Please check the examination details below before entering your candidate information

Candidate surname	Other names
StemUp Model Solution	

Pearson Edexcel Level 3 GCE

Centre Number	Candidate Number

Monday 3 June 2019

Afternoon (Time: 2 hours 30 minutes) | Paper Reference **9PH0/03**

Physics

Advanced

Paper 3: General and Practical Principles in Physics

You must have:
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.*
- 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.

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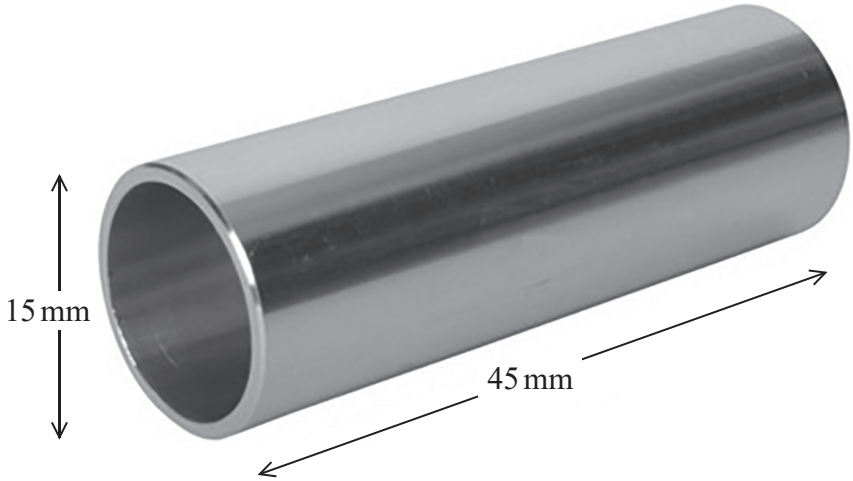
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Answer ALL questions in the spaces provided.

1 An engineer was checking the dimensions of a steel tube. The tube had a length of about 45 mm and an external diameter of about 15 mm as shown.



She used a digital micrometer to measure the diameter of the tube. Before taking the reading she closed the jaws of the micrometer to check for a zero error.

(a) State the type of error she avoided by doing this.

(1)

Systematic error (a zero error).

(b) Describe the procedure she should follow to determine an accurate value for the external diameter of the tube.

(3)

Take readings of the diameter at several different places (positions) along the length of the tube.

At each place take readings at different orientations (angles), rotating the micrometer around the tube.

Calculate the mean (average) of all the readings.

(c) The engineer determined the length of the tube using the micrometer. The reading on the micrometer scale was 45.043 mm. She recorded the reading as 45.0 mm. State why recording a reading of 45.043 mm could not be justified.

(1)

There will be variations in positioning the jaws of the micrometer, and variations in the length of the tube at different points around its circumference, so the third decimal place is not reproducible.

(Total for Question 1 = 5 marks)

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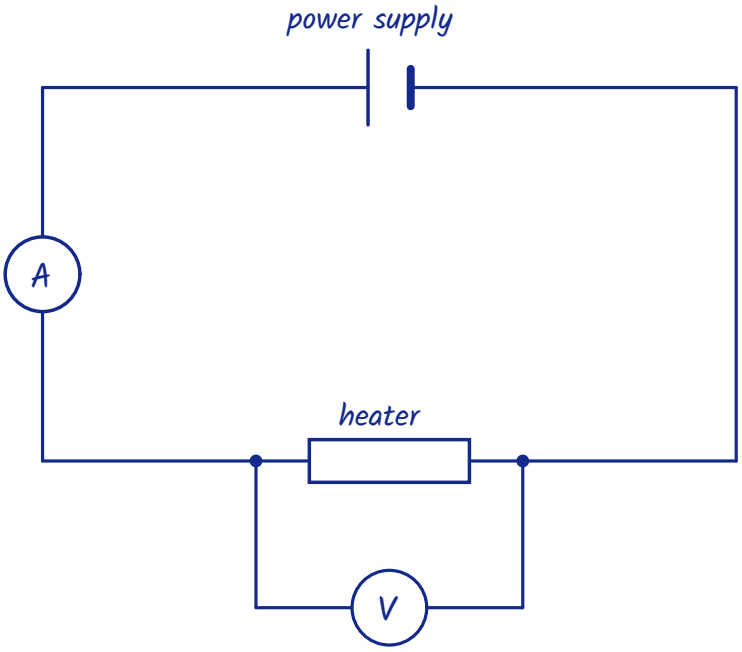
2 A student determined the specific heat capacity of aluminium.

She used an electrical heater to heat an aluminium block and measured the temperature of the block with a digital thermometer.

(a) She connected the electrical heater into a circuit and took measurements to determine the power of the heater.

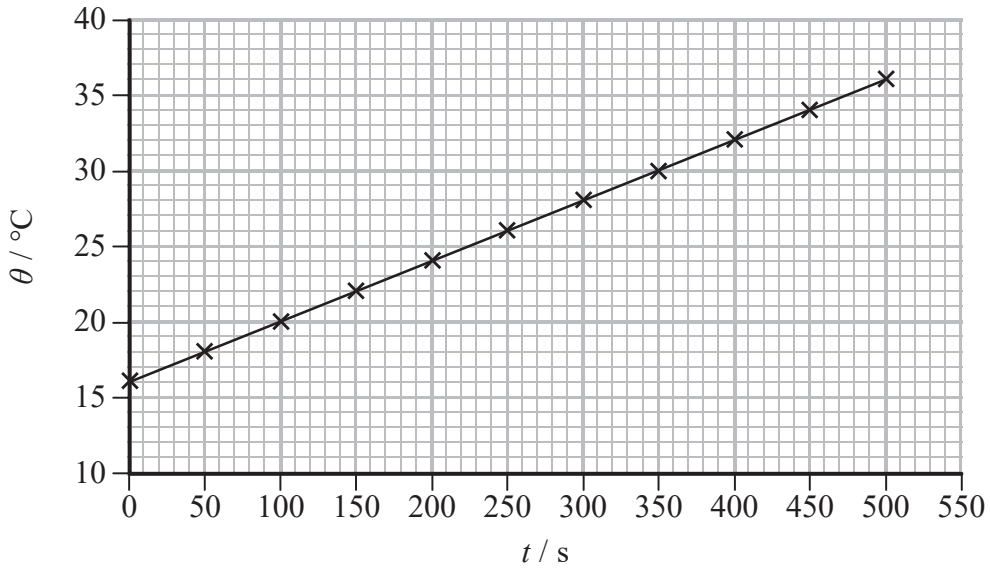
Draw a circuit diagram of a suitable circuit.

(2)



(b) The student monitored the temperature θ of the aluminium block over the time t for which the heater was switched on.

Her results are plotted on the graph.



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(i) Determine the specific heat capacity of aluminium.

power of heater = 37.5 W
mass of aluminium block = 0.986 kg

(3)

From the graph: $\Delta\theta = 36 - 16 = 20$ K in $\Delta t = 500 - 0 = 500$ s, so $\Delta\theta/\Delta t = 0.040$ K s^{-1}

$P = \Delta E/\Delta t$ and $\Delta E = mc\Delta\theta$, so $P = mc \times \Delta\theta/\Delta t$

37.5 W = 0.986 kg × c × 0.040 K s^{-1}

$c = 37.5 \div (0.986 \times 0.040) = 951$ J kg^{-1} K^{-1}

Specific heat capacity of aluminium = 951 J kg^{-1} K^{-1}

(ii) The student looked up the accepted value for the specific heat capacity of aluminium. Using this value, the student predicted that it should have taken 240 s for the temperature of the aluminium block to increase by 10 °C.

Explain the difference between the predicted time and the student's actual observations.

(2)

From the graph, in 240 s the temperature of the block rose by only 9.6 °C; it actually took 250 s (10 s longer) for the temperature to rise by 10 °C.

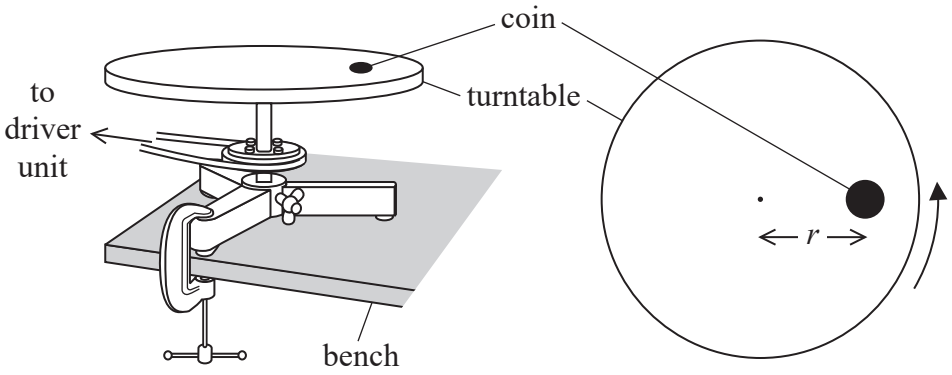
Hence there must have been energy transfer from the block to the surroundings by heating, so not all of the energy from the heater raised the temperature of the block.

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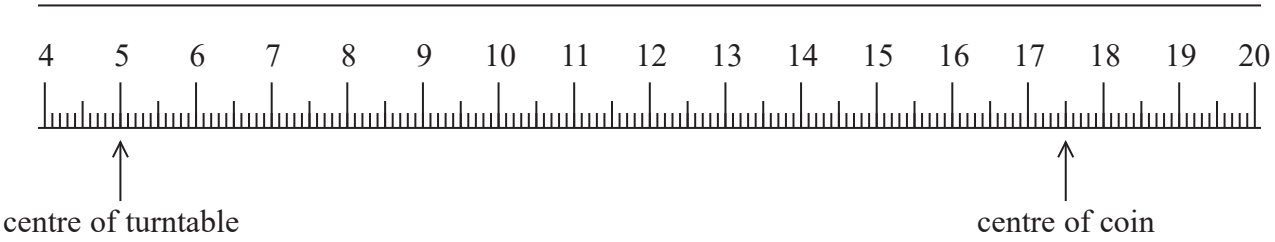
3 A student was investigating the forces involved in circular motion.

He placed a small coin on a horizontal turntable as shown. The turntable was connected to a driver unit so that it could be rotated at a constant rate.



plan view

(a) The student measured the distance r between the centre of the turntable and the centre of the coin, with a metre rule as shown.



Explain why the percentage uncertainty in the value of r is about 1%.
Your answer should include a calculation.

(3)

Readings: centre of turntable = 5.0 cm, centre of coin = 17.5 cm, so r = 17.5 − 5.0 = 12.5 cm

Uncertainty in each reading = 0.05 cm (half the 1 mm resolution of the rule)

r needs two readings, so the uncertainty in r = 2 × 0.05 cm = 0.1 cm

% uncertainty = 0.1 cm ÷ 12.5 cm × 100% = 0.8%, which is about 1%

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(b) The student switched on the driver unit and increased the rate of rotation until the coin slid off the turntable. He read the angular velocity ω of the turntable from a digital display on the driver unit. He then replaced the coin in the original position on the turntable and repeated the procedure.

His results are shown.

ω / rad s^{-1}				
0.125	0.112	0.118	0.123	0.116

(i) The student used the results to calculate a mean value of ω.

State the purpose of calculating a mean.

(1)

To reduce the effect of random errors.

(ii) Calculate the percentage uncertainty in the mean value of ω.

(3)

Mean ω = (0.125 + 0.112 + 0.118 + 0.123 + 0.116) ÷ 5 = 0.119 rad s^{-1}

Uncertainty = half range = (0.125 − 0.112) ÷ 2 = 0.0065 rad s^{-1}

% uncertainty = 0.0065 ÷ 0.119 × 100% = 5.5%

Percentage uncertainty = 5.5%

(iii) The student used ω and r to calculate the centripetal acceleration of the coin at the instant it started to slide.

Calculate the percentage uncertainty in this centripetal acceleration.

(3)

$a = r\omega^2$, so % uncertainty in a = 2 × (% uncertainty in ω) + % uncertainty in r

= 2 × 5.5% + 0.8% = 11.8%

Percentage uncertainty = 12%

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(c) The student repeated the procedure with different values of r.

Explain how the value of ω at which the coin started to slide varied as r increased.

(3)

The centripetal force on the coin is provided by friction between the coin and the turntable.

There is a maximum frictional force, so the coin starts to slide when the frictional force reaches the same maximum value, whatever the value of r.

$F = m\omega^2 r$ with F and m constant, so $\omega^2 \propto 1/r$: as r increased, the value of ω at which the coin started to slide decreased.

(Total for Question 3 = 13 marks)

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4 A student carried out an experiment to determine the focal length of a converging lens.

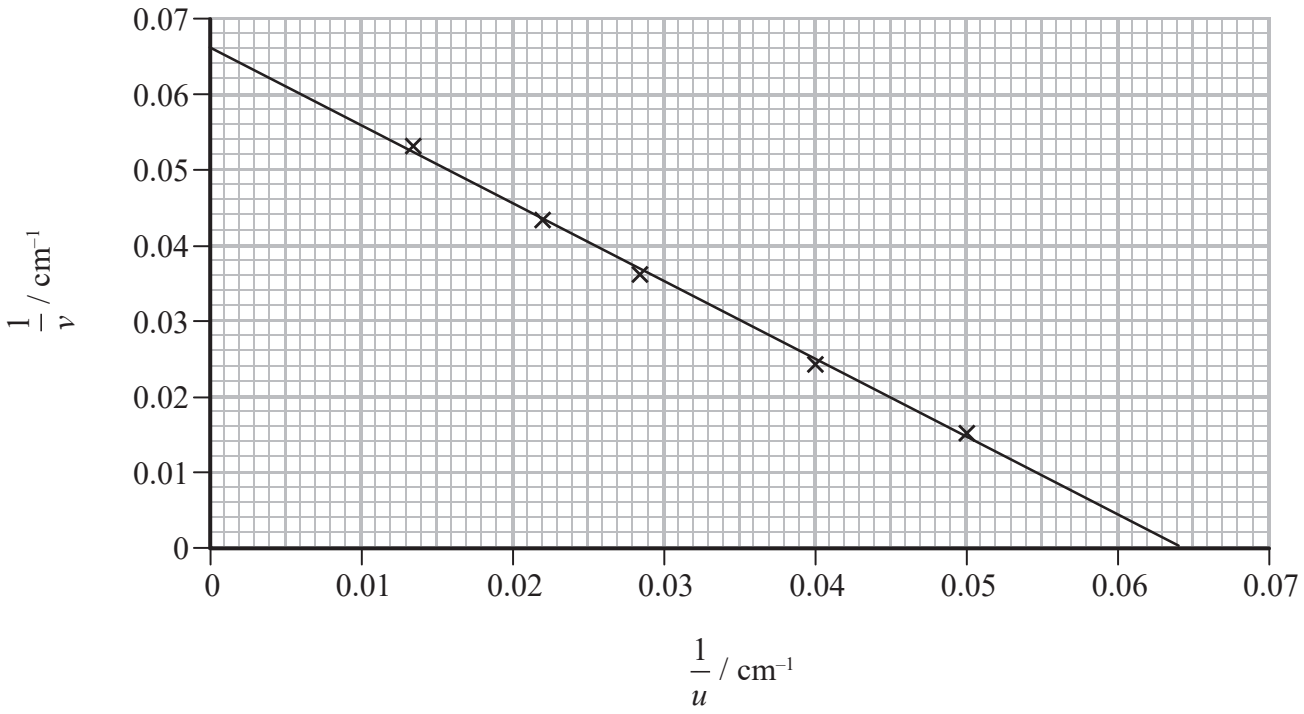
He placed the lens a distance u from an illuminated object. He placed a screen on the other side of the lens and moved the screen until a sharp image of the object was produced. He measured the corresponding image distance v.

The student repeated the procedure for four more values of u.

In his lab report he wrote:

"I made an initial determination of the focal length of the lens and concluded that it was about 15 cm. When I plotted a graph it confirmed my initial determination of the lens focal length."

The student's graph is shown.



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Comment on whether the student's data is consistent with his initial determination of the focal length of the lens.

(5)

1/f = 1/u + 1/v, which rearranges to 1/v = −1/u + 1/f

Comparing with y = mx + c: the gradient is −1 and the intercept on the 1/v axis (y-intercept) equals 1/f.

y-intercept = 0.066 cm^{-1}, so f = 1 ÷ 0.066 cm^{-1} = 15.2 cm

Also, when 1/v = 0, 1/u = 1/f: x-intercept = 0.064 cm^{-1}, so f = 1 ÷ 0.064 cm^{-1} = 15.6 cm

Both values of f are about 15 cm (they differ from 15 cm by less than 4%), the points lie close to the line and the gradient is close to −1, so the data is consistent with his initial determination of 15 cm.

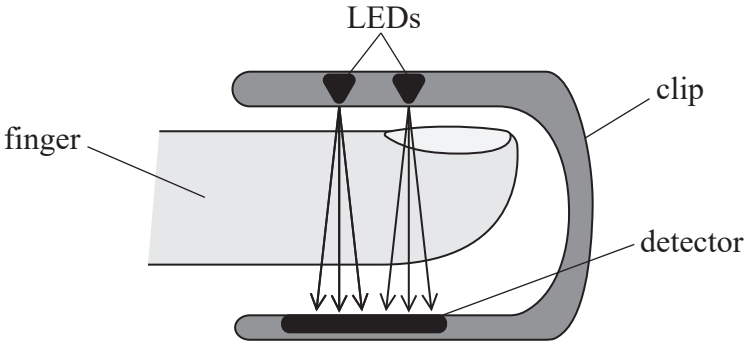
(Total for Question 4 = 5 marks)

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5 An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.





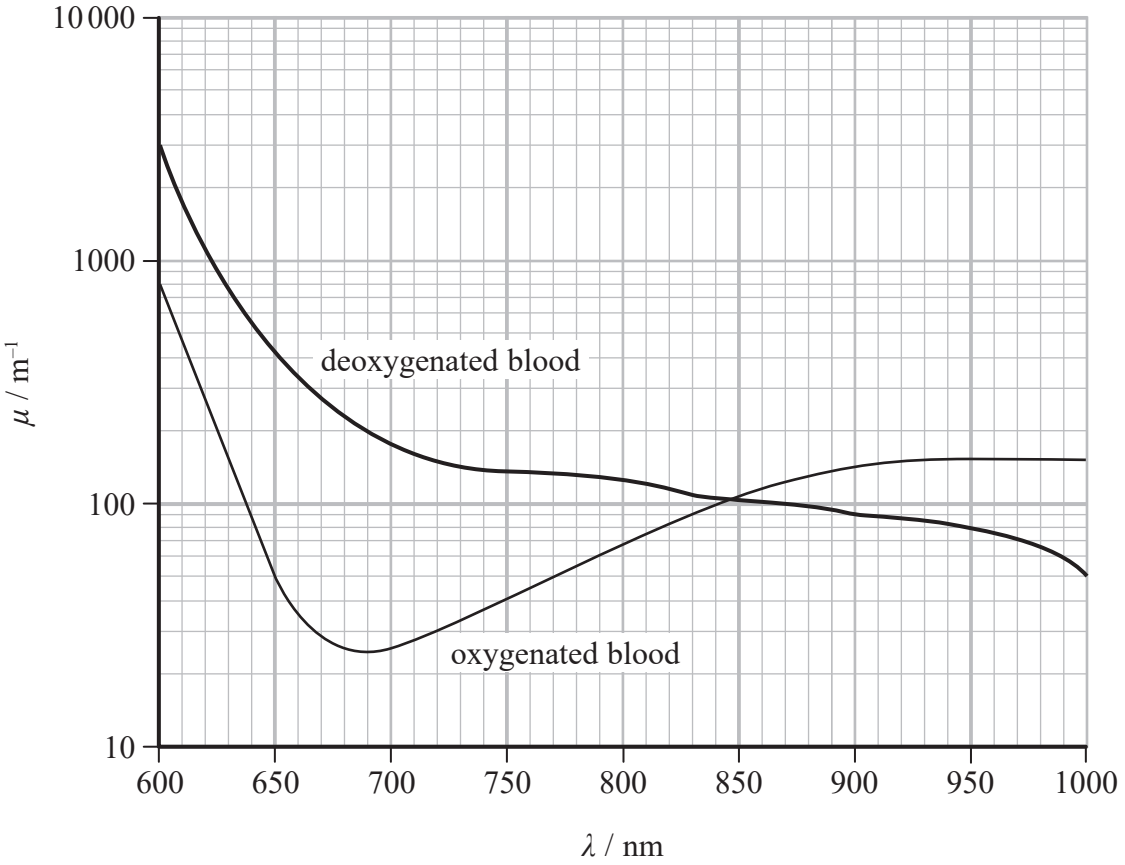
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

$$I = I_0 e^{-\mu x}$$

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



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(a) I_0 for the infrared LED is 1.8 W m^{-2}.

Calculate I for the infrared after passing through 1.4 mm of oxygenated blood.

(3)

From the graph, at 950 nm for oxygenated blood, μ = 150 m^{-1}

$I = I_0 e^{-\mu x}$ where $\mu x = 150\ m^{-1} \times 1.4 \times 10^{-3}\ m = 0.21$

$I = 1.8\ W\ m^{-2} \times e^{-0.21} = 1.46\ W\ m^{-2}$

$I =$ 1.5 W m^{-2}

(b) The oximeter determines I/I_0 the fraction of radiation transmitted at each wavelength.

Deduce whether I/I_0 will be smaller for the red or the infrared radiation if the blood is deoxygenated.

(3)

For deoxygenated blood, μ for red (650 nm, several hundred m^{-1}) is much greater than μ for infrared (950 nm, about 100 m^{-1}).

Hence more red is absorbed: $e^{-\mu x}$ is smaller for red for the same thickness x.

So I/I_0 is smaller for the red radiation.

It is suggested that ambient light could affect the readings produced by the oximeter.

Halogen lamps have a filament temperature of 3200 K.

(c) Deduce whether the light from such a lamp would have a significant effect on the oximeter readings.

(3)

Wien's law: $\lambda_{max} T = 2.898 \times 10^{-3}\ m\ K$

$\lambda_{max} = 2.898 \times 10^{-3}\ m\ K \div 3200\ K = 9.06 \times 10^{-7}\ m = 910\ nm$

Yes: the peak emission of the lamp is at a wavelength close to the 950 nm infrared, so the detector would receive a lot of this radiation and the readings would be significantly affected.

(Total for Question 5 = 9 marks)

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6 In 1990, the Hubble Space Telescope (HST) was launched into a low Earth orbit above the Earth's atmosphere.

(a) HST orbits the Earth in a circular orbit with a speed of $7.59\,\text{km}\,\text{s}^{-1}$.

mass of Earth = $5.97 \times 10^{24}\,\text{kg}$
radius of Earth = $6.37 \times 10^{6}\,\text{m}$

(i) Show that the height of HST above the surface of the Earth is about $6 \times 10^{5}\,\text{m}$.

(3)

Gravitational force provides the centripetal force: $GMm/r^2 = mv^2/r$, so $r = GM/v^2$

$r = 6.67 \times 10^{-11}\ N\ m^2\ kg^{-2} \times 5.97 \times 10^{24}\ kg \div (7.59 \times 10^{3}\ m\ s^{-1})^2$

$r = 6.91 \times 10^{6}\ m$

$h = r - R = 6.91 \times 10^{6}\ m - 6.37 \times 10^{6}\ m = 5.4 \times 10^{5}\ m$ (about $6 \times 10^{5}\ m$)

(ii) Calculate the increase in the gravitational potential energy as HST is raised, from its initial position at the Earth's surface, to its orbital height.

mass of HST = 11 600 kg

(2)

$\Delta GPE = GMm(1/r_1 - 1/r_2)$

$= 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 11\ 600 \times (1/6.37 \times 10^{6} - 1/6.91 \times 10^{6})$

$= 5.67 \times 10^{10}\ J$

Increase in gravitational potential energy = $5.7 \times 10^{10}\ J$

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(iii) A student suggests that giving HST more energy than that required in (ii) would result in the satellite orbiting at a greater height and with a greater speed.

Assess the validity of the student's suggestion.

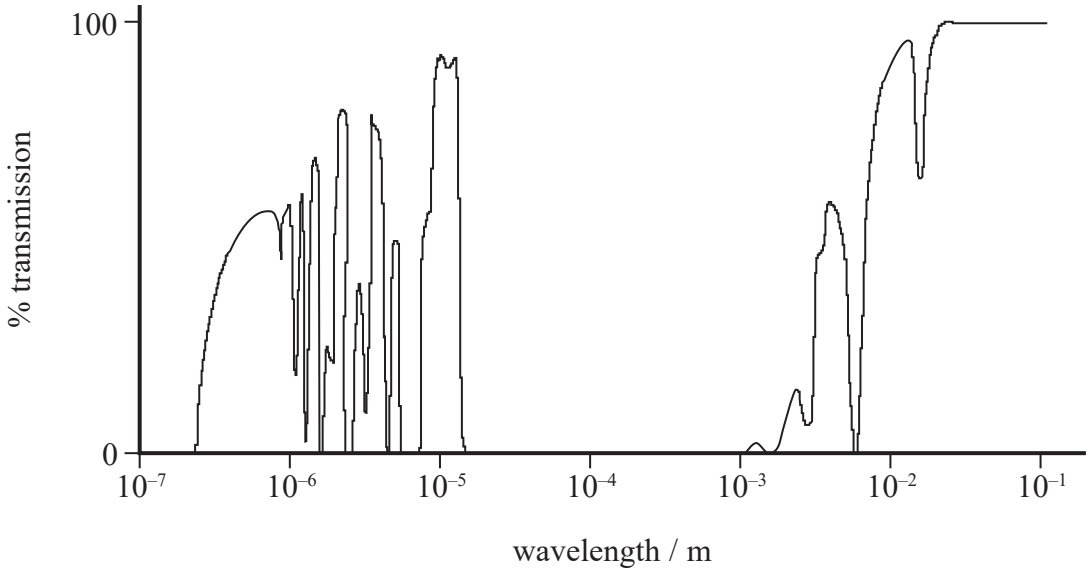
(4)

Giving HST more energy would bring its gravitational potential energy closer to zero (GPE = −GMm/r), so the satellite would orbit at a greater height, as GPE ∝ −1/r. This part is valid.

But to remain in orbit the centripetal acceleration must equal the gravitational field strength at the orbit height: $GMm/r^2 = mv^2/r$, so $v^2 = GM/r$.

At the greater height r is greater, so v must be smaller: the satellite would orbit at a lower speed, not a greater speed. So the student's suggestion is not fully valid.

(b) The transmission of electromagnetic radiation through the atmosphere is shown on the graph.



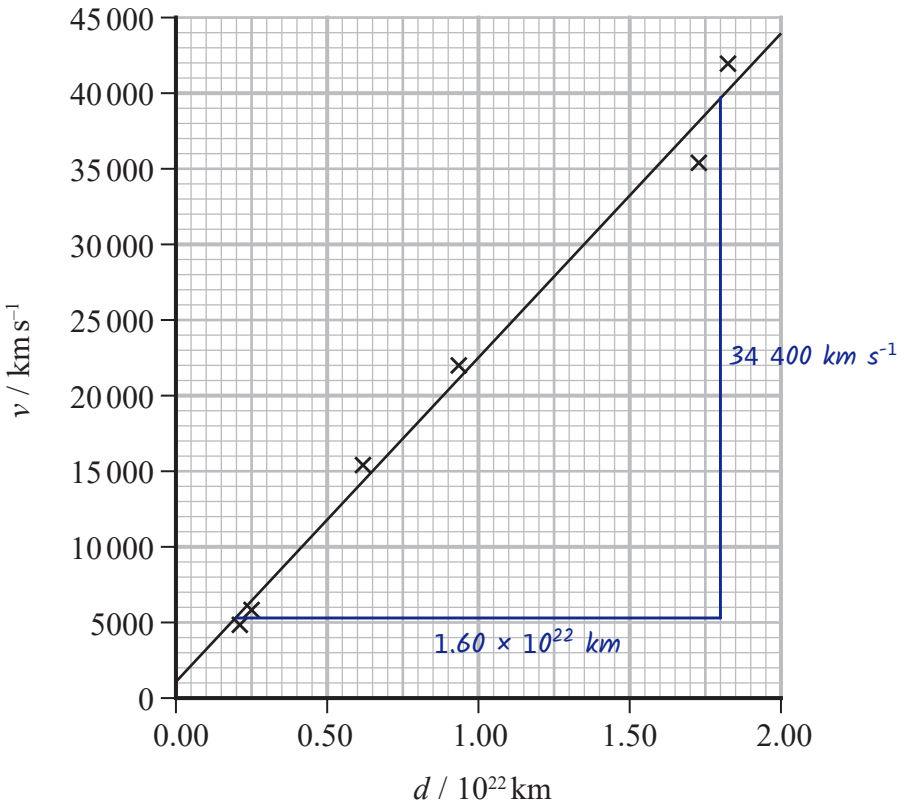
State one advantage shown by this graph of positioning a telescope above the atmosphere.

(1)

Infrared radiation from stars (about 10^{-5} m to 10^{-3} m) is absorbed by the atmosphere, so it can only be detected above the atmosphere.

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(c) High resolution images from HST allow astronomers to make detailed measurements of very distant galaxies. The graph shows how the recessional velocities of distant galaxies depend on their distance from Earth.



Determine an age for the universe.

(3)

Gradient = (39 700 − 5300) km s^{-1} ÷ ((1.80 − 0.20) × 10^{22} km) = 2.15 × 10^{-18} s^{-1}

v = H_0d, so H_0 = gradient, and the age of the universe t = 1/H_0 = 1/gradient

t = 1 ÷ 2.15 × 10^{-18} s^{-1} = 4.65 × 10^{17} s

Age for the universe = 4.7 × 10^{17} s

(Total for Question 6 = 13 marks)

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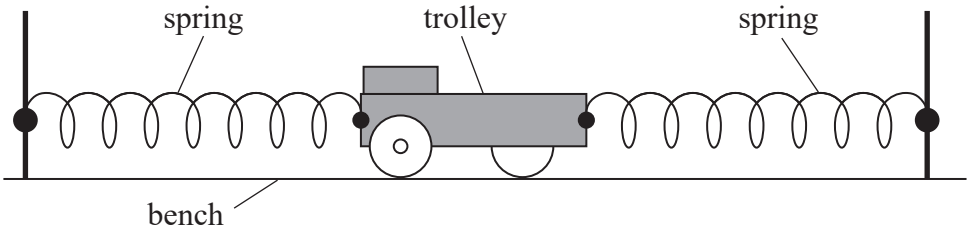
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7 A trolley is attached to the ends of two springs as shown. When displaced from its equilibrium position, the trolley moves with simple harmonic motion.



(a) A student has a stopwatch and metre rule available.

(i) Explain the procedure that the student should follow to make an accurate determination of the time period T of the trolley.

(6)

Place a fiducial marker (e.g. a vertical pin) at the equilibrium position of the trolley, and use the equilibrium position as the reference position for timing.

The trolley is moving fastest at this point, so the uncertainty in judging when to start and stop the stopwatch is least.

Displace the trolley and release it. Time 10 complete oscillations and divide the total time by 10 to find T. Increasing the time measured reduces the (percentage) uncertainty in T due to reaction time.

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

(ii) Describe how the student should use her value of T to determine the maximum speed of the trolley.

(3)

Use $\omega = 2\pi/T$ to calculate a value for ω.

Measure the maximum displacement (amplitude A) of the trolley from the equilibrium position with the metre rule.

Use $v_{max} = \omega A$ to calculate the maximum speed of the trolley.

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(b) Another student suggests that a more accurate value for T could be obtained by using a position sensor and data logger.

Comment on this suggestion.

(1)

The position sensor and data logger eliminate the reaction time of a person starting and stopping the stopwatch, so the value of T would be more accurate.

(c) The student displaces the trolley a greater distance from the equilibrium position, so the amplitude of oscillation is doubled. The trolley still moves with simple harmonic motion.

Explain how the maximum kinetic energy of the trolley will change.

(3)

$v_{max} = \omega A$, and ω is constant because the period of simple harmonic motion does not depend on the amplitude.

So if A doubles, then v_{max} doubles.

Hence the maximum kinetic energy will quadruple (increase by a factor of 4), since $E_k = \frac{1}{2}mv^2 \propto v_{max}^2$.

(Total for Question 7 = 13 marks)

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8 In the sport of curling, two teams of 'curlers' take turns sliding polished granite stones across an ice surface towards a circular target marked on the ice.



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(a) A stone of mass 19.6 kg is accelerated uniformly for 1.25 s before being released by a curler. The stone then decelerates uniformly to rest, travelling 32.5 m in a time of 17.5 s.

Calculate the average useful power developed by the curler in accelerating the stone.

(4)

Deceleration: $s = (u + v)t/2$, so $32.5\ m = (u + 0) \times 17.5\ s \div 2$

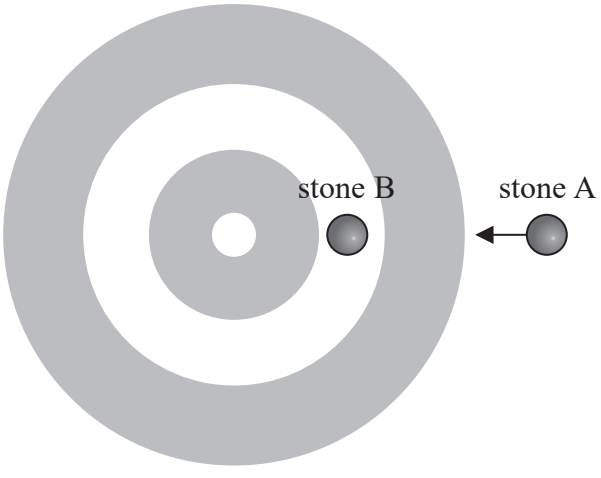
$u = 2 \times 32.5\ m \div 17.5\ s = 3.71\ m\ s^{-1}$ (speed when released)

$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 19.6\ kg \times (3.71\ m\ s^{-1})^2 = 135\ J$

$P = \Delta W/\Delta t = 135\ J \div 1.25\ s = 108\ W$

Average power = 110 W

*(b) Stone B is stationary. Stone A travels towards the target and makes a direct hit on stone B as shown. Both stones have mass *m*.



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The collision is elastic. Just before the collision stone A has a velocity v. After the collision stone B moves off with velocity v.

Discuss how the relevant conservation laws apply to this collision.

(6)

The collision takes place on an ice surface, so there is minimal friction and external forces are negligible. So momentum is conserved in the collision.

Before the collision the total momentum is mv (B is stationary). After the collision stone B has momentum mv, so the momentum of stone A before the collision equals the momentum of B after the collision.

This means stone A must be at rest after the collision, as the total momentum after must still be mv.

The collision is elastic, so kinetic energy is also conserved: the kinetic energy of A before is $\frac{1}{2}mv^2$ and B has kinetic energy $\frac{1}{2}mv^2$ after.

So all of the kinetic energy of stone A has been transferred to stone B, which is consistent with A being at rest after the collision.

(c) While a stone is moving towards the target, the curlers vigorously sweep the ice directly in front of the stone.

Explain why this may make the stone travel further.

(2)

Sweeping the ice smooths out the surface (and the heating melts the surface of the ice, giving a layer of water).

So the frictional forces on the stone are reduced, so its deceleration is reduced and it travels further before stopping.

(Total for Question 8 = 12 marks)

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9 The Beaufort scale is used to describe wind intensity. On this scale the average wind speed v increases with the Beaufort scale value B.

The relationship between v and B is given by

$$v = kB^p$$

where k and p are constants.

(a) Explain why a graph of $\log v$ against $\log B$ should give a straight line.

(2)

Taking logs of $v = kB^p$: $\log v = \log k + p \log B$, i.e. $\log v = p \log B + \log k$

Comparing with $y = mx + c$: p and k are constants, so $\log v$ against $\log B$ is a straight line with gradient p (and intercept $\log k$).

(b) The table gives some values of v and corresponding values of B.

v / m s^{-1}	B	$\log (v / \text{m s}^{-1})$	$\log B$
2.00	1	0.301	0.00
10.0	3	1.00	0.477
21.5	5	1.33	0.699
36.0	7	1.56	0.845
50.5	9	1.70	0.954
68.0	11	1.83	1.04

(i) Plot a graph of $\log v$ against $\log B$ on the grid opposite.
Use the columns provided to show any processed data.

(5)

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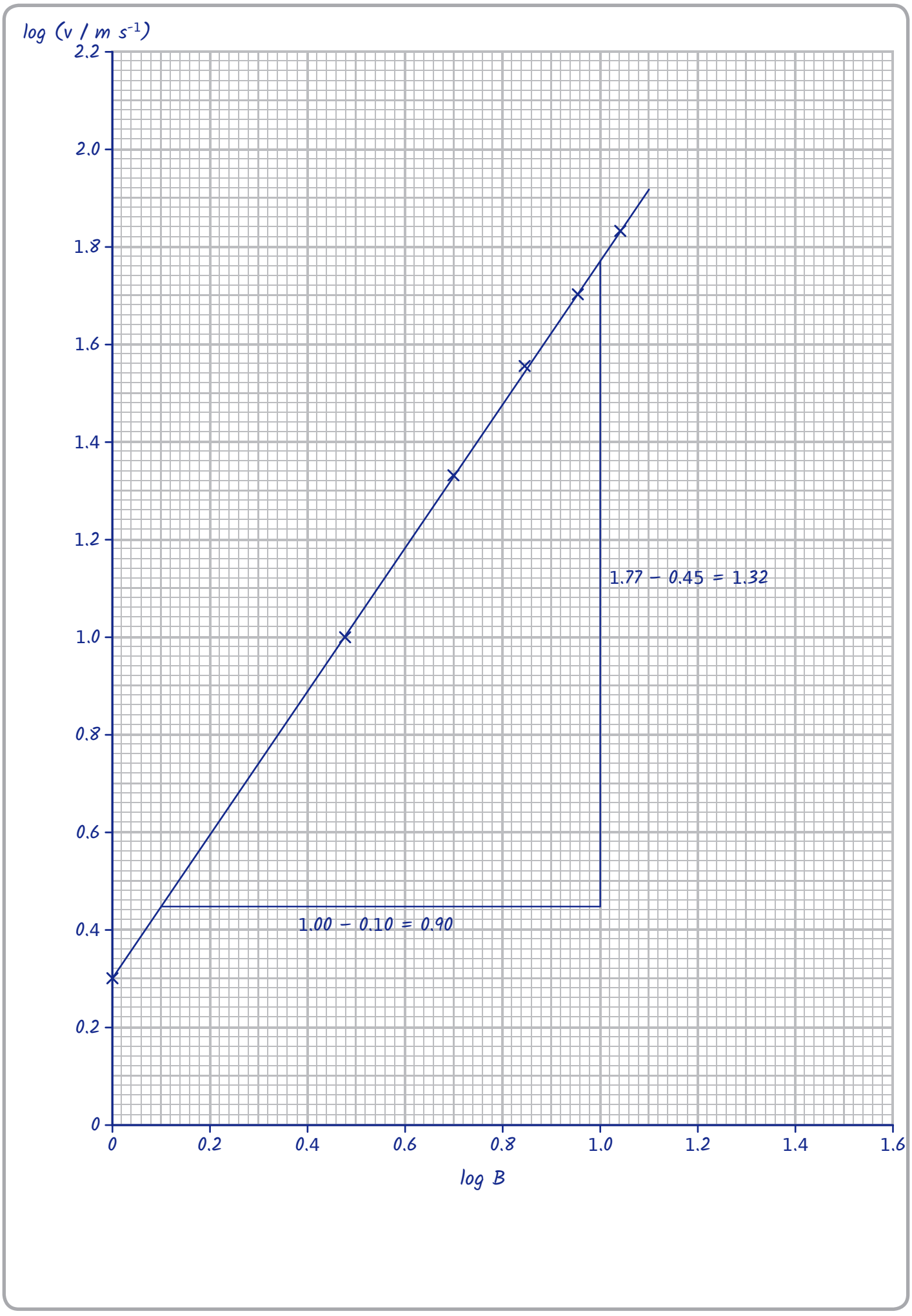
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(ii) Determine the values of p and k.

(3)

Gradient (large triangle) = (1.77 − 0.45) ÷ (1.00 − 0.10) = 1.32 ÷ 0.90 = 1.47, so p = 1.47

Intercept on the log v axis (log B = 0) = 0.301 = log k

$k = 10^{0.301} = 2.00 \text{ m s}^{-1}$

$p =$ 1.47

$k =$ 2.00 m s^{-1}

(Total for Question 9 = 10 marks)

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10 Seat belts are being tested by a car manufacturer. In the test, a car moving at a steady speed of 28 m s^{-1} collides with a wall and stops.

A crash-test dummy in the driving seat is wearing a seat belt made from polyester webbing. The seat belt has a cross-sectional area of 0.85 cm^2 and a total length of 2.0 m. A student suggests that in the collision the seat belt absorbs all the kinetic energy of the dummy.

(a) Show that the energy per unit volume that would have to be absorbed by the seat belt is about 2×10^8 J m^{-3}.

mass of dummy = 75 kg

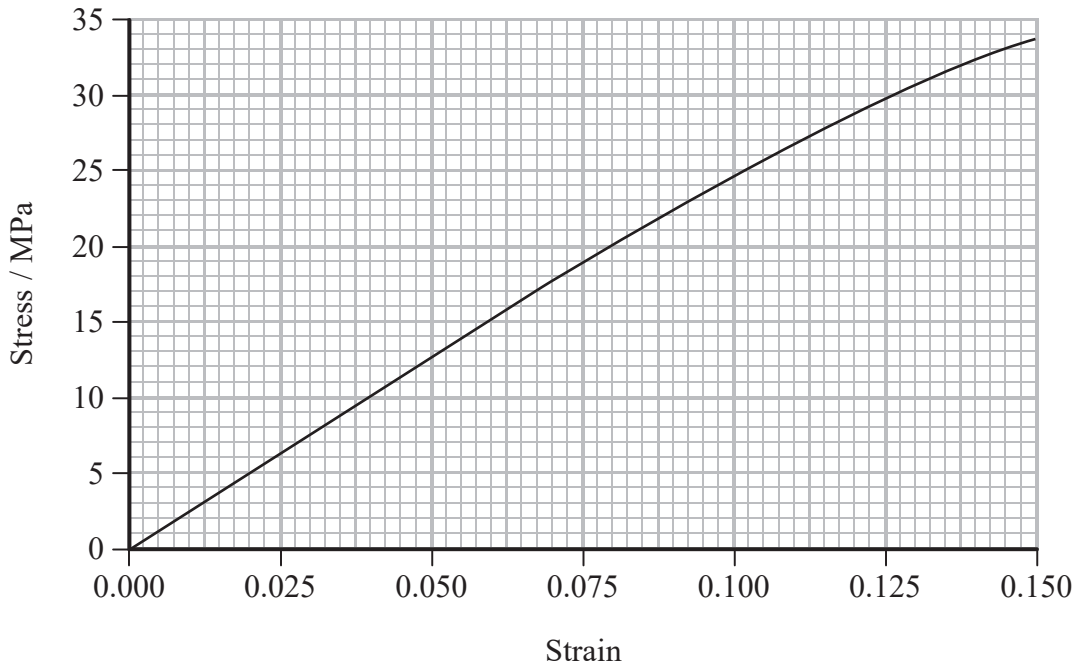
(3)

Volume of belt V = 0.85 × 10^{-4} m^2 × 2.0 m = 1.7 × 10^{-4} m^3

E_k = ½mv^2 = ½ × 75 kg × (28 m s^{-1})^2 = 2.9 × 10^4 J

Energy per unit volume = 2.9 × 10^4 J ÷ 1.7 × 10^{-4} m^3 = 1.73 × 10^8 J m^{-3} (about 2 × 10^8 J m^{-3})

(b) The graph shows how stress varies with strain for the seat belt.



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(i) Show that the area under the graph represents the energy stored per unit volume in the seat belt.

(2)

For the linear section, area under graph = ½ × stress × strain

Stress = F/A and strain = Δx/x, so area = ½ × F/A × Δx/x = ½FΔx/(Ax) = E/V, as

½FΔx is the energy stored and Ax is the volume.

(ii) Use the graph to determine whether the seat belt absorbs all the kinetic energy of the dummy from part (a).

In this collision, the maximum strain of the seat belt is 0.075

(3)

From the graph, when strain = 0.075, stress = 19 MPa (graph is linear up to here)

Area = ½ × 19 × 10^6 Pa × 0.075 = 7.1 × 10^5 J m^{-3}

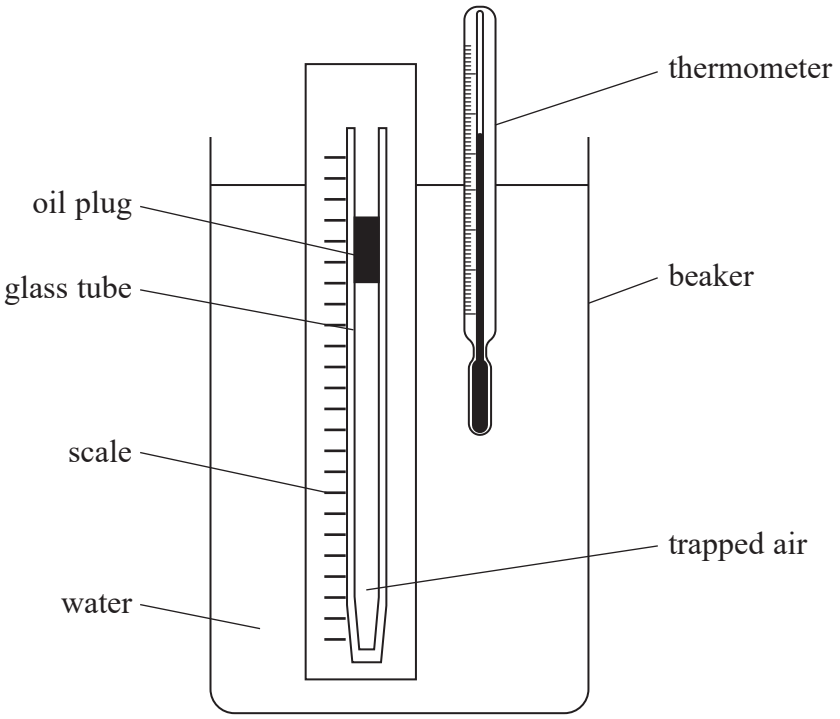
This is much less than the 1.7 × 10^8 J m^{-3} from (a), so the seat belt does not absorb

all the kinetic energy of the dummy.

(Total for Question 10 = 8 marks)

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11 A student investigated how the volume of a fixed mass of air varies with the temperature of the air. She used the apparatus shown.



A glass tube was sealed at one end. A plug of oil trapped a length l of air in the tube. The water in the beaker was heated to a temperature θ. The corresponding value of l was measured. This was repeated for a range of temperatures.

The thermometer had a resolution of 0.5 °C. The scale had mm divisions.

The student's results are shown in the table.

θ / °C	l / cm
24	8.8
60	9.8
78.5	10.3
95.5	10.9

(a) (i) Criticise the student's results.

(3)

The temperatures are recorded to an inconsistent number of decimal places (24 and 60 but 78.5 and 95.5).

There is no evidence of repeat readings.

Only four pairs of readings is not enough, the range is too small, and there are no readings between 24 °C and 60 °C.

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(ii) Explain two possible sources of error in this investigation.

(4)

The trapped air may not have been at the temperature of the water, because the water temperature may not be uniform, or because transfer of thermal energy through the glass takes time.

The volume of the trapped air column may not be proportional to the length of the column, because the bore of the glass tube may not have been uniform.

The temperature or length may be read incorrectly because of a parallax error.

(iii) Describe two improvements that would increase the accuracy of measurements obtained in this investigation.

(2)

Stir the water in the beaker and let the tube reach thermal equilibrium before taking readings.

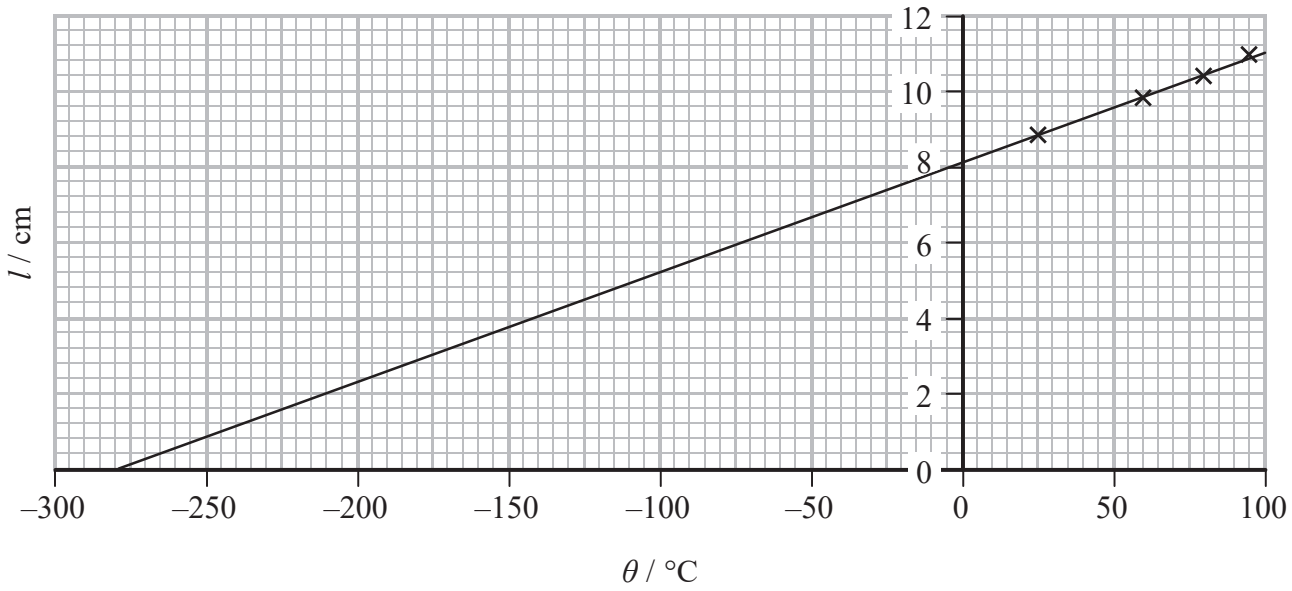
Use a digital thermometer (or temperature sensor) close to the tube, and read the scale in line with it.

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(b) The student plotted a graph of l against θ as shown.



(i) Explain the significance of the intercept on the x-axis.

(3)

The intercept (about −275 °C) represents the temperature of the air at which the volume occupied by the air would be zero.

This is absolute zero (of temperature), 0 K.

Absolute zero is the lowest attainable temperature: it is the temperature at which the molecules of the gas have zero kinetic energy.

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(ii) The student wrote a report of the investigation in her lab book. In the conclusion she wrote:

"In this investigation uncertainties were minimised by selecting measuring instruments with a high resolution. The points lie on a perfect straight line, indicating that the investigation is accurate."

Discuss the student's conclusion.

(4)

It is correct that uncertainties would be reduced by using high resolution instruments, but these instruments are not high resolution (a thermometer reading to 0.5 °C and a scale with mm divisions).

Also, there could be a systematic error in the measurements (e.g. the air not at the thermometer temperature), which high resolution does not remove, so the results may not be accurate.

The points do not lie on a perfect straight line, and the true relationship may not be linear.

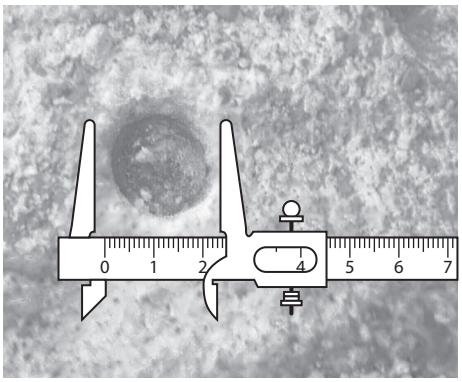
The temperature intercept may not be accurate because of extrapolation errors over such a large range. More points over a wider range are needed.

(Total for Question 11 = 16 marks)

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12 Impact craters are formed when meteorites strike the surface of a planet. A student investigated some factors that might influence the formation of impact craters. He did this by dropping spheres of modelling clay into a tray of sand.

The diameter of the crater produced by each sphere was measured using vernier calipers as shown.



This process was repeated for spheres of different diameters.

(a) In one test, the spheres were dropped from the same height.

Determine the factor by which the kinetic energy of the sphere just before impact increases when the sphere diameter is increased from 2.0 cm to 4.0 cm.

(3)

Dropped from the same height, so the speed of impact is the same for both spheres.

Mass of sphere $\propto$ volume $\propto$ (diameter)^3, so $m_2/m_1 = (4.0\ cm \div 2.0\ cm)^3 = 8$

$E_k = \frac{1}{2}mv^2$ with v the same, so $E_{k2}/E_{k1} = m_2/m_1 = 8$

Factor = 8

*(b) The student also dropped the spheres from different heights. His results are shown in the table.

Drop height / m	Sphere diameter / cm	Crater diameter / cm
0.30	2.0	3.6
	4.0	7.0
	6.0	6.8
0.60	2.0	4.8
	4.0	7.5
	6.0	7.3
0.90	2.0	5.6
	4.0	8.0
	6.0	8.3

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The student wrote the following conclusion:

"The greater the drop height, the greater the diameter of the crater formed when a sphere hits the sand. This is because the impact velocity increases as the drop height is increased. As the speed of the sphere increases the diameter of the crater formed also increases. Also, the bigger the sphere the bigger the crater."

Assess the validity of the student's conclusion.

(6)

The table shows that increasing the drop height does increase the crater diameter for every sphere size (e.g. 3.6, 4.8, 5.6 cm for 2.0 cm spheres), so this part of the conclusion is valid.

Increasing the drop height increases the impact velocity, because there is a greater acceleration time, so there is a greater transfer of gravitational potential energy to kinetic energy ($mg\Delta h = \frac{1}{2}mv^2$).

However the table does not show that increasing the sphere diameter always increases the crater diameter.

For smaller spheres (2.0 cm to 4.0 cm), increasing the sphere diameter does increase the crater diameter (e.g. 3.6 cm to 7.0 cm at 0.30 m).

For bigger spheres (4.0 cm to 6.0 cm), increasing the sphere diameter has little effect: the crater diameter decreases at 0.30 m and 0.60 m and only increases slightly at 0.90 m. So 'the bigger the sphere the bigger the crater' is not valid.

There are only three heights and no repeats, so more data is needed for firmer conclusions.

(Total for Question 12 = 9 marks)

TOTAL FOR PAPER = 120 MARKS

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List of data, formulae and relationships

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

$$\Sigma F = ma$$

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

$$W = mg$$

moment of force $= Fx$

Momentum

$$p = mv$$

Work, energy and power

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

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

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

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

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

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

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

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

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

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

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

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

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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