air (a few cm).

The radiation spreads out from the source in all directions, so not all the emitted radiation reaches the GM tube.

The GM tube won't detect all the γ photons which enter it.

So the true activity of the source is much greater than 3.0 Bq.

(Total for Question 2 = 8 marks)

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3 Genuine crystal balls are made from clarified quartz rather than glass.
A student was given a small crystal ball and wanted to know whether it was genuine.

(a) The mean diameter of the crystal ball was measured to be 5.06 cm and the mass of the crystal ball was measured to be 175 g.

Show that the density of the material of the crystal ball is about 2600 kg m^{-3}.

(3)

$V = 4/3\ \pi r^3 = 4/3 \times \pi \times (2.53 \times 10^{-2}\ m)^3 = 6.78 \times 10^{-5}\ m^3$

$\rho = m/V = 0.175\ kg \div 6.78 \times 10^{-5}\ m^3$

$\rho = 2580\ kg\ m^{-3}$, which is about $2600\ kg\ m^{-3}$

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(b) The student measured the diameter of the crystal ball using vernier calipers with a resolution of 0.01 cm.
She measured the mass of the crystal ball using a balance with a resolution of 1 g.

The table gives the densities of clarified quartz and glass.

Material	Density / kg m^{-3}
Clarified quartz	2650
Glass	2590

Determine whether the crystal ball was genuine.

(6)

% uncertainty in diameter (and r) = (0.005 cm ÷ 5.06 cm) × 100% = 0.10%

% uncertainty in V = 3 × 0.10% = 0.30%

% uncertainty in m = (0.5 g ÷ 175 g) × 100% = 0.29%

% uncertainty in ρ = 0.30% + 0.29% = 0.59%

uncertainty in ρ = 0.0059 × 2580 kg m^{-3} = ±15.5 kg m^{-3}

So ρ lies in the range 2565 kg m^{-3} to 2596 kg m^{-3} (upper value 2596 kg m^{-3}).

Glass (2590 kg m^{-3}) is in the range but clarified quartz (2650 kg m^{-3}) isn't, so the crystal ball may not be genuine (it is probably glass).

(Total for Question 3 = 9 marks)

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4 Radioactive decay is often described in textbooks as a spontaneous, random process.

(a) State what is meant by spontaneous decay.

(1)

The decay happens without any external stimulus: it is unaffected by external factors such as temperature.

*(b) Explain why there is an exponential decrease in the rate of decay for a sample containing a large number of unstable nuclei.

(6)

Each individual unstable nucleus has a fixed probability of decaying in the next second. This probability is the decay constant λ.

We cannot predict when a particular nucleus will decay, but for a sample with a large number of unstable nuclei there is a predictable pattern.

The fraction of the nuclei decaying in the next second is therefore equal to the decay constant λ.

Hence the number of nuclei decaying per second (the rate of decay, or activity) depends on the number of unstable nuclei N present: $A = \lambda N$, or $dN/dt = -\lambda N$.

As nuclei decay, the number of unstable nuclei remaining decreases. Because the rate of decrease of N is proportional to N, the number of unstable nuclei decreases exponentially with time: $N = N_0 e^{-\lambda t}$.

So, since $A = \lambda N$, the rate of decay also decreases exponentially with time: $A = A_0 e^{-\lambda t}$.

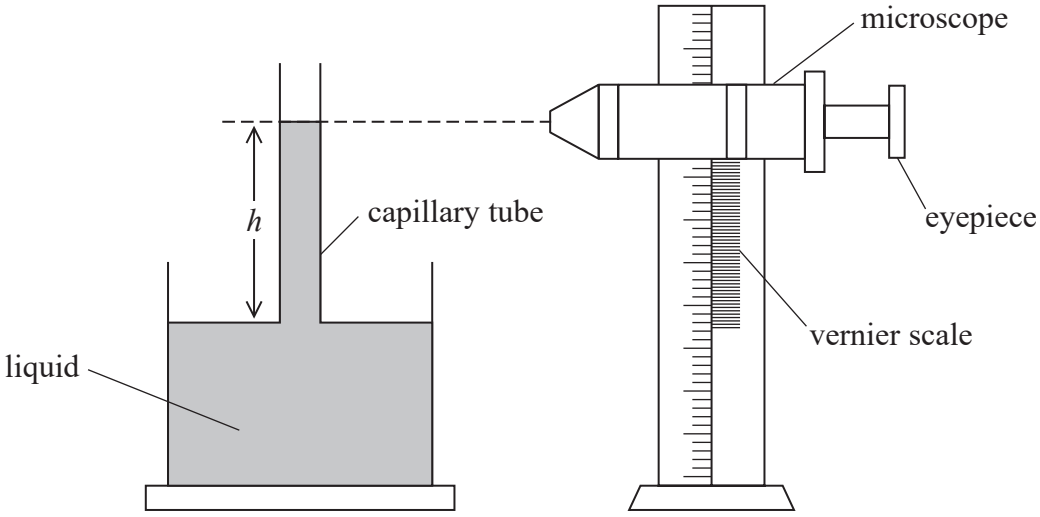
(Total for Question 4 = 7 marks)

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5 A student measured the height h of a liquid column in a capillary tube. She used a travelling microscope to make measurements of the positions of the top and bottom of the liquid column.

The travelling microscope consists of a simple microscope that can be moved vertically along a vernier scale.



(a) The student used a capillary tube with an internal radius r equal to 0.10 mm and recorded the following readings from the vernier scale.

Bottom of liquid column / cm	Top of liquid column / cm
12.00	27.10

(i) State the uncertainty in each of these readings.

(1)

±0.005 cm

(ii) Calculate the percentage uncertainty in the student's value of h.

(2)

h = 27.10 cm − 12.00 cm = 15.10 cm

uncertainty in h = 2 × 0.005 cm = 0.01 cm

% uncertainty in h = (0.01 cm ÷ 15.10 cm) × 100% = 0.066%

Percentage uncertainty in h = 0.07%

(iii) The student repeated the measurement of h for capillary tubes of different radii.

The table shows the student's final data.

r / mm	$1/r$	h / cm
0.09	11.1	16.56
0.10	10.0	15.1
0.12	8.3	12.6
0.15	6.7	10.33

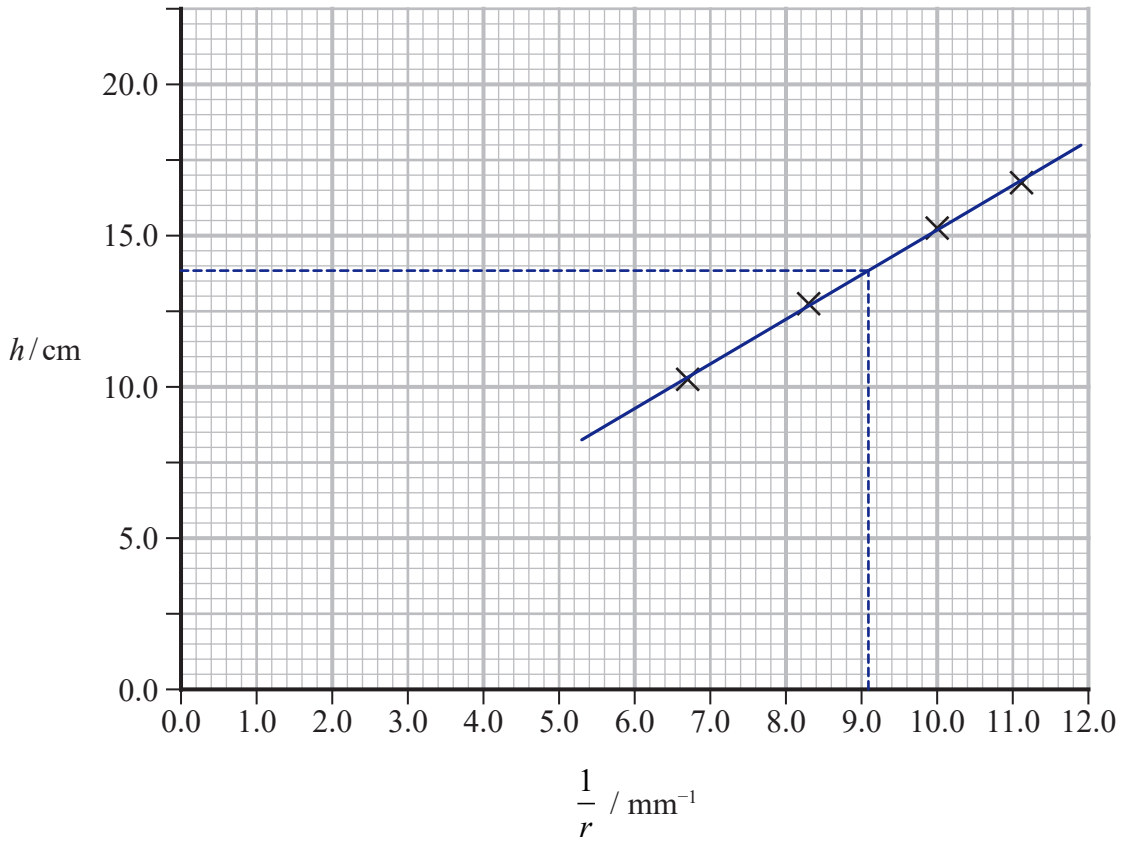
Criticise the student's recording of the data.

(2)

No unit is given for 1/r in the table (it should be mm^{-1}), and 1/r is recorded to more significant figures than r.

h is recorded to an inconsistent number of decimal places, and the raw data (top and bottom readings) for h are not shown.

(b) The student plotted the following graph.



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(i) Determine the height of the liquid column that the student could expect for a tube with an internal radius of 0.11 mm.

(3)

Line of best fit drawn on the graph.

$1/r = 1 \div 0.11\ mm = 9.1\ mm^{-1}$

Reading from the line of best fit at $1/r = 9.1\ mm^{-1}$: $h = 13.8\ cm$

Height of liquid column = 13.8 cm

(ii) In her notes it stated that

$$h = \frac{k}{r} \qquad \text{where } k \text{ is constant}$$

Assess the extent to which the student's data supports this relationship.

(4)

$h = k/r$ means a graph of h against $1/r$ should be a straight line through the origin.

The points plotted do lie on a straight line, and hr is approximately constant ($k \approx 1.5$ cm mm, e.g. $16.56 \times 0.09 = 1.49$, $10.33 \times 0.15 = 1.55$), which supports it.

However, there are only 4 points, which isn't enough to form a firm conclusion.

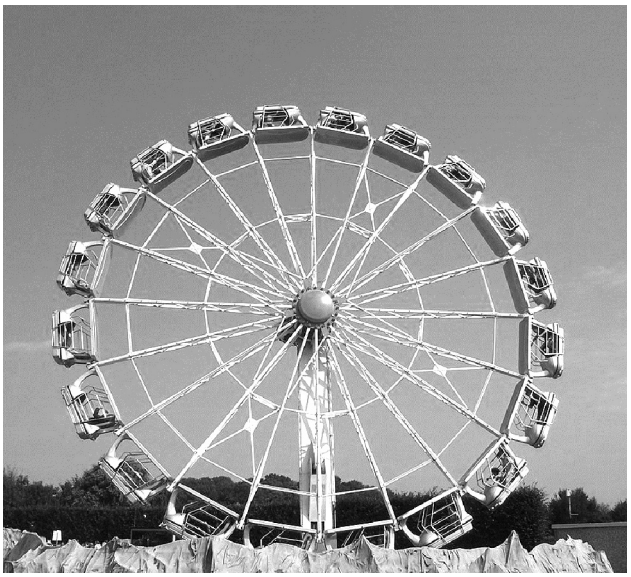
The range of the points is insufficient: there is no data between 0.0 and 6.0 mm^{-1}, so we cannot tell if the line passes through the origin (there may be a systematic error in h).

(Total for Question 5 = 12 marks)

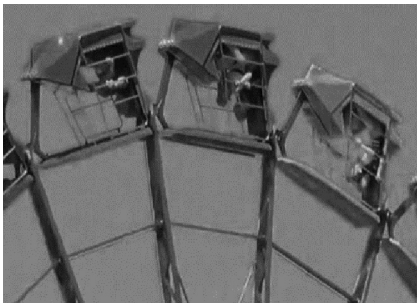
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6 The Enterprise is an amusement park ride. Riders sit in cars that are made to rotate in a vertical circle.

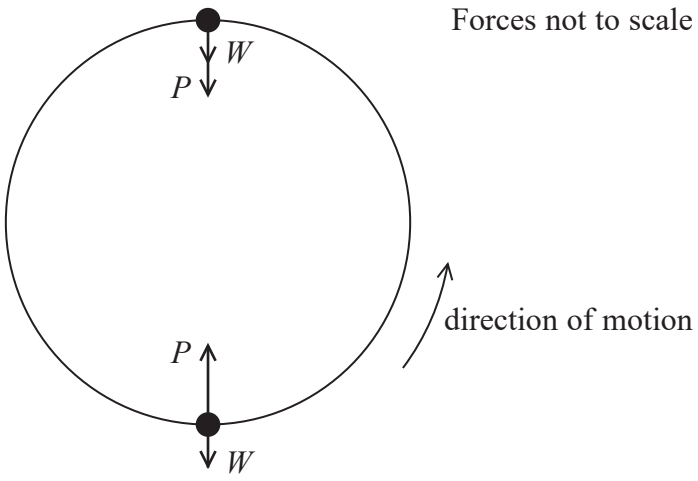
The ride starts by moving in a horizontal circle. The speed of rotation increases, and the frame tilts until the ride is rotating vertically as shown.



The photograph below shows riders at the top of the vertical circle. The riders are in contact with their seats at all times during the ride.



The diagram shows the weight W of a rider and the push P from the seat on the rider at the top and bottom of the circular path.



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*(a) The rider moves from the bottom to the top of the circular path.

Explain how the apparent weight experienced by the rider would change.

(6)

To move in a circle the rider must experience a resultant (centripetal) force acting towards the centre of the circular path.

The rider moves with a constant (angular) velocity, so this resultant force, mv^2/r, is constant. The weight W is also constant.

At the bottom of the circle P and W act in opposite directions (P upwards towards the centre), so $P - W = mv^2/r$ and P must be greater than W.

At the top of the circle P and W act in the same direction (both down towards the centre), so $P + W = mv^2/r$ and P must be less than at the bottom.

P is the weight the rider appears to have (apparent weight).

So the apparent weight decreases from bottom to top: the rider feels heavier at the bottom of the circle and lighter at the top.

(b) On the website of the amusement park it states

"The ride is perfectly safe without the need for safety harnesses for the riders.
Centrifugal force ensures that the riders remain in their seats at all stages in the ride."

Assess the validity of this statement.

(4)

There is no centrifugal force: it is the need for a centripetal force that keeps the riders in their seats.

Riders are most at risk of falling out at the top of the circular path, but as long as the contact force P from the seat is greater than zero they will not fall out.

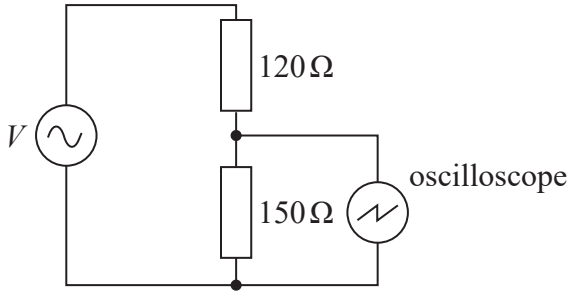
The faster it rotates, the larger the P needed to maintain the circular path, so there is a minimum speed; harnesses are needed if the ride slows or stops.

(Total for Question 6 = 10 marks)

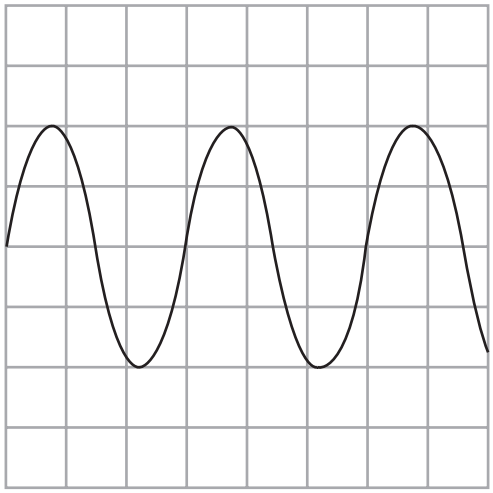
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7 A student connected the output from a source of alternating potential difference (p.d.) to a series resistor combination.

She connected an oscilloscope across the 150 Ω resistor as shown.



(a) The trace obtained on the oscilloscope is shown below.



(i) Determine the peak p.d. across the 150 Ω resistor.

y-sensitivity of oscilloscope = 2.0 V per division

(2)

peak = 2.0 divisions, so V_0 = 2.0 × 2.0 V = 4.0 V

Peak p.d. across 150 Ω resistor = 4.0 V

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(ii) Calculate the root mean square (r.m.s.) value of the current in the circuit.

(3)

$I_0 = V_0/R = 4.0\ V \div 150\ \Omega = 0.0267\ A$

$I_{rms} = I_0/\sqrt{2} = 0.0267\ A \div \sqrt{2} = 0.0189\ A$

r.m.s. value of current = $0.019\ A$

(iii) Calculate the power dissipated in the circuit.

(3)

total resistance $R = 150\ \Omega + 120\ \Omega = 270\ \Omega$

$P = I_{rms}^2 R = (0.0189\ A)^2 \times 270\ \Omega = 0.096\ W$

Power dissipated in circuit = $0.096\ W$

(b) Another student suggested that a voltmeter would be more accurate than using an oscilloscope to determine the magnitude of the p.d.

Comment on this suggestion.

(3)

The voltmeter must measure an alternating p.d. (a d.c. voltmeter would read zero); an a.c. voltmeter would give the r.m.s. p.d. directly.

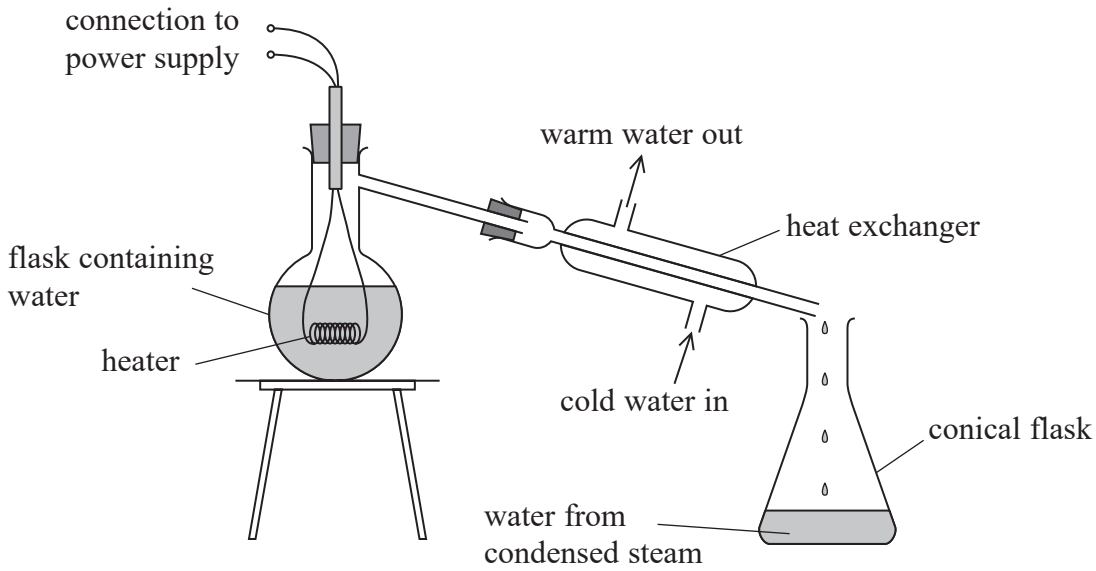
A digital voltmeter would give better resolution than measuring the trace height on an oscilloscope, but accuracy depends on its calibration.

A voltmeter may draw current and affect the circuit, whereas an oscilloscope has little effect on the circuit it is connected to.

(Total for Question 7 = 11 marks)

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8 The apparatus shown can be used to determine a value for the specific latent heat of vaporisation of water.



(a) In one experiment the current in the heater was 8.20 A, and the potential difference across the heater was 230 V.

(i) Show that the power of the heater was about 2 kW.

(2)

$P = VI = 230\ V \times 8.20\ A = 1890\ W = 1.89\ kW$, which is about 2 kW

(ii) There was 0.655 kg of water in the flask at an initial temperature of 22.5 °C. The heater was switched on, and the water in the flask was heated to boiling point.

Calculate the minimum time taken for the water to be heated to 100.0 °C.

specific heat capacity of water = 4190 J kg^{-1} K^{-1}

(3)

$\Delta E = mc\Delta\theta = 0.655\ kg \times 4190\ J\ kg^{-1}\ K^{-1} \times (100.0 - 22.5)\ K = 2.13 \times 10^5\ J$

$P = \Delta E/\Delta t$, so $\Delta t = 2.13 \times 10^5\ J \div 1890\ W = 112.5\ s$

Minimum time taken for water to be heated = 113 s

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(b) The heater was left on and water continued to boil in the flask. The water was allowed to boil for a few minutes. The conical flask was then placed under the heat exchanger and water was collected in it.

(i) Give a reason why the water was left boiling for a few minutes before the conical flask was put in place.

(1)

So that all the apparatus is at 100 °C; energy is no longer being used to heat up the flask, and steam won't condense in the flask.

(ii) Water with a mass of 95.0 g was collected in a time of 125 s.

Calculate the rate of energy transfer in the heat exchanger.

specific latent heat of vaporisation of water = $2.26 \times 10^6\,J\,kg^{-1}$

(3)

$\Delta m/\Delta t = 95.0 \times 10^{-3}\ kg \div 125\ s = 7.6 \times 10^{-4}\ kg\ s^{-1}$

$\Delta E = L\Delta m$, so $P = \Delta E/\Delta t = 2.26 \times 10^6\ J\ kg^{-1} \times 7.6 \times 10^{-4}\ kg\ s^{-1}$

$P = 1720\ W$

Rate of energy transfer in the heat exchanger = 1720 W

(iii) Discuss your answers to (a)(i) and (b)(ii).

(3)

The rate at which energy is supplied to the water by the heater (1890 W) is greater than the rate of energy transfer in the heat exchanger (1720 W).

Not all the energy from the heater is used to turn water from liquid into vapour, and not all the steam condenses in the heat exchanger.

Some energy is transferred to the surroundings.

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(c) State how the apparatus could be modified to minimise the effect of a significant source of error.

(1)

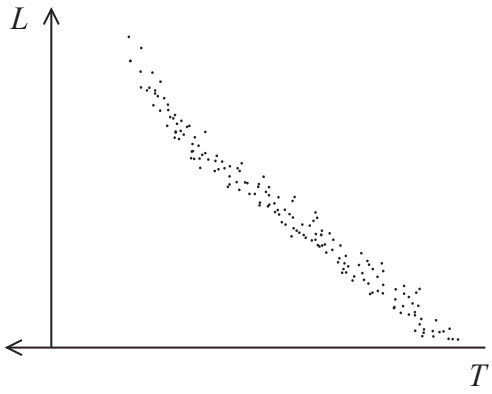
Lag (insulate) the flask, to reduce energy transfer to the surroundings.

(Total for Question 8 = 13 marks)

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9 A Hertzsprung-Russell (HR) diagram shows how the luminosity L depends on the surface temperature T for a group of stars.

The HR diagram below is for a young star cluster.



(a) (i) Explain how we can tell that the young star cluster is in the early stages of its evolution.

(2)

All the stars are on the main sequence; in an older cluster there would be red giant stars.

(ii) Explain why the most massive stars in the cluster have the greatest luminosities.

(4)

The most massive stars experience much greater gravitational forces, so their core temperature and density are greatest.

So the rate of fusion in the core is greatest: the power generated in the core is greatest.

These stars have the greatest surface temperature and the greatest surface area.

So according to Stefan's law ($L = \sigma A T^4$) the power radiated from these massive stars is greatest.

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(b) The HR diagram on the previous page shows an approximately linear relationship for stars in this cluster.

(i) It is suggested that the relationship between luminosity L and surface temperature T is of the form

$$L = kT^n$$

where k and n are constants.

Explain why a graph of log L against log T would give a straight line.

(2)

Taking logs of $L = kT^n$: $\log L = n \log T + \log k$

Compared with $y = mx + c$, a graph of $\log L$ against $\log T$ is a straight line with gradient n (and intercept $\log k$).

(ii) The table shows data for stars in this cluster.

L / L_{Sun}	T / K	$\log (L/L_{Sun})$	$\log (T/K)$
39.5	10 600	1.597	4.025
545	16 400	2.736	4.215
20 600	26 800	4.314	4.428
535 000	44 900	5.728	4.652
1 770 000	53 300	6.248	4.727

Plot a graph of log L against log T on the grid opposite. Use the columns provided to show any processed data.

(5)

(iii) Determine a value for n.

(2)

gradient from large triangle = (6.07 − 1.72) ÷ (4.70 − 4.05)

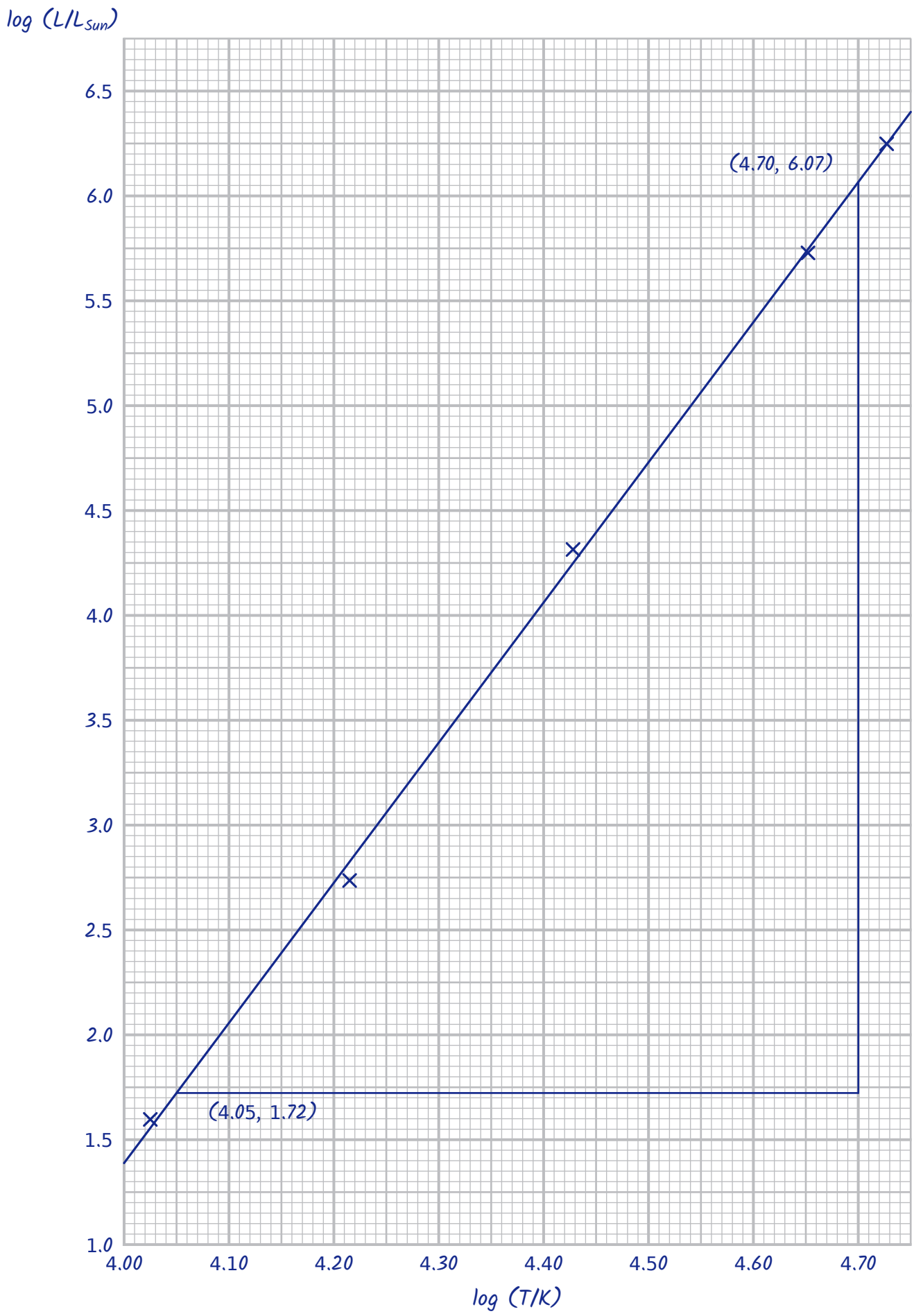
n = gradient = 4.35 ÷ 0.65 = 6.69

$n =$ 6.69

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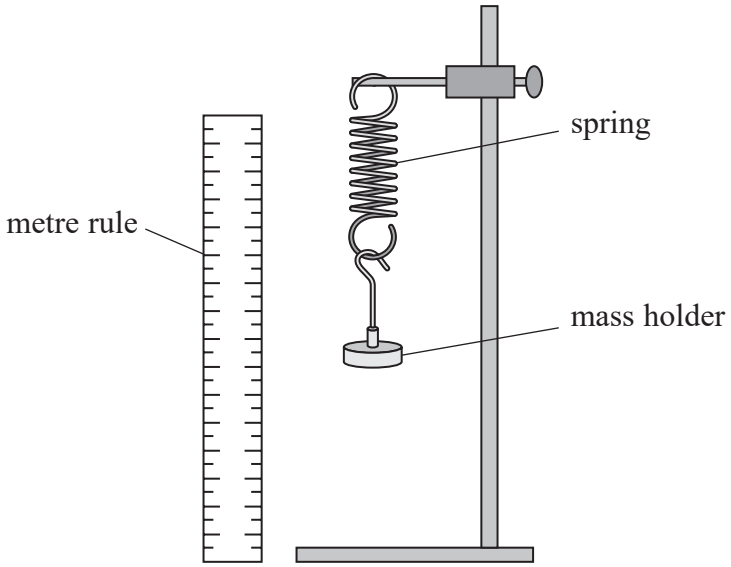
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10 A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached as shown.



(a) The student measured the length of the spring as he added masses to the holder. The rule was held as shown to measure the distance between the top and bottom coils of the spring. He determined the extension for each value of total mass on the holder. He did this by subtracting the original length of the spring from each extended length.

(i) Explain whether this method would produce accurate values for the extensions of the spring.

(4)

It is difficult to measure from the same position on the spring each time, as the coils move and the ends are hard to judge.

The ruler may move between readings, and as it is away from the spring there may be parallax error in reading positions.

The student has only taken one measurement for each added mass.

Hence this method would not produce accurate values for the extensions.

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(ii) Explain how the student could modify his method in order to obtain more accurate values for the extensions of the spring.

(5)

Attach a pointer to the bottom of the spring (or take measurements from the bottom of the mass holder) and bring the metre rule closer to the spring.

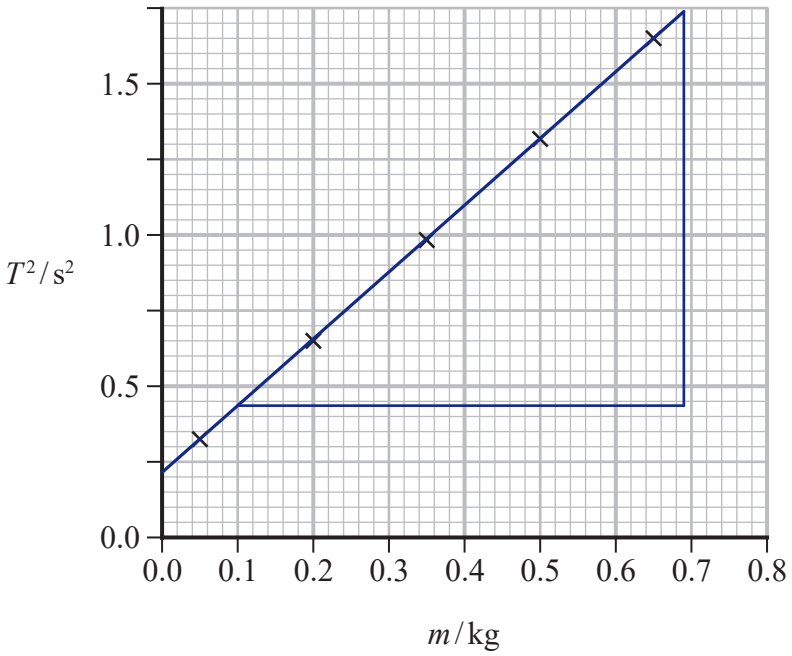
Clamp the metre rule and check it is vertical using a set square against the bench (or a spirit level).

Take each reading with the eye level with the pointer, to reduce parallax error.

Take measurements as masses are added and as masses are removed, and calculate a mean extension for each mass.

(b) In another experiment, the student displaced the mass vertically each time a mass was added to the spring. He used a stopwatch to determine the period of vertical oscillations of each mass.

The student used his data to plot a graph of T^2 against m as shown.



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The student expected the graph to be a straight line through the origin. He thought that there may be systematic error due to reaction time.

(i) Give an example of another possible systematic error in this experiment.

(1)

Ignoring the mass of the holder (and spring) when determining the oscillating mass.

(ii) Another student suggests that to reduce the uncertainty in the value for the period, a data logger connected to a light gate could be used to measure time.

Comment on the student's suggestion.

(3)

Using a data logger and light gate would eliminate reaction time, so the uncertainty in the measurement of the time would be reduced. However, it is not easy to measure timings for multiple oscillations with a data logger and light gate.

(iii) Determine a value for the stiffness of the spring.

(3)

$T = 2\pi\sqrt{(m/k)}$, so $T^2 = (4\pi^2/k)m$ and the gradient $= 4\pi^2/k$

gradient $= (1.74 - 0.44)\ s^2 \div (0.69 - 0.10)\ kg = 2.20\ s^2\ kg^{-1}$

$k = 4\pi^2 \div 2.20\ s^2\ kg^{-1} = 17.9\ N\ m^{-1}$

Stiffness of spring = *$17.9\ N\ m^{-1}$*

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(c) When determining the period of oscillation for each mass, the student measured the time for 20 oscillations. He repeated this measurement to obtain a mean time for 20 oscillations.

Explain how the student's procedure contributed to the accuracy of the measurement.

(3)

Timing a large number of oscillations (20) makes the measured time much larger than the uncertainty in timing, so it minimised the percentage uncertainty in the measurement.

Repeating each timing measurement and calculating a mean minimised the effect of random errors.

Taking a repeat measurement also allowed a check for gross timing errors (e.g. miscounting oscillations).

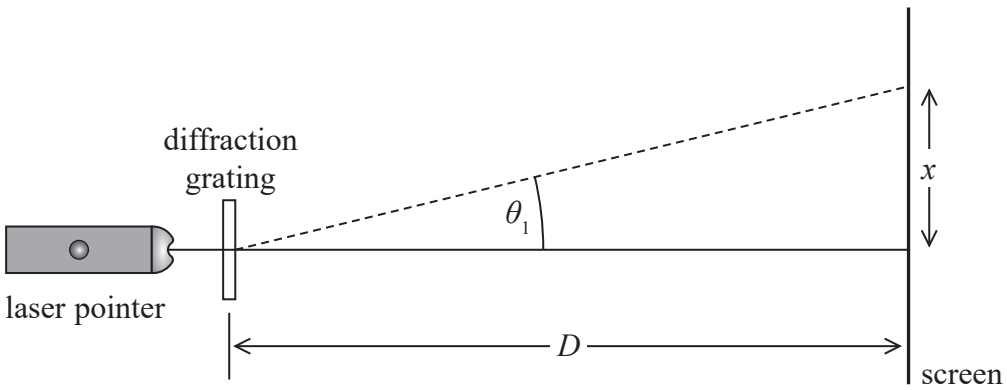
(Total for Question 10 = 19 marks)

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11 Light from a laser pointer was passed through a diffraction grating. The light was perpendicular to the diffraction grating as shown. A diffraction pattern was produced on a screen.



The distance between the first order maximum and the central maximum of the diffraction pattern was x. The distance between the diffraction grating and the screen was D.

(a) Distance x was measured to be 0.500 m with a metre rule. The wavelength of light λ_1 from the laser pointer was 650 nm.

The laser pointer was replaced with one that produced light of a different wavelength. The new distance x was measured to be 0.400 m.

$D = 1.45$ m

Calculate the wavelength λ_2 of the light emitted by the replacement laser pointer.

(5)

$\tan \theta_1 = x/D = 0.500\ m \div 1.45\ m$, so $\theta_1 = 19.0°$

$\tan \theta_2 = 0.400\ m \div 1.45\ m$, so $\theta_2 = 15.4°$

$d \sin \theta = n\lambda$ with $n = 1$: $d = 650 \times 10^{-9}\ m \div \sin 19.0° = 1.99 \times 10^{-6}\ m$

$\lambda_2 = d \sin \theta_2 = 1.99 \times 10^{-6}\ m \times \sin 15.4°$

$\lambda_2 = 5.3 \times 10^{-7}\ m$ (530 nm)

$\lambda_2 =$ $5.3 \times 10^{-7}\ m$

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(b) Explain one modification to this method that would decrease the uncertainty in the calculated value of λ_2.

(2)

Measure the distance between the two first order maxima (and halve it), or increase the distance D from the grating to the screen.

This increases the distance measured on the screen, so the percentage uncertainty in x (and so in λ_2) is reduced.

(c) In another experiment, the light from the laser pointer was not quite perpendicular to the screen.

Explain how this would change the diffraction pattern produced on the screen.

(3)

The maxima on one side would move closer to the central maximum, and the maxima on the other side would move further away from the central maximum.

The intensity of the maxima would be different on each side of the central maximum.

(Total for Question 11 = 10 marks)

TOTAL FOR PAPER = 120 MARKS

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List of data, formulae and relationships

Acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$	(close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$	
Coulomb law constant	$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9} \text{ N m}^2 \text{ C}^{-2}$	
Electron charge	$e = -1.60 \times 10^{-19} \text{ C}$	
Electron mass	$m_e = 9.11 \times 10^{-31} \text{ kg}$	
Electronvolt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$	
Gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$	
Gravitational field strength	$g = 9.81 \text{ N kg}^{-1}$	(close to Earth's surface)
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$	
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$	
Proton mass	$m_p = 1.67 \times 10^{-27} \text{ kg}$	
Speed of light in a vacuum	$c = 3.00 \times 10^{8} \text{ m s}^{-1}$	
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$	
Unified atomic mass unit	$u = 1.66 \times 10^{-27} \text{ kg}$	

Mechanics

Kinematic equations of motion

$$s = \frac{(u + v)t}{2}$$

$$v = u + at$$

$$s = ut + \tfrac{1}{2}at^2$$

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

Forces

$$\Sigma F = ma$$

$$g = \frac{F}{m}$$

$$W = mg$$

moment of force $= Fx$

Momentum

$$p = mv$$

Work, energy and power

$$\Delta W = F\Delta s$$

$$E_k = \tfrac{1}{2}mv^2$$

$$\Delta E_{grav} = mg\Delta h$$

$$P = \frac{E}{t}$$

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

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

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Electric circuits

Potential difference

$$V = \frac{W}{Q}$$

Resistance

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

Electrical power and energy

$$P = VI$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

$$W = VIt$$

Resistivity

$$R = \frac{\rho l}{A}$$

Current

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = nqvA$$

Materials

Density

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

Stokes' law

$$F = 6\pi\eta rv$$

Hooke's law

$$\Delta F = k\Delta x$$

Young modulus

$$\text{Stress } \sigma = \frac{F}{A}$$

$$\text{Strain } \varepsilon = \frac{\Delta x}{x}$$

$$E = \frac{\sigma}{\varepsilon}$$

Elastic strain energy

$$\Delta E_{\text{el}} = \tfrac{1}{2}F\Delta x$$

Waves and particle nature of light

Wave speed

$$v = f\lambda$$

Speed of a transverse wave on a string

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

Intensity of radiation

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

Power of a lens

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

$$P = P_1 + P_2 + P_3 + \ldots$$

Thin lens equation

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

Magnification for a lens

$$m = \frac{\text{image height}}{\text{object height}} = \frac{v}{u}$$

Diffraction grating

$$n\lambda = d \sin\theta$$

Refractive index

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n = \frac{c}{v}$$

Critical angle

$$\sin C = \frac{1}{n}$$

Photon model

$$E = hf$$

Einstein's photoelectric equation

$$hf = \phi + \tfrac{1}{2}mv^2_{\text{max}}$$

de Broglie wavelength

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

Further mechanics

Impulse

$$F\Delta t = \Delta p$$

Kinetic energy of a non-relativistic particle

$$E_k = \frac{p^2}{2m}$$

Motion in a circle

$$v = \omega r$$

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

$$F = ma = \frac{mv^2}{r}$$

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

$$a = r\omega^2$$

$$F = mr\omega^2$$

Fields

Coulomb's law

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

Electric field strength

$$E = \frac{F}{Q}$$

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{V}{d}$$

Electric potential

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

Capacitance

$$C = \frac{Q}{V}$$

Energy stored in a capacitor

$$W = \tfrac{1}{2}QV$$

$$W = \tfrac{1}{2}CV^2$$

$$W = \tfrac{1}{2}\frac{Q^2}{C}$$

Capacitor discharge

$$Q = Q_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$

$$V = V_0 e^{-t/RC}$$

$$\ln Q = \ln Q_0 - \frac{t}{RC}$$

$$\ln I = \ln I_0 - \frac{t}{RC}$$

$$\ln V = \ln V_0 - \frac{t}{RC}$$

In a magnetic field

$$F = BIl \sin\theta$$

$$F = Bqv \sin\theta$$

Faraday's and Lenz's laws

$$\mathscr{E} = \frac{-\mathrm{d}(N\phi)}{\mathrm{d}t}$$

Root-mean-square values

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

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Nuclear and particle physics

In a magnetic field

$$r = \frac{p}{BQ}$$

Thermodynamics

Heating

$$\Delta E = mc\Delta\theta$$

$$\Delta E = L\Delta m$$

Molecular kinetic theory

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

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

Ideal gas equation

$$pV = NkT$$

Stefan-Boltzmann law

$$L = \sigma AT^4$$

$$L = 4\pi r^2\sigma T^4$$

Wien's law

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

Space

Intensity

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

Redshift of electromagnetic radiation

$$z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$$

Cosmological expansion

$$v = H_0 d$$

Nuclear radiation

Mass-energy

$$\Delta E = c^2\Delta m$$

Radioactive decay

$$A = \lambda N$$

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

$$\lambda = \frac{\ln 2}{t_{½}}$$

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

$$A = A_0\, e^{-\lambda t}$$

Gravitational fields

Gravitational force

$$F = \frac{Gm_1m_2}{r^2}$$

Gravitational field strength

$$g = \frac{Gm}{r^2}$$

Gravitational potential

$$V_{grav} = \frac{-Gm}{r}$$

Oscillations

Simple harmonic motion

$$F = -kx$$

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

$$x = A\cos\omega t$$

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

$$a = -A\omega^2\cos\omega t$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega}$$

$$\omega = 2\pi f$$

Simple harmonic oscillator

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

$$T = 2\pi\sqrt{\frac{l}{g}}$$

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