Write your name here

Surname: StemUp Model Solution

Other names:

Pearson Edexcel Level 3 GCE

Centre Number

Candidate Number

Physics

Advanced
Paper 3: General and Practical Principles in Physics

Thursday 29 June 2017 – Morning
Time: 2 hour 30 minutes

Paper Reference
9PH0/03

You do not need any other materials.

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.*
- You may use a scientific calculator.
- 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.

Turn over ▶

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Pearson

Answer ALL questions in the spaces provided.

1 A physics textbook states that "when carrying out experimental measurements there will always be errors and uncertainties".

(a) Describe what physicists mean by error and by uncertainty.

(2)

An error is the difference between the measured result and the true value of the quantity.

An uncertainty is the interval (range) within which the true value can be considered to lie.

(b) Give two reasons why a measurement may have an uncertainty.

(2)

The instrument used: its resolution is limited (or it has a zero error), e.g. a metre rule can only be read to the nearest mm.

The way the measurement is made: e.g. parallax error when reading a scale, or human reaction time when using a stopwatch.

(Total for Question 1 = 4 marks)

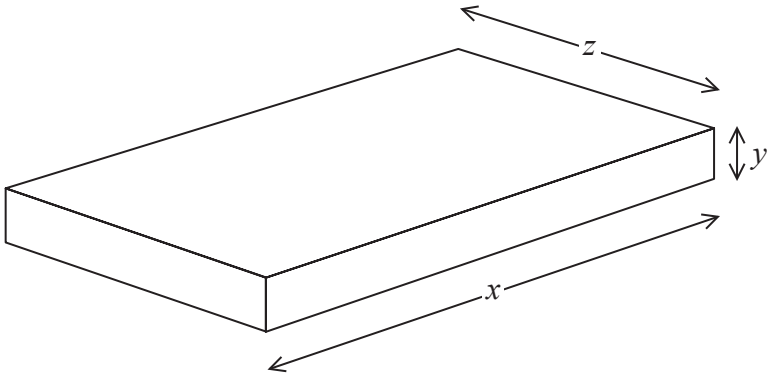
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2 A student carries out measurements to determine the density of glass. The student has 20 glass microscope slides available.

The approximate dimensions of one slide are shown.



$x \approx 75\,\text{mm}$
$y \approx 1\,\text{mm}$
$z \approx 25\,\text{mm}$

(a) The density is calculated using the equation

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Describe how the student can determine an accurate value for the density of the glass. Your answer should include the measuring instruments required.

(4)

Use a micrometer screw gauge to measure the thickness y. Use Vernier calipers to measure the length x and the width z.

Better: measure the thickness of a stack of all 20 slides with the calipers and divide by 20.

Measure the mass of the slides using a top pan balance.

Repeat each length measurement at different places on the slides and calculate the mean of each.

Volume = xyz, then density = mass ÷ volume.

(b) State one precaution that the student should take to ensure the measurements are accurate.

(1)

Check for (and correct) zero error on the micrometer, calipers and balance before use.

(Total for Question 2 = 5 marks)

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3 In the 19th century experiments with magnetic and electric field deflections were used to determine the charge to mass ratio of electrons.
Later experiments showed the diffraction of electrons as they passed through thin metal foils.
Deduce what these experiments tell us about electrons.

(3)

The deflection of electrons by electric and magnetic fields shows that electrons have a charge and a mass, so they behave as particles.

The diffraction of electrons by thin metal foils shows that electrons have a wave nature (diffraction is a wave property).

So electrons behave both as particles and as waves: any model of electron behaviour must include wave-particle duality.

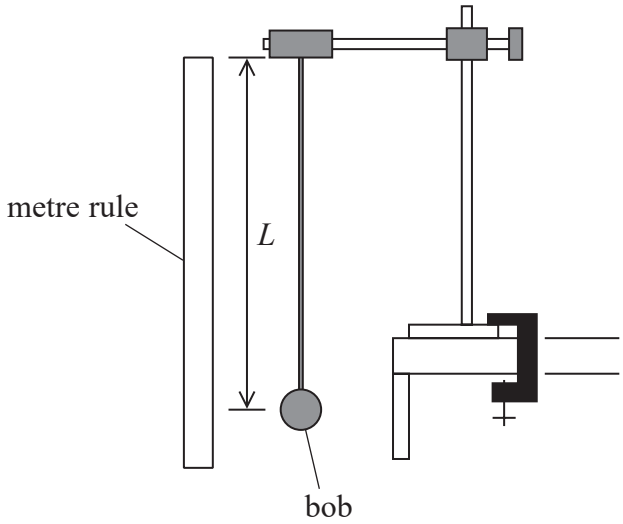
(Total for Question 3 = 3 marks)

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4 A student set up a "seconds pendulum". This is a simple pendulum for which the time taken to move from the bob's highest position on one side to its highest position on the opposite side is 1.00 s.



(a) Calculate the length L required for the pendulum to be a "seconds pendulum".

(2)

Highest point to opposite highest point is half a period, so $T = 2.00$ s

$T = 2\pi\sqrt{(L/g)}$ so $L = gT^2/4\pi^2 = 9.81\ m\ s^{-2} \times (2.00\ s)^2 \div 4\pi^2 = 0.994\ m$

$L =$ 0.994 m

(b) The student set the pendulum into oscillation. She used a stopwatch to check the accuracy of the pendulum's period T.

Describe the procedure the student should have used to obtain an accurate value for T.

(2)

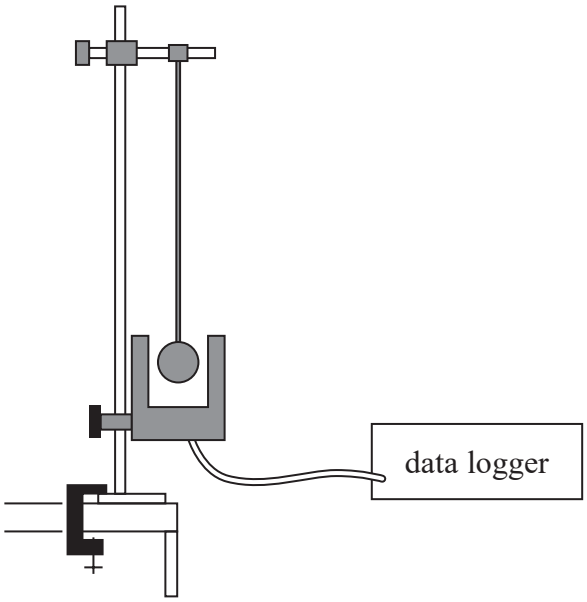
Use a fiducial marker at the equilibrium position of the bob and start and stop the timing as the bob passes it.

Time 20 oscillations (20T) and divide by 20 to find T.

Repeat the timing several times and calculate a mean value of T.

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(c) Another student suggested that the uncertainty in the measurement of the time period of the pendulum could be reduced by using a light gate and a data logger. The data logger would record the time between successive interruptions of the light beam. Both the data logger and the stopwatch have a resolution of 0.01 s.



Comment on the student's suggestion of using a data logger rather than a stopwatch.

(4)

With the stopwatch there is human reaction time, so the uncertainty in the time measurement is larger with the stopwatch than with the data logger (which has no reaction time).

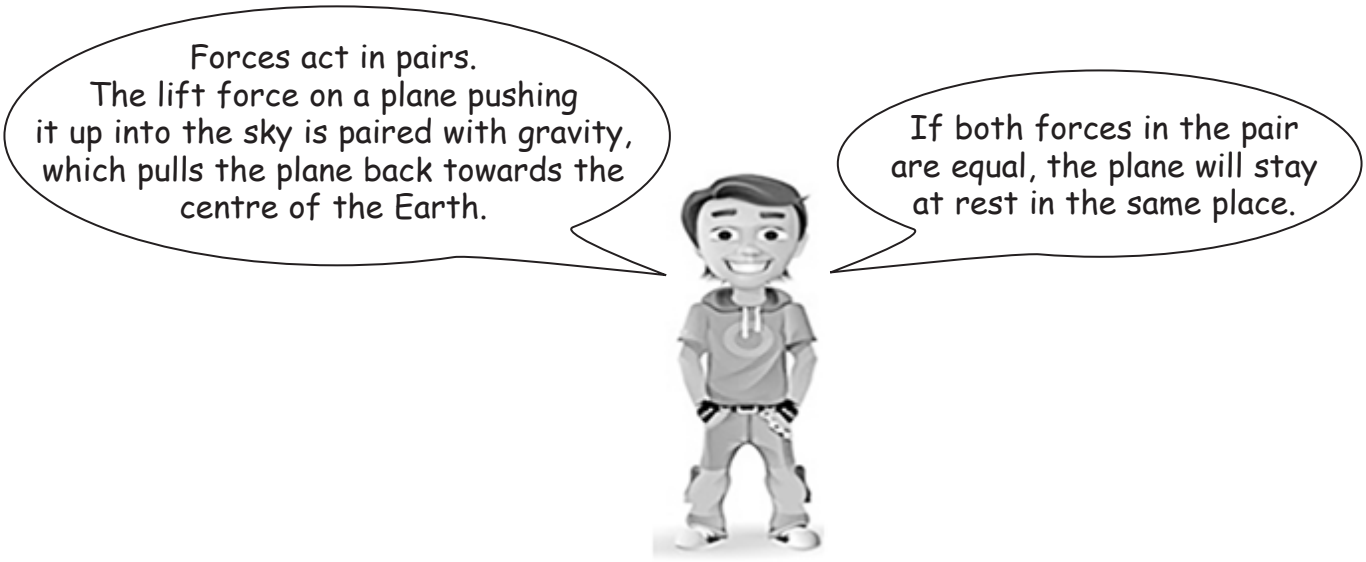
However, timing many swings with the stopwatch reduces the percentage uncertainty, so the stopwatch can still give an accurate T.

Also light gates are difficult to use with a pendulum bob: the bob must pass through the narrow beam on every swing, so the suggestion is not as useful as it seems.

(Total for Question 4 = 8 marks)

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***5** The following extract comes from a section on forces, on a website written for children.



Criticise this extract.

(6)

Newton's third law pairs of forces must be of the same type and must act on different bodies.

The lift force on the plane (from the air) and gravity (the Earth's pull on the plane) are different types of force and both act on the same body (the plane), so they are not a third law pair. Also 'gravity' is not a good description of a force.

The lift on the plane should be paired with the push of the plane on the air, and the gravitational force of the Earth on the plane should be paired with the gravitational force of the plane on the Earth.

If the lift and the weight are equal, the vertical resultant force on the plane is zero, so the plane does not accelerate vertically.

So the plane could be at rest or moving with a uniform velocity in the vertical direction.

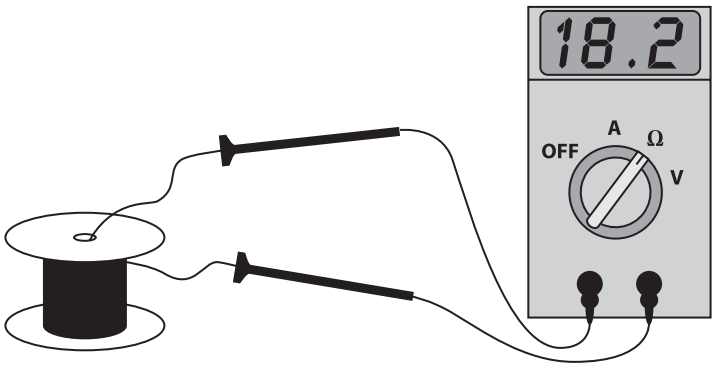
A plane needs to move horizontally to produce lift, so there must be some horizontal motion and the plane cannot stay in the same place.

(Total for Question 5 = 6 marks)

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6 A student carried out an experiment to determine the resistivity of nichrome wire.

He used an ohmmeter to measure the resistance of a length of nichrome wire as shown.



The diameter of the wire was measured as 0.27 mm ± 0.01 mm.
The length of the wire was measured as 1.25 m ± 0.05 m.

(a) Determine which of the three measurements introduces the greatest uncertainty into the value for the resistivity.
Your answer should include calculations.

(4)

Resistance: % uncertainty = 0.1 Ω ÷ 18.2 Ω × 100% = 0.55% (about 0.6%)

Length: % uncertainty = 0.05 m ÷ 1.25 m × 100% = 4.0%

Diameter: % uncertainty = 0.01 mm ÷ 0.27 mm × 100% = 3.7% (about 4%)

A = $\pi d^2/4$, so the % uncertainty in d is doubled: 2 × 3.7% = 7.4% in the area. So the diameter introduces the greatest uncertainty into the resistivity.

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(b) Explain how the student could reduce the uncertainty in the measurement of the diameter.

(2)

Measure the diameter at several places along the wire and in different orientations, then calculate a mean.

Calculating a mean reduces the effect of random errors.

(c) Calculate the minimum value of resistivity possible from the student's data.

(4)

Minimum ρ uses minimum R and d and maximum L: R = 18.1 Ω, L = 1.30 m, d = 0.26 mm so r = 0.13 mm

$A = \pi r^2 = \pi \times (0.13 \times 10^{-3}\ m)^2 = 5.31 \times 10^{-8}\ m^2$

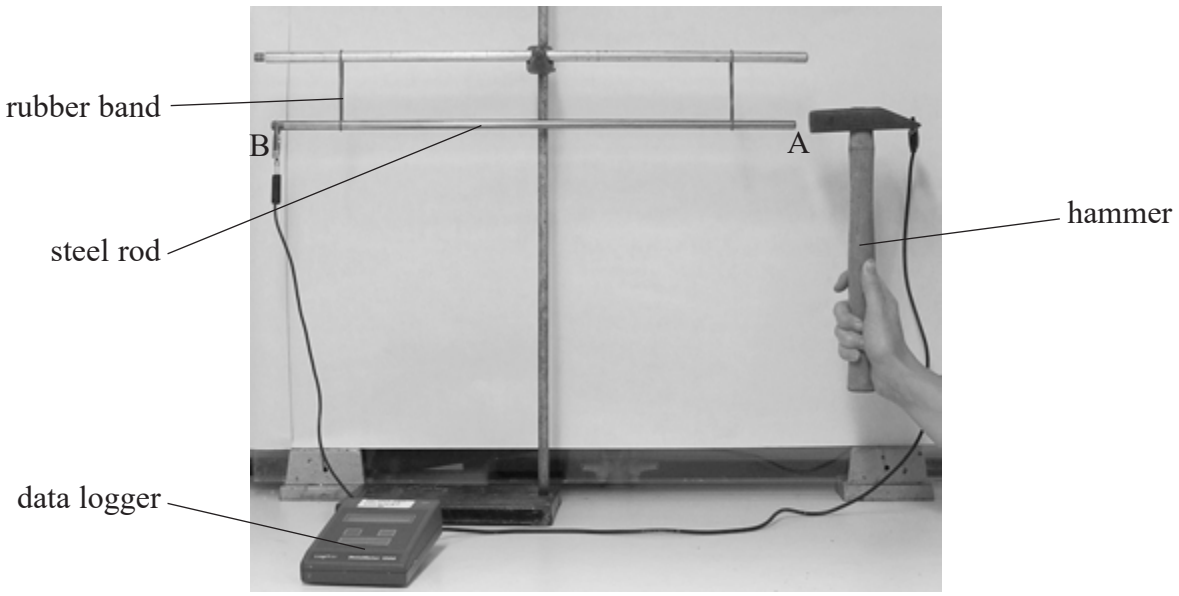
$R = \rho L/A$ so $\rho = RA/L = 18.1\ \Omega \times 5.31 \times 10^{-8}\ m^2 \div 1.30\ m = 7.39 \times 10^{-7}\ \Omega\ m$

Minimum resistivity = $7.39 \times 10^{-7}\ \Omega\ m$

(Total for Question 6 = 10 marks)

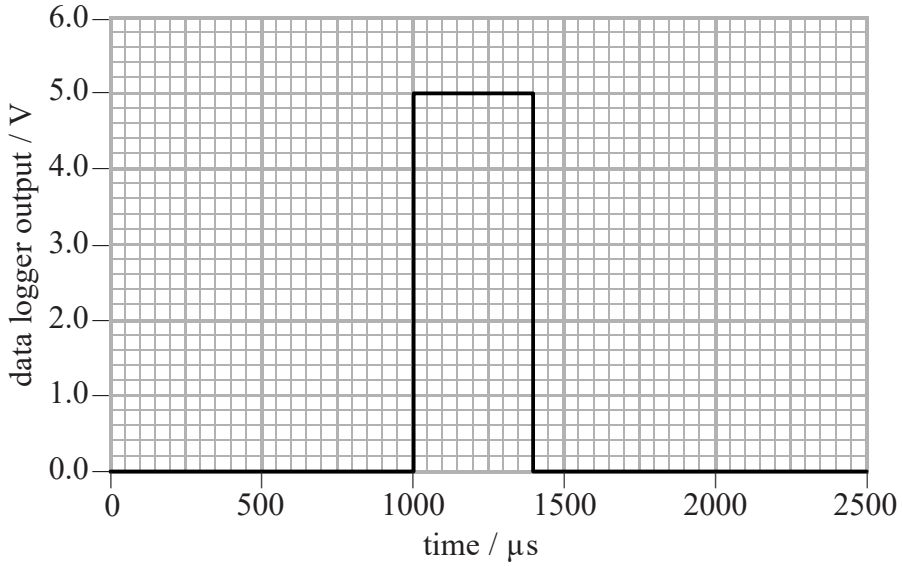
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7 A teacher is demonstrating how to measure the speed of sound in a steel rod. The equipment comprises a hanging steel rod and a hammer connected to a data logger as shown.



The rod is tapped at A with the hammer. A compression pulse travels to B and is reflected back. When the reflection reaches A the hammer loses contact with the rod. Whilst the hammer is in contact with the rod the output from a 5 V supply is recorded by the data logger.

The graph shows the output from the data logger for one hammer tap.



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(a) Explain why a data logger is appropriate for this demonstration.

(2)

The time interval to be measured is very short (about 400 μs), far shorter than human reaction time.

A data logger has a high sample rate (many recordings per second), so the uncertainty in the time measured is small.

(b) (i) Use the graph to show that the speed of the pulse in the rod is about 6000 m s^{-1}.

length of steel rod = 1.18 m

(3)

Pulse starts at 1000 μs and ends at 1400 μs, so $t = 400 \times 10^{-6}$ s

The pulse travels to B and back, $s = 2 \times 1.18$ m = 2.36 m

$v = s/t = 2.36 \text{ m} \div 400 \times 10^{-6} \text{ s} = 5900 \text{ m s}^{-1}$ (about 6000 m s^{-1})

(ii) The speed of sound v in the rod depends on the Young modulus E and the density ρ of the material of the rod as given by the equation

$$v = \sqrt{\frac{E}{\rho}}$$

Calculate the Young modulus of steel.

$\rho_{steel} = 7850 \text{ kg m}^{-3}$

(2)

$v = \sqrt{(E/\rho)}$ so $E = v^2\rho$

$E = (5900 \text{ m s}^{-1})^2 \times 7850 \text{ kg m}^{-3} = 2.73 \times 10^{11}$ Pa

Young modulus of steel = *2.7×10^{11} Pa*

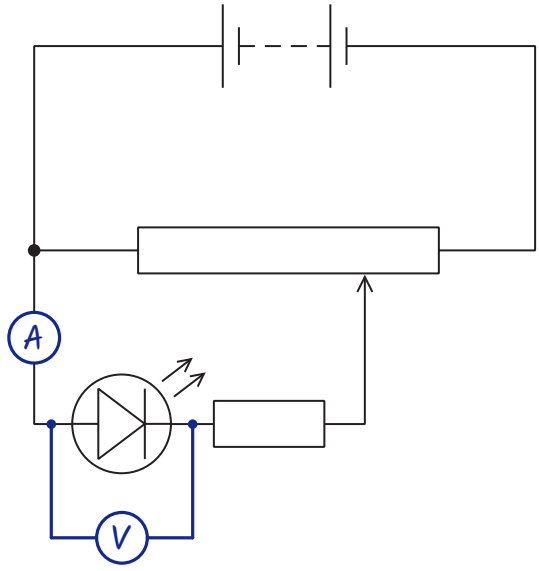
(Total for Question 7 = 7 marks)

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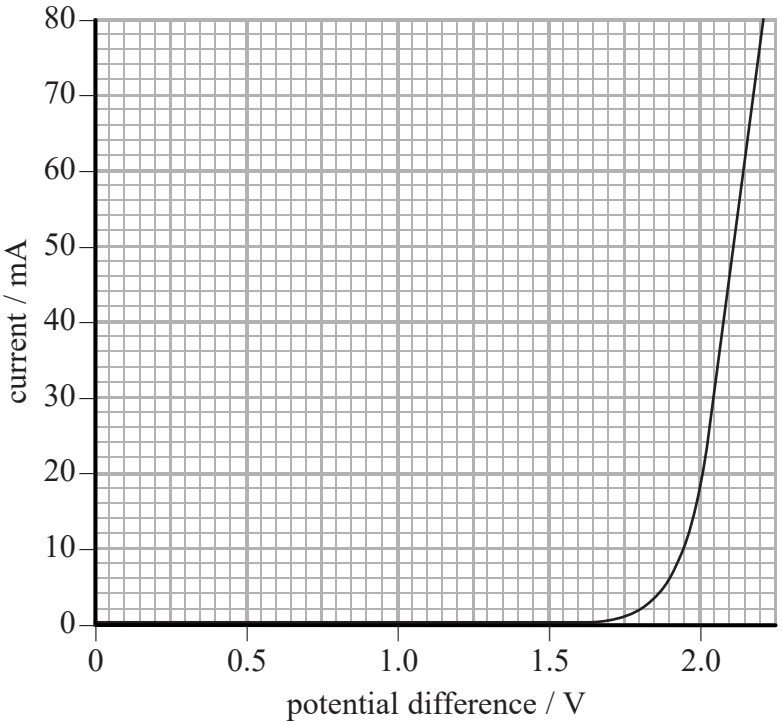
8 A student wanted to plot a graph of current against potential difference for a light emitting diode (LED). He used the circuit shown.



(a) Add an ammeter and a voltmeter to the circuit diagram that would enable the data to be collected.

(1)

(b) The graph of current against potential difference obtained by the student is shown.



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(i) The student wrote the following conclusion.

"The graph shows that in general the LED is not an ohmic conductor. However, for potential differences greater than +2 V, Ohm's law is obeyed since the graph is linear in this region."

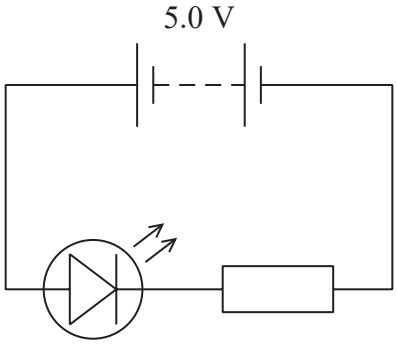
Criticise the student's conclusion.

(2)

For an ohmic conductor the I-V graph is a straight line through the origin (V is directly proportional to I).

Above 2 V the graph is linear but it does not pass through the origin, so V is not proportional to I and Ohm's law is not obeyed for the LED.

(ii) The student used the LED with a 5.0 V power supply as shown in the circuit.



To be lit to normal brightness the current through the LED must be 18 mA.

Calculate the resistance of the resistor needed in the circuit.

(4)

From the graph, at I = 18 mA the p.d. across the LED is V_{LED} = 2.0 V

V_{LED} + V_R = 5.0 V so V_R = 5.0 V − 2.0 V = 3.0 V

R = V/I = 3.0 V ÷ 18 × 10^{-3} A = 167 Ω

Resistance = *170 Ω*

(Total for Question 8 = 7 marks)

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9 The majority of stars in the universe are thought to be main sequence stars. For such stars the luminosity increases with the mass of the star.

(a) It is suggested that the relationship between luminosity and mass is of the form

$$L = L_{\text{Sun}} M^{p}$$

where L = luminosity, M = (mass of star / mass of the Sun) and L_{Sun} and p are constants.

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

(2)

Taking logs: log L = p log M + log L_{Sun}

Compare with y = mx + c: y = log L and x = log M, the gradient p and the intercept log L_{Sun} are constants, so it is a straight line.

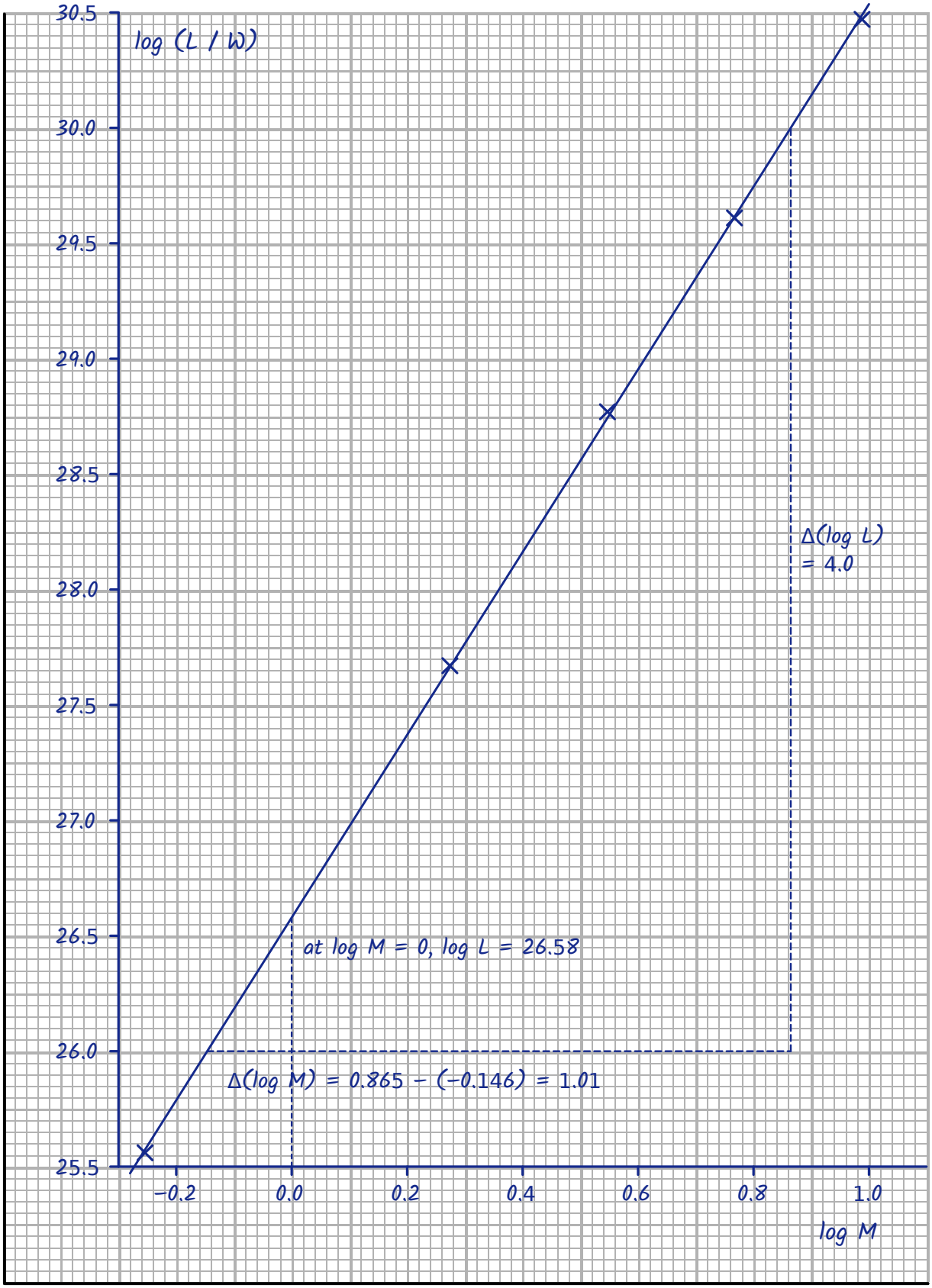
(b) The table shows data for a range of main sequence stars.

$L/10^{25}$ W	M	log (L / W)	log M
3.63	0.557	25.56	−0.254
469	1.88	27.67	0.274
5920	3.52	28.77	0.547
40 800	5.85	29.61	0.767
294 000	9.72	30.47	0.988

(i) Plot a graph of log L against log M. You may use the columns provided to show any processed data.

(5)

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(ii) Determine values for p and L_{Sun} and hence state the mathematical relationship between L and M.

(4)

Gradient = $p = \Delta(\log L)/\Delta(\log M) = (30.0 - 26.0) \div (0.865 - (-0.146)) = 4.0 \div 1.01 = 3.96$, so $p = 4.0$

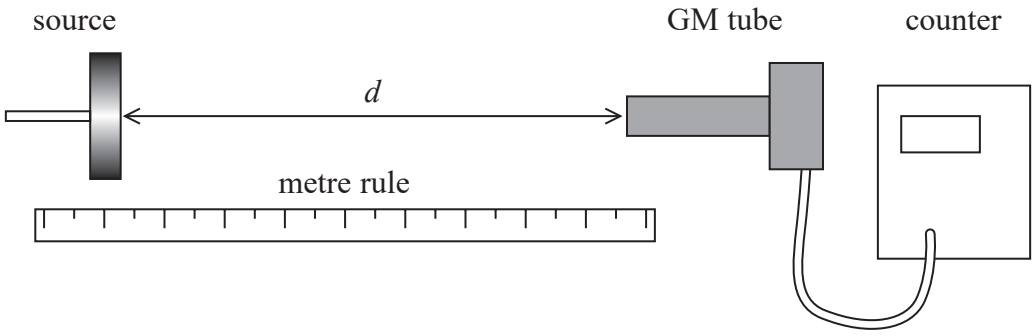
Intercept at $\log M = 0$: $\log L_{Sun} = 26.58$, so $L_{Sun} = 10^{26.58}$ W $= 3.8 \times 10^{26}$ W

So $L = 4 \times 10^{26}$ W $\times M^4$ $(L = L_{Sun}M^4)$

(Total for Question 9 = 11 marks)

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10 A student investigated the way in which gamma radiation spreads out from a source. He placed a cobalt-60 source in a source holder and set up a Geiger-Müller (GM) tube a short distance *d* away. He connected the GM tube to a counter as shown.



The student recorded the count for 2 minutes.

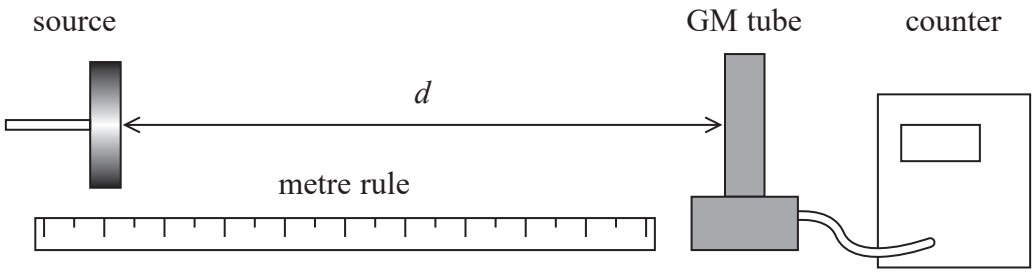
(a) Describe how to determine the corrected count rate from the source.

(2)

Remove the source and record the background count for a long time (e.g. 10 minutes), then divide by the time to give the background count rate.

Divide the count from the source by 120 s to give a count rate and subtract the background count rate from it.

(b) His teacher turned the GM tube through 90° so that the side of the tube faced the source as shown below.



(i) Explain why this arrangement could lead to more accurate data.

(2)

The GM tube has a low efficiency for detecting γ-rays; side on, there is a larger area (and length of gas) exposed to the γ-rays, so the count rate is increased.

γ-rays can be detected anywhere inside the tube, so side on the uncertainty in the distance d is reduced.

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(ii) Explain another modification to the experimental method which would improve the accuracy of the data.

(2)

Record the count for a much longer time (or repeat the count at least twice and find an average count rate).

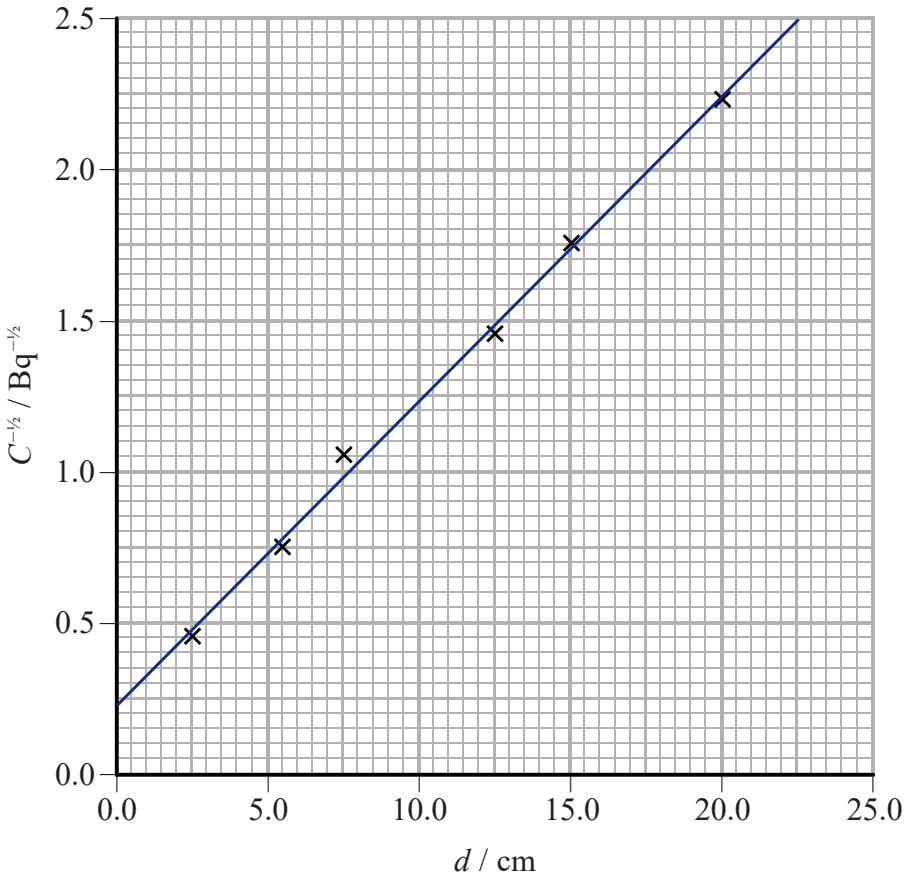
This reduces the effect of random errors (random nature of decay) in the measurement of the count rate.

(c) The variation in the intensity of gamma radiation with distance from a point source should obey an inverse square law. If this is the case, then the count rate C should vary with d according to the equation

$$C = \frac{K}{4\pi d^2}$$

where K is a constant.

The student plotted $\frac{1}{\sqrt{C}}$ against d and obtained the following graph.



(i) Draw a line of best fit on the graph.

(1)

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(ii) The student concluded that the graph was consistent with the gamma radiation intensity obeying an inverse square law.

Discuss the extent to which the data obtained supports the student's conclusion.

(4)

$C = K/4\pi d^2$ gives $1/\sqrt{C} = \sqrt{(4\pi/K)} \times d$, so a graph of $C^{-½}$ against d should be a straight line through the origin, with gradient $\sqrt{(4\pi/K)}$, which is constant.

The points lie close to a straight line, so the data is consistent with an inverse square law.

However, the line does not pass through the origin: it has a positive intercept on the $C^{-½}$ axis (about 0.23 $Bq^{-½}$).

This indicates a systematic error in measuring the distance: d is measured from the outside of the source holder to the front of the tube, not from the source to where the γ-rays are detected (about 2.3 cm more).

So the data supports the conclusion, provided this systematic error is allowed for.

(d) It is suggested that the investigation into the way in which gamma radiation spreads out from a source, using the apparatus as shown in (b), could be carried out successfully using a radium-226 source.

Radium-226 emits α, β and γ radiation.

Justify this suggestion.

(2)

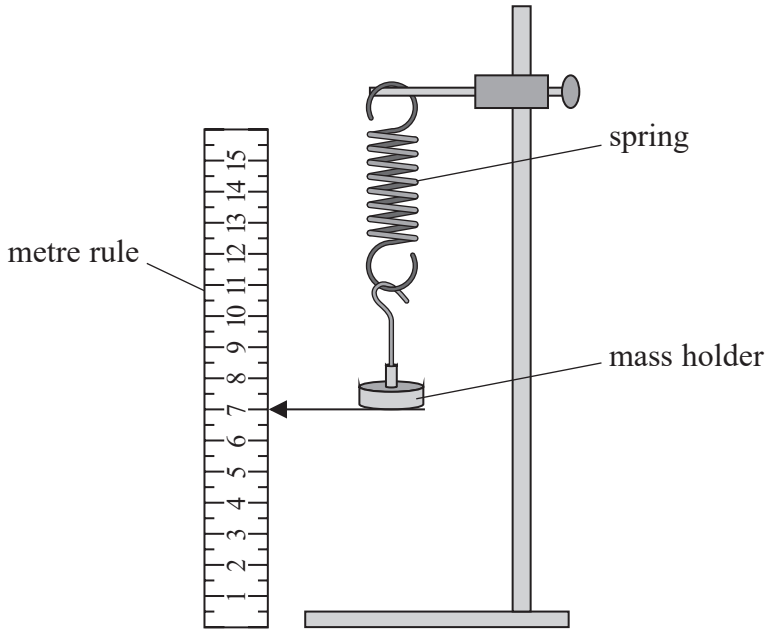
α-particles only travel a few cm in air, so they would not reach the GM tube (and could not pass through its side).

β-particles would probably not pass through the sides of the GM tube, so they would not be detected. Only γ is counted, so the suggestion is correct.

(Total for Question 10 = 13 marks)

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



The position of the bottom of the mass holder was recorded. The spring was stretched by adding masses to the mass holder and the new positions were recorded. The extension of the spring each time was calculated.

The student produced the following table.

Mass added / g	Extension / cm	Stretching force / N
50	1.9	0.49
70	3	0.69
90	3.5	0.9
110	4.5	1.08
130	5.3	1.28
150	5.8	1.47

(a) Criticise the student's table.

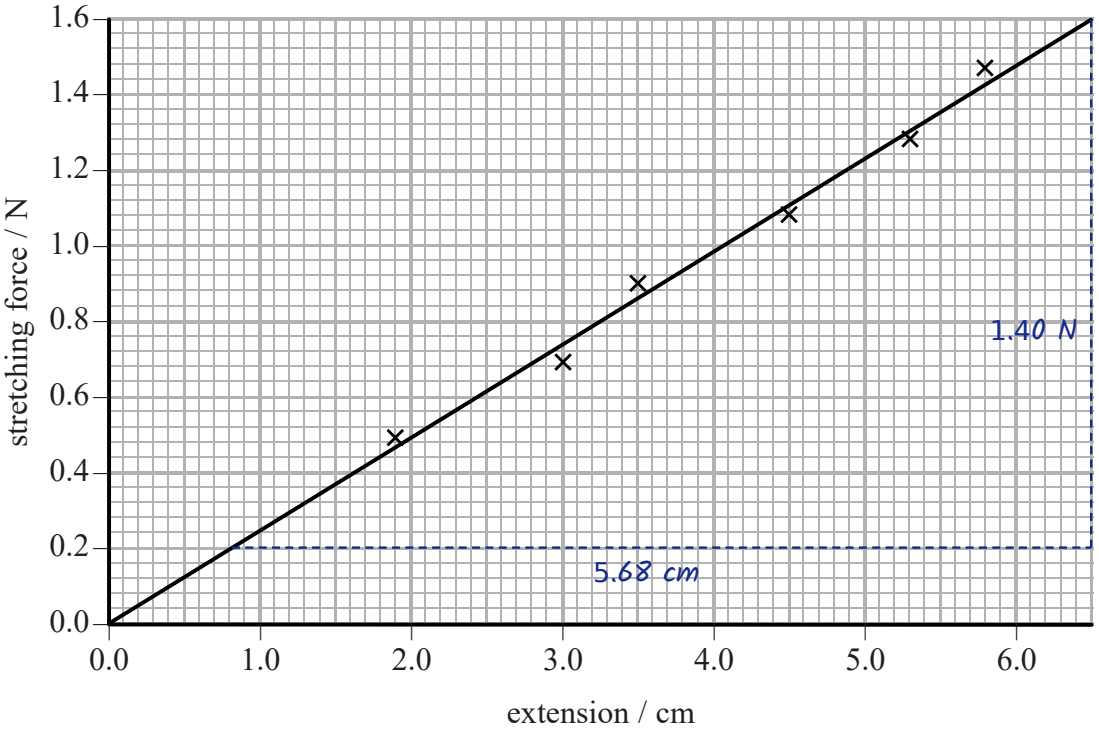
(2)

The data is not recorded to the same number of significant figures / decimal places (e.g. 3 and 0.9).

The positions of the mass holder (the raw readings) were not recorded.

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(b) The student used her data to plot a graph as shown.



Determine a value for the force constant k of the spring.

(2)

k = gradient of the force-extension graph, using a large triangle:

gradient = (1.60 − 0.20) N ÷ (6.49 − 0.81) × 10^{-2} m = 1.40 N ÷ 0.0568 m

k = 24.6 N m^{-1}

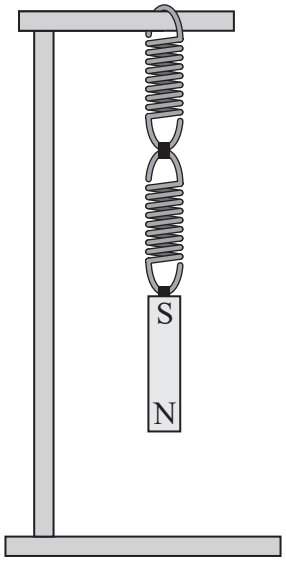
k = 24.6 N m^{-1}

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(c) Two identical springs are joined in series and a bar magnet is hung from one end as shown.



The bar magnet is displaced a small distance vertically from its equilibrium position and released.

Calculate the frequency at which the system oscillates.

mass of magnet = 120 g
spring constant of each spring = 22 N m^{-1}

(4)

Two identical springs in series: each stretches by the same amount, so k = 22 ÷ 2 =

11 N m^{-1}

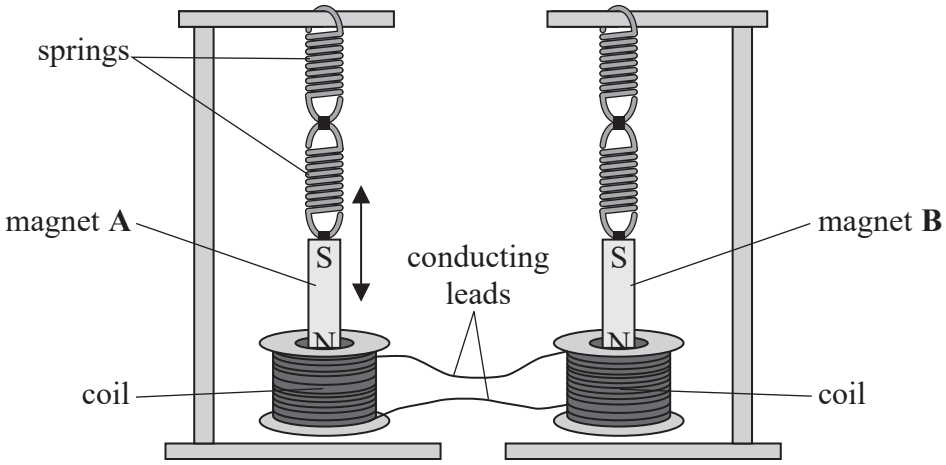
$T = 2\pi\sqrt{(m/k)} = 2\pi\sqrt{(0.120\ kg \div 11\ N\ m^{-1})} = 0.66\ s$

$f = 1/T = 1 \div 0.66\ s = 1.5\ Hz$

Frequency = *1.5 Hz*

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*(d) Identical bar magnets are suspended from identical springs, with the North pole of each magnet inside a coil of wire as shown. The two coils are connected together with conducting leads.



Magnet A is displaced so that it oscillates vertically. The North pole of magnet A moves into and out of the coil of wire with simple harmonic motion. As this motion continues, magnet B starts to oscillate. The amplitude of oscillation of magnet B increases over time.

Explain why magnet B starts to oscillate with an increasing amplitude.

(6)

As magnet A oscillates, its North pole moves into and out of its coil, so the coil experiences a changing magnetic flux linkage.

By Faraday's law the changing flux linkage induces an emf in the coil of magnet A.

The coils are connected, forming a complete circuit, so the induced emf causes an (alternating) current in both coils.

The current in the second coil produces a magnetic field, so a force acts on magnet B, which drives magnet B into oscillation at the frequency of magnet A.

The magnets and springs are identical, so both mass-spring systems have the same natural frequency (period): the driving frequency equals the natural frequency of B.

So resonance occurs: energy is transferred to B on each cycle and magnet B oscillates with increasing amplitude.

(Total for Question 11 = 14 marks)

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12 Barnard's star is a red dwarf star in the vicinity of the Sun. The wavelength of a line in the spectrum of light emitted from Barnard's star is measured to be 656.0 nm. The same light produced by a source in a laboratory has a wavelength of 656.2 nm.

(a) Calculate the velocity of Barnard's star relative to the Earth.

(3)

$\Delta\lambda/\lambda = v/c$ with $\lambda = 656.2$ nm: $\Delta\lambda = 656.2 - 656.0 = 0.2$ nm

$v = c\Delta\lambda/\lambda = 3.00 \times 10^8$ m s^{-1} $\times$ 0.2 nm $\div$ 656.2 nm $= 9.14 \times 10^4$ m s^{-1}

The observed wavelength is shorter (blueshift), so the star is moving towards the Earth.

Velocity = 9×10^4 m s^{-1} towards Earth

(b) A diffraction grating can be used to analyse the radiation emitted by a variety of sources.

(i) A diffraction grating of known grating spacing is used in a school laboratory to analyse the light emitted by a laser.

Describe how the diffraction grating is used and the measurements that should be taken.

(3)

Set up the grating at right angles to the laser beam, with a screen parallel to the grating.

Measure the distance D between the diffraction grating and the screen with a metre rule.

Measure the distance between the two 1st order bright spots on the screen and halve it to get x.

Then $\tan\theta = x/D$ gives θ, and $n\lambda = d \sin\theta$ with $n = 1$ gives λ.

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(ii) A diffraction grating with grating spacing of 2.2×10^{-6} m is used to determine the difference in wavelength for the spectral line emitted by Barnard's star.

Comment on the suitability of using a diffraction grating with this spacing. You should include appropriate calculations.

(4)

$d \sin \theta = n\lambda$, for $n = 1$: $\sin \theta_1 = 656.2 \times 10^{-9}\ m \div 2.2 \times 10^{-6}\ m = 0.2983$, $\theta_1 = 17.354°$

$\sin \theta_2 = 656.0 \times 10^{-9}\ m \div 2.2 \times 10^{-6}\ m = 0.2982$, $\theta_2 = 17.348°$

Difference in angle = $17.354° - 17.348° = 0.006°$: the two angles are very similar.

Such a small difference could not be measured accurately, so this grating is not suitable to determine the difference in wavelength.

(c) Visible light from the star originates from the photosphere. In the photosphere of Barnard's star, hydrogen and helium atoms are at a temperature of 3100 K.

(i) Calculate the mean kinetic energy of an atom in the photosphere at a temperature of 3100 K.

(2)

$\frac{1}{2}m\langle c^2 \rangle = (3/2)kT = 1.5 \times 1.38 \times 10^{-23}\ J\ K^{-1} \times 3100\ K$

mean kinetic energy = 6.42×10^{-20} J

Mean kinetic energy = 6.4×10^{-20} J

(ii) Describe how these atoms emit visible light.

(2)

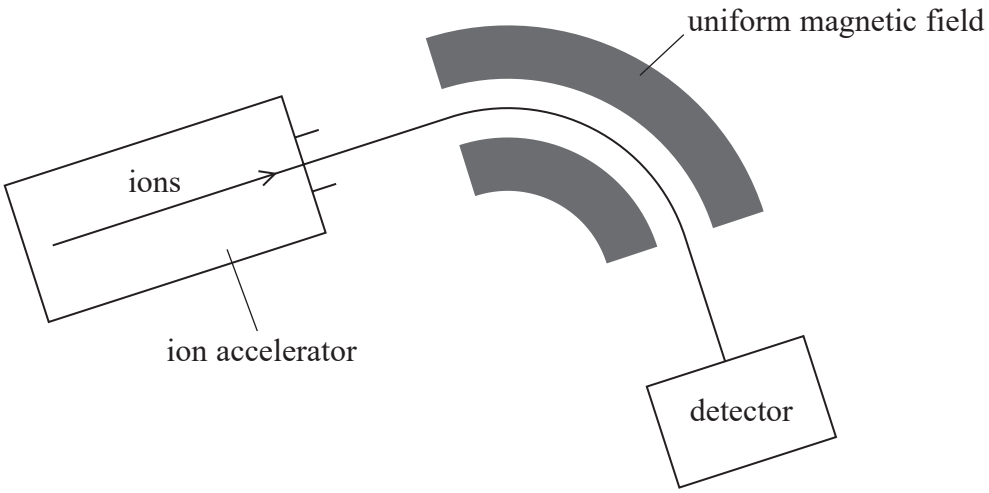
The atoms are excited (e.g. by collisions at this temperature), so there are electron transitions between energy levels in the atoms.

When electrons return to a lower energy level they emit energy in the form of photons, with $hf = E_1 - E_2$; the transitions with the right energy difference give visible light.

(Total for Question 12 = 14 marks)

13 Mass spectrometry is a technique used to separate ions based on their charge to mass ratio.

The atoms in a sample are ionised and then accelerated and formed into a fine beam. This beam is passed into a region of uniform magnetic field and the ions are deflected by different amounts according to their mass.



Analysis of mass spectrometer data shows that chlorine exists in nature as two isotopes, chlorine-35 and chlorine-37.

(a) State what is meant by isotopes.

(1)

Atoms with the same number of protons but different numbers of neutrons in the nucleus.

(b) In a mass spectrometer, chlorine-35 ions are accelerated through a potential difference of 8.50 kV to produce an ion beam.

Show that the speed of singly ionised chlorine-35 atoms is about 2.2×10^5 m s^{-1}.

mass of an ion of chlorine-35 = 34.97 u

(4)

$W = QV = \frac{1}{2}mv^2$, with $Q = 1.6 \times 10^{-19}$ C and $V = 8.50 \times 10^3$ V

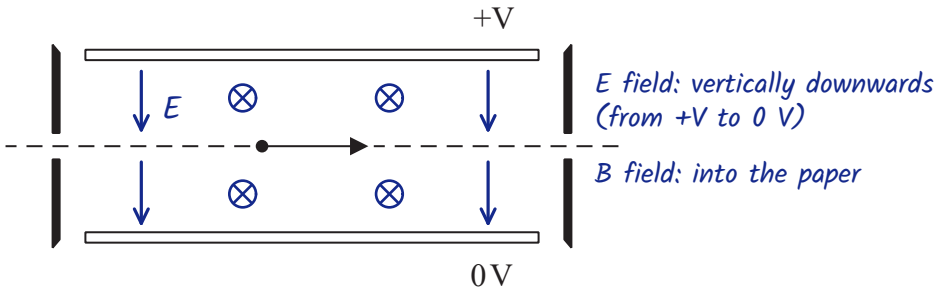
$m = 34.97 \times 1.66 \times 10^{-27}$ kg $= 5.81 \times 10^{-26}$ kg

$v = \sqrt{(2QV/m)} = \sqrt{(2 \times 1.6 \times 10^{-19}\ C \times 8.50 \times 10^3\ V \div 5.81 \times 10^{-26}\ kg)}$

$v = 2.16 \times 10^5$ m s^{-1} (about 2.2×10^5 m s^{-1})

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(c) In most mass spectrometers the ions are passed through a velocity selector, after being accelerated, to produce a beam of ions of a particular velocity.
The velocity selector consists of a pair of parallel plates, across which a potential difference (p.d.) is applied to create an electric field.



In one mass spectrometer the plates are 2.5 cm apart and a p.d. of 135 V is applied.

A magnetic field is also applied to produce a force on the ions in the opposite direction to the force from the electric field. For one particular speed the ions travel in a straight line and emerge from the selector.

(i) Add to the diagram to indicate the directions of the electric field and the magnetic field.

(2)

(ii) The magnetic flux density applied to the velocity selector is 24.5 mT.

Deduce whether this magnetic flux density is suitable to produce a beam of chlorine-35 ions of speed 2.2×10^5 m s^{-1}.

(4)

$E = V/d = 135\ V \div 2.5 \times 10^{-2}\ m = 5400\ V\ m^{-1}$

$F_E = EQ = 5400\ V\ m^{-1} \times 1.6 \times 10^{-19}\ C = 8.6 \times 10^{-16}\ N$

$F_M = BQv = 24.5 \times 10^{-3}\ T \times 1.6 \times 10^{-19}\ C \times 2.2 \times 10^5\ m\ s^{-1} = 8.6 \times 10^{-16}\ N$

The forces are equal and opposite, so ions of 2.2×10^5 m s^{-1} go straight through: the flux density is suitable.

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(d) After passing through the velocity selector the ion beam enters a region of uniform magnetic flux density 0.35 T with the ions travelling at right angles to the field direction.

(i) Explain why the ions travel in a circular path.

(2)

The magnetic force on the ions is always perpendicular to their velocity (and to the field), so it does no work and the speed stays constant.

The force causes an acceleration at right angles to the velocity, i.e. towards the centre of the path, so the ions move in a circle.

(ii) Calculate the radius of the circular path.

(2)

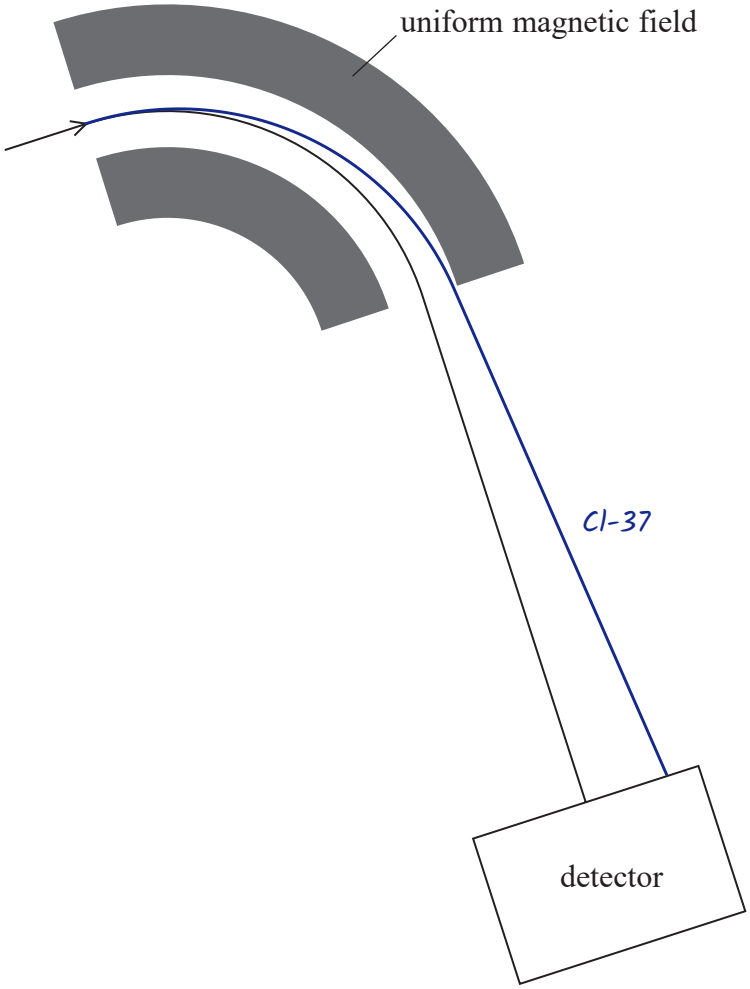
$r = mv/BQ = (34.97 \times 1.66 \times 10^{-27}\ kg \times 2.2 \times 10^{5}\ m\ s^{-1}) \div (0.35\ T \times 1.6 \times 10^{-19}\ C)$

$r = 0.228\ m$

Radius = 0.23 m

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(iii) The diagram shows the path of the chlorine-35 ions in the field. Chlorine-37 ions enter the magnetic field with the same velocity.



1. Add another line to the diagram to show the path of these chlorine-37 ions.

(1)

2. Explain any differences in the paths.

(2)

The chlorine-37 ions are more massive than the chlorine-35 ions.

They have the same charge and velocity, so from r = mv/BQ the radius of their path is greater: they are deflected less.

(Total for Question 13 = 18 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

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

$$v = u + at$$

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

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

Forces

$$\Sigma F = ma$$

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

$$W = mg$$

$$\text{moment of force} = Fx$$

Momentum

$$p = mv$$

Work, energy and power

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

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

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

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

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

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

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

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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

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

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

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

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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

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

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

$$v = \omega r$$

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

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

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

$$a = r\omega^2$$

Centripetal force

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

$$F = mr\omega^2$$

Fields

Coulomb's law

$$F = k\frac{Q_1Q_2}{r^2}$$

$$\text{where } k = \frac{1}{4\pi\varepsilon_0}$$

Electric field strength

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

$$E = k\frac{Q}{r^2}$$

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

Electric potential

$$V = k\frac{Q}{r}$$

Capacitance

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

Energy stored in a capacitor

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

Capacitor discharge

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

Resistor – capacitor discharge

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

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

In a magnetic field

$$F = BIl \sin \theta$$

$$F = Bqv \sin \theta$$

Faraday's and Lenz's laws

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

Root-mean-square values

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

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

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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

$$L = \sigma AT^4$$

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

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

$$F = \frac{Gm_1 m_2}{r^2}$$

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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