

Please check the examination details below before entering your candidate information

Candidate surname

Other names

**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.

Turn over ►

P58359A

©2019 Pearson Education Ltd.

1/1/1/1/1/



  
Pearson

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**BLANK PAGE**



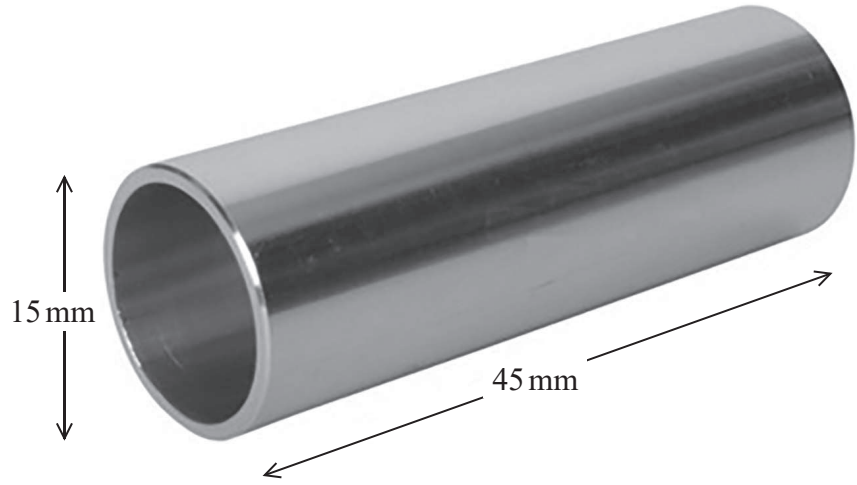
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**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)

.....

- (b) Describe the procedure she should follow to determine an accurate value for the external diameter of the tube. (3)

.....  
.....  
.....  
.....  
.....  
.....

- (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)

.....  
.....  
.....

**(Total for Question 1 = 5 marks)**



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.

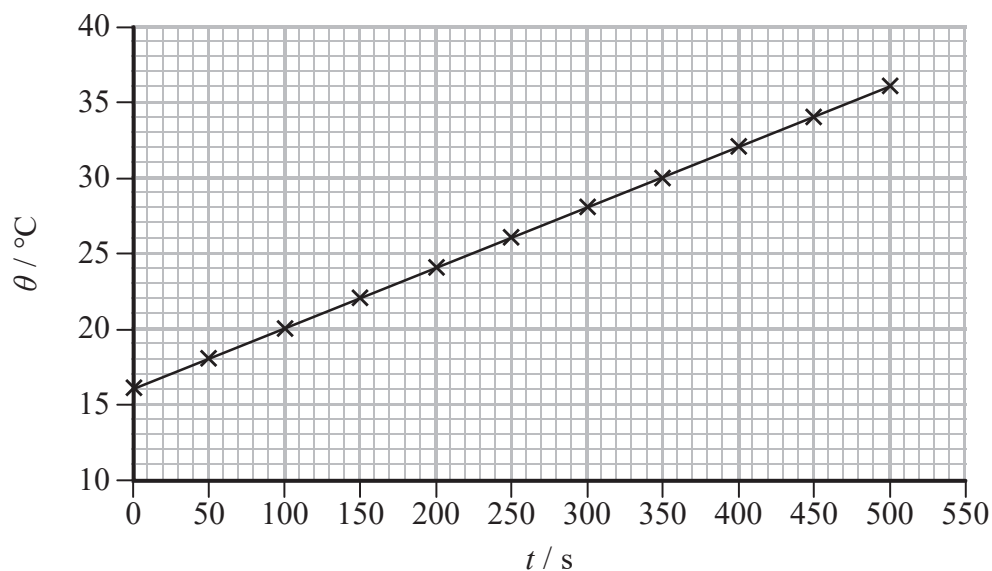
(a) She connected the electrical heater into a circuit and took measurements to determine the power of the heater.

Draw a circuit diagram of a suitable circuit.

(2)

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

Her results are plotted on the graph.



(i) Determine the specific heat capacity of aluminium.

power of heater = 37.5 W

mass of aluminium block = 0.986 kg

(3)

Specific heat capacity of aluminium = .....

(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)

**(Total for Question 2 = 7 marks)**

DO NOT WRITE IN THIS AREA

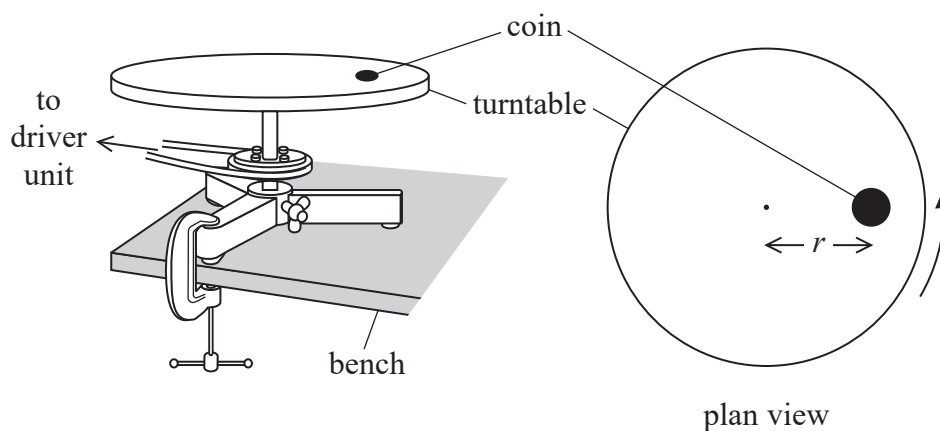
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

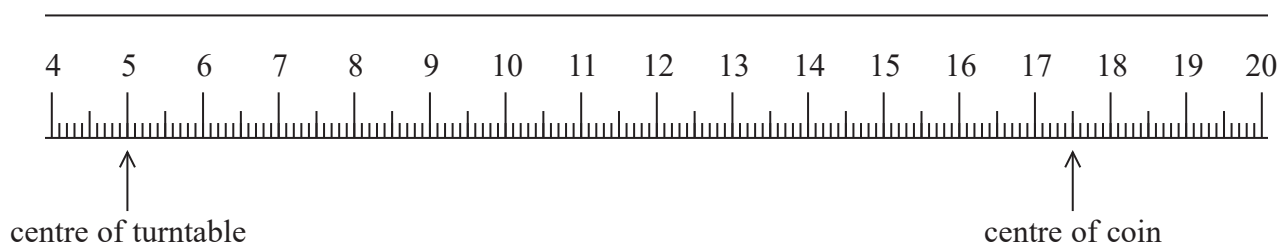


3 A student was investigating the forces involved in circular motion.

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.



(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)



- (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  $\omega$  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.

| $\omega / \text{rad s}^{-1}$ |       |       |       |       |
|------------------------------|-------|-------|-------|-------|
| 0.125                        | 0.112 | 0.118 | 0.123 | 0.116 |

- (i) The student used the results to calculate a mean value of  $\omega$ .

State the purpose of calculating a mean.

(1)

- (ii) Calculate the percentage uncertainty in the mean value of  $\omega$ .

(3)

Percentage uncertainty = .....

- (iii) The student used  $\omega$  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)

Percentage uncertainty = .....



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

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

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

(3)

.....

.....

.....

.....

.....

.....

**(Total for Question 3 = 13 marks)**





DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**BLANK PAGE**



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

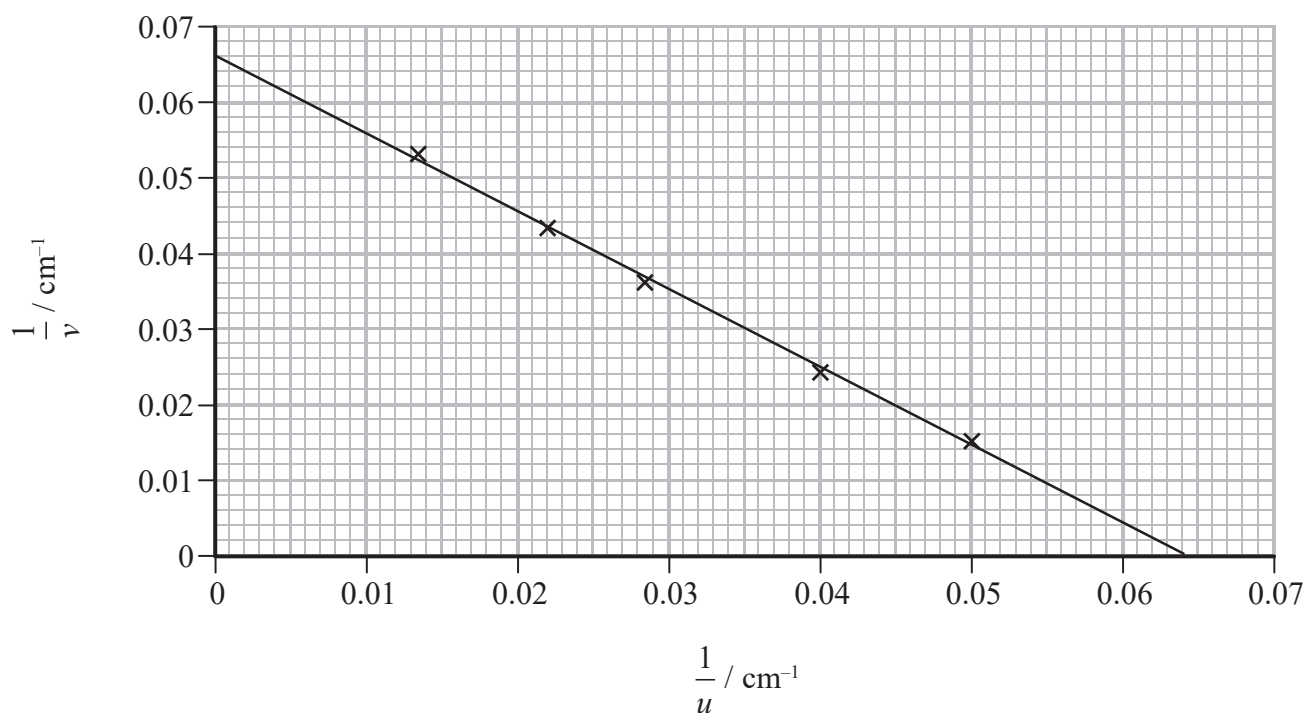
He placed the lens a distance  $u$  from an illuminated object. He placed a screen on the other side of the lens and moved the screen until a sharp image of the object was produced. He measured the corresponding image distance  $v$ .

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.



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

(5)

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

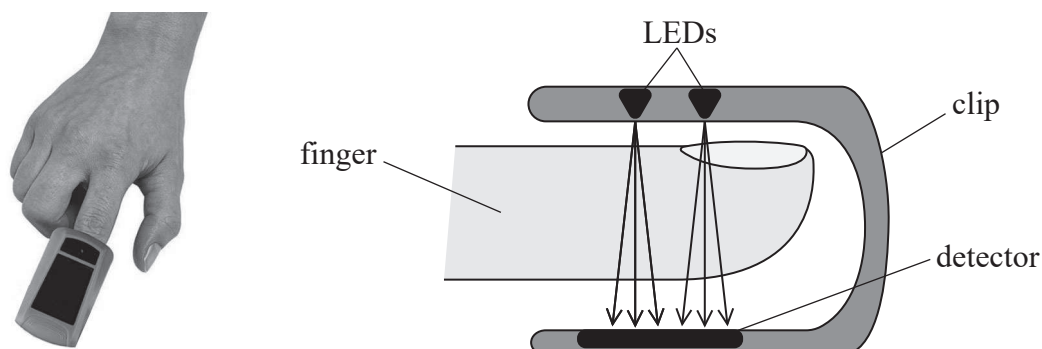
(Total for Question 4 = 5 marks)



P 5 8 3 5 9 A 0 1 1 4 0

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.



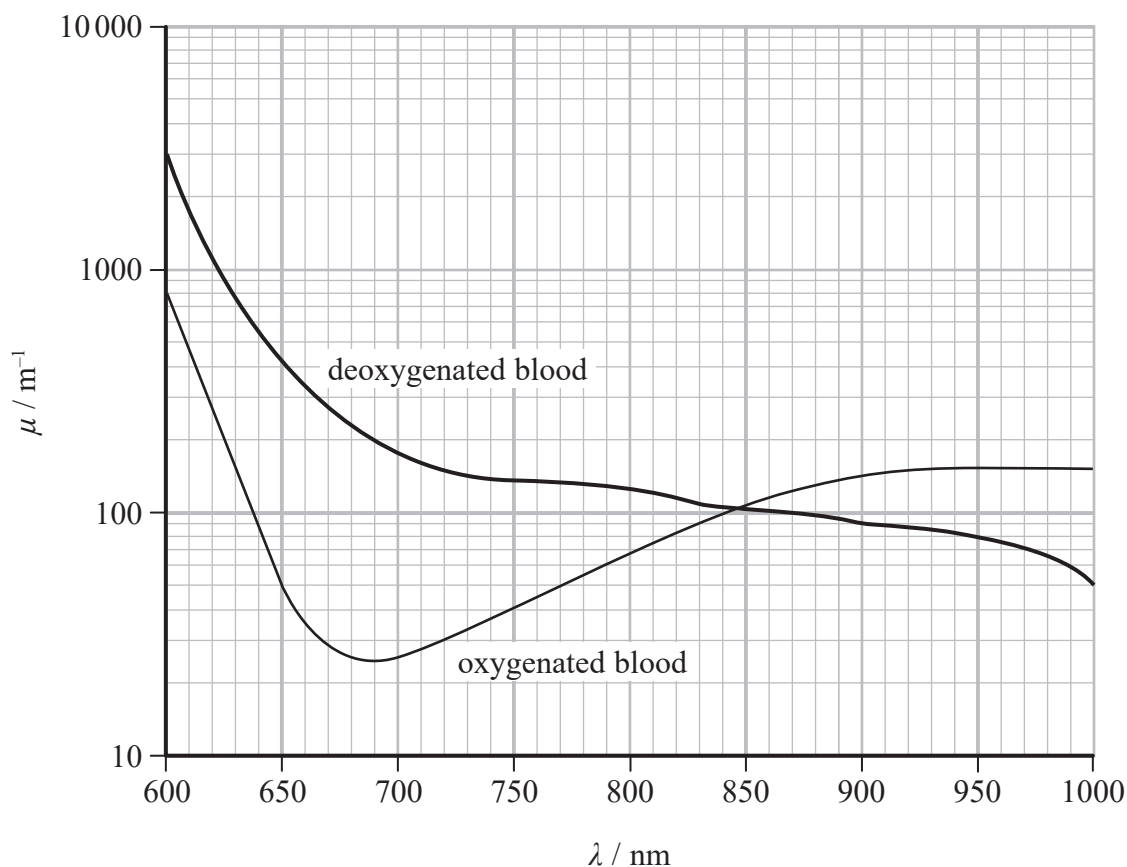
The intensity  $I$  of electromagnetic radiation received by the detector, after passing through a thickness  $x$  of blood, is given by

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

where  $I_0$  is the intensity that would have been received if the blood were not present and  $\mu$  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  $\mu$  varies with wavelength  $\lambda$  for oxygenated blood and deoxygenated blood.



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

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

(3)

$I = \dots\dots\dots$

(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)

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)

(Total for Question 5 = 9 marks)



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  $7.59 \text{ km s}^{-1}$ .

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)

.....

.....

.....

.....

.....

.....

.....

(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 =  $11\,600 \text{ kg}$

(2)

.....

.....

.....

.....

.....

.....

.....

Increase in gravitational potential energy = .....



(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)

.....

.....

.....

.....

.....

.....

.....

.....

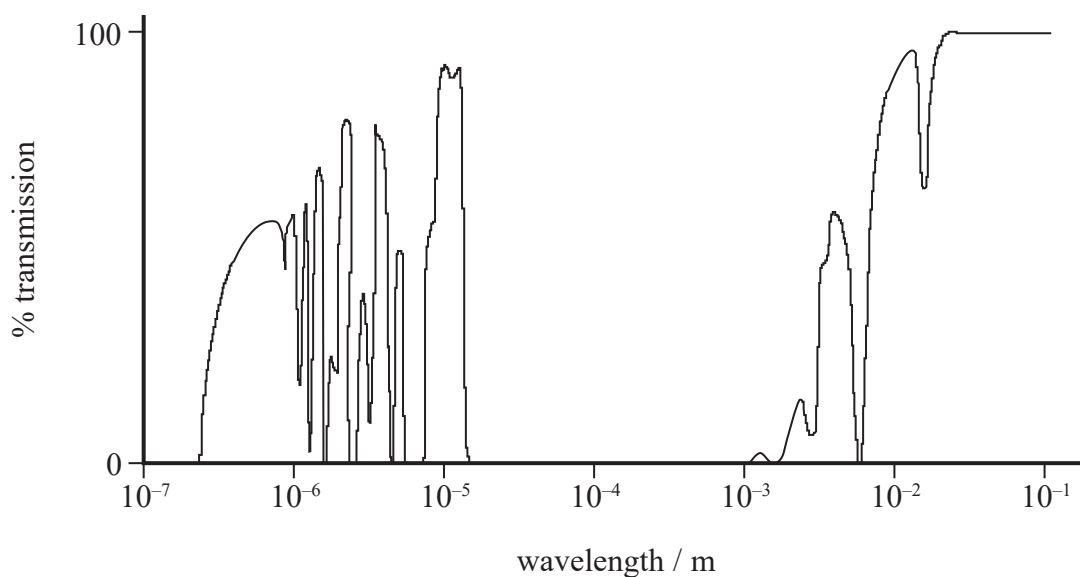
.....

.....

.....

.....

(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)

.....

.....

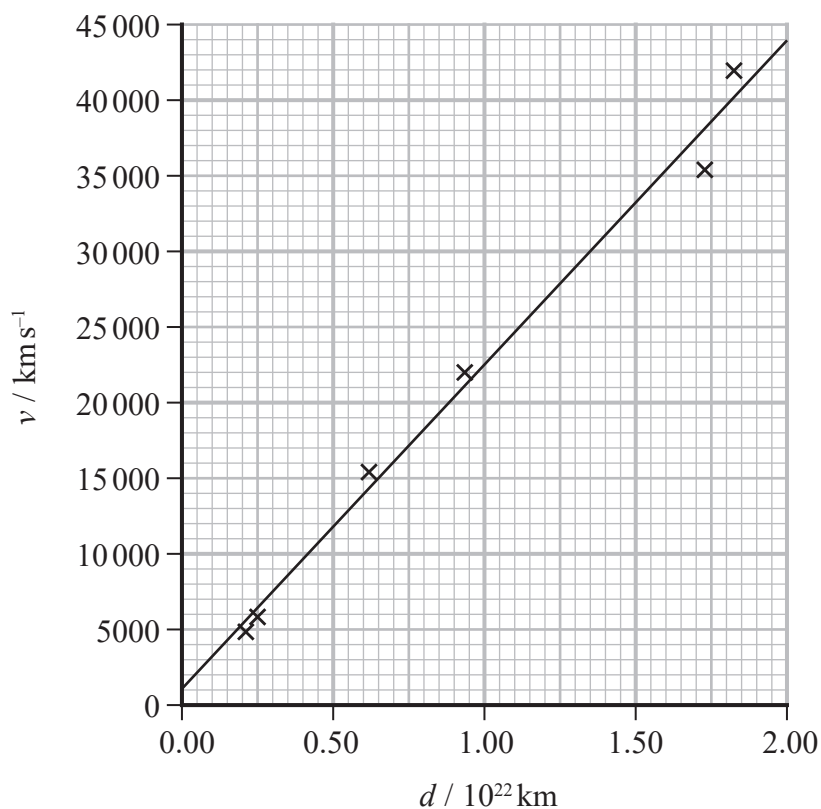
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



(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)

.....

.....

.....

.....

.....

.....

.....

Age for the universe = .....

**(Total for Question 6 = 13 marks)**





DO NOT WRITE IN THIS AREA

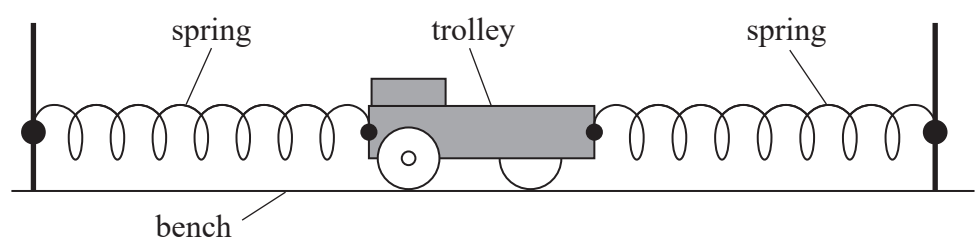
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**BLANK PAGE**



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)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

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

(3)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

- (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)

.....

.....

.....

.....

- (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)

.....

.....

.....

.....

.....

.....

.....

**(Total for Question 7 = 13 marks)**



- 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.



commons.wikimedia.org

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

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

(4)

.....

.....

.....

.....

.....

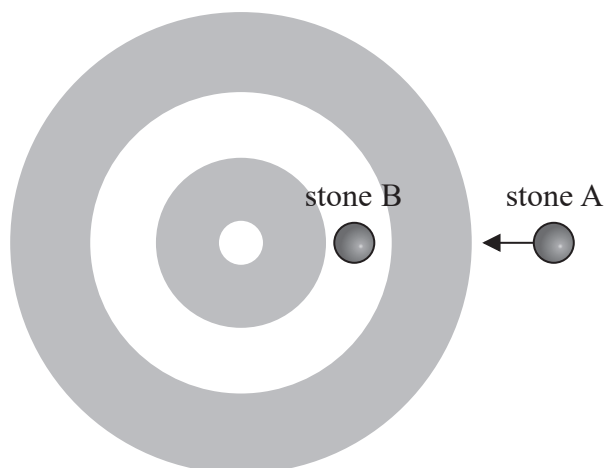
.....

.....

.....

Average power = .....

- \*(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  $m$ .



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)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(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)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

**(Total for Question 8 = 12 marks)**

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



- 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)

.....

.....

.....

.....

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

| $v / \text{m s}^{-1}$ | $B$ |  |  |
|-----------------------|-----|--|--|
| 2.00                  | 1   |  |  |
| 10.0                  | 3   |  |  |
| 21.5                  | 5   |  |  |
| 36.0                  | 7   |  |  |
| 50.5                  | 9   |  |  |
| 68.0                  | 11  |  |  |

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

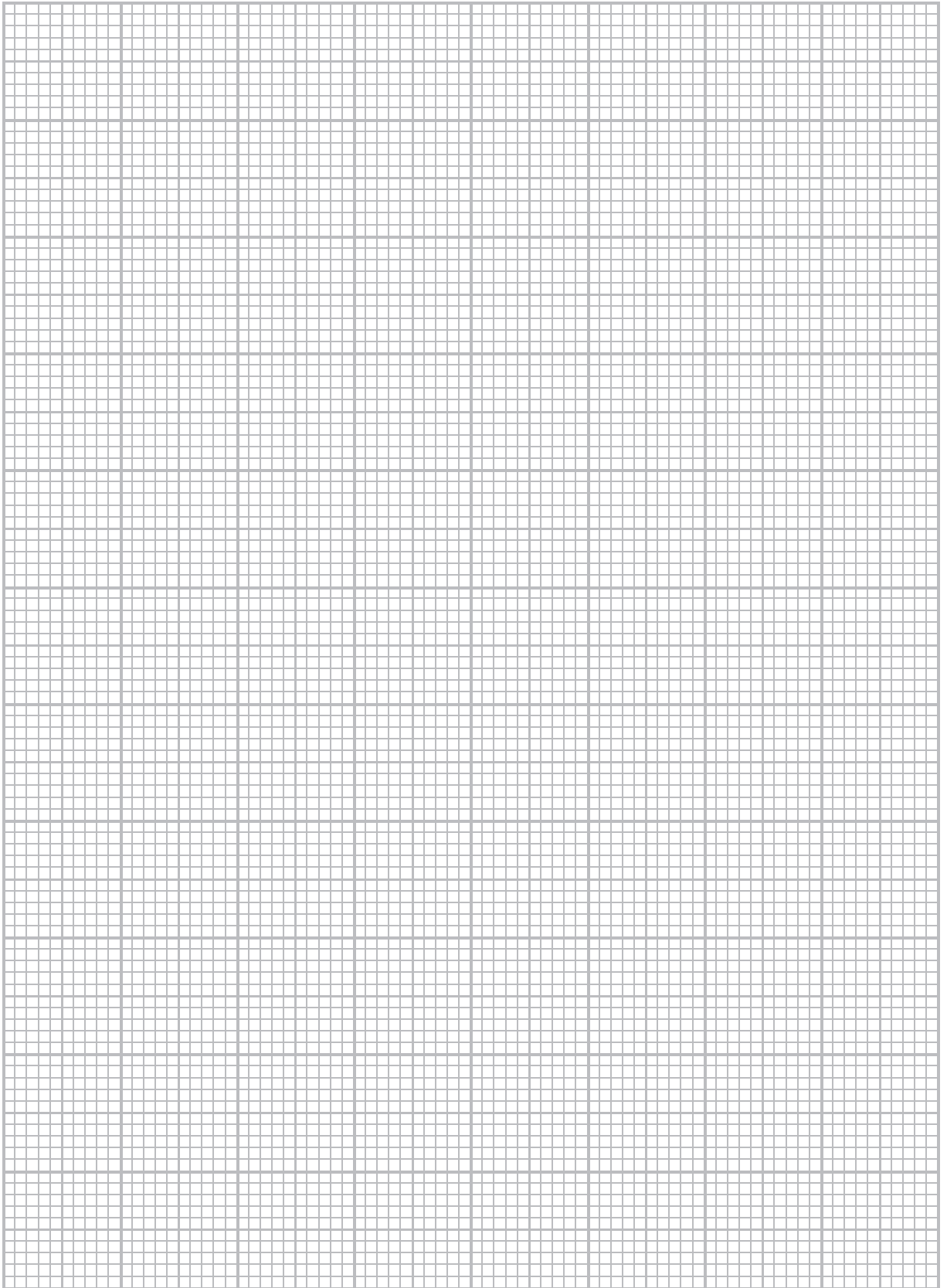
(5)



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



(ii) Determine the values of  $p$  and  $k$ .

(3)

$p =$  .....

$k =$  .....

**(Total for Question 9 = 10 marks)**

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA





DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**BLANK PAGE**



P 5 8 3 5 9 A 0 2 5 4 0

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

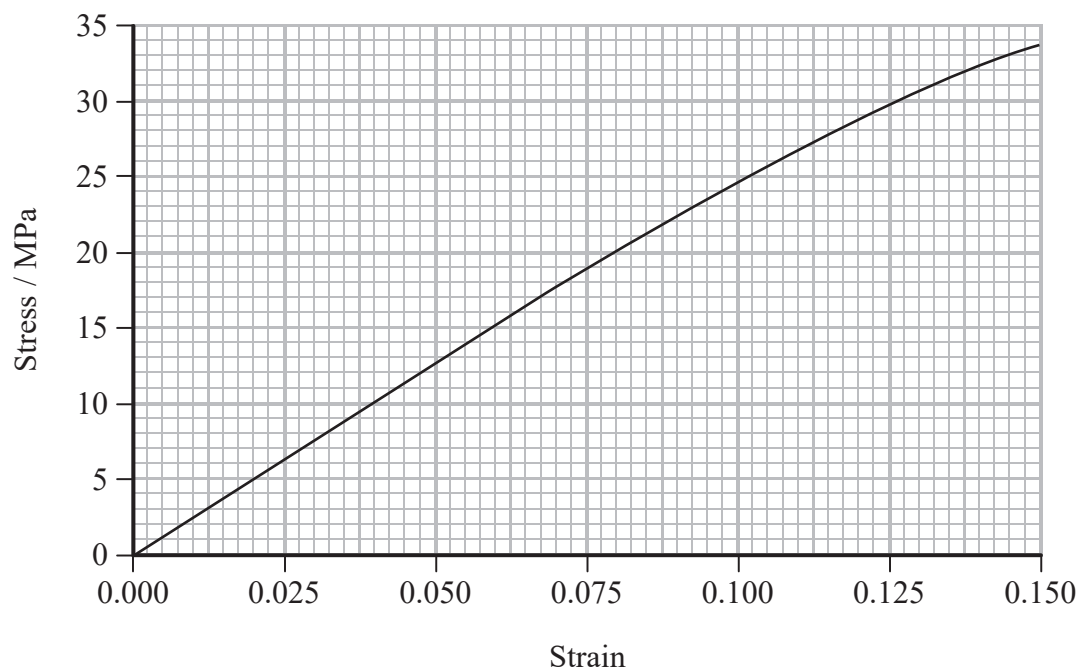
A crash-test dummy in the driving seat is wearing a seat belt made from polyester webbing. The seat belt has a cross-sectional area of  $0.85 \text{ cm}^2$  and a total length of  $2.0 \text{ m}$ . A student suggests that in the collision the seat belt absorbs all the kinetic energy of the dummy.

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

mass of dummy =  $75 \text{ kg}$

(3)

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



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

(2)

.....

.....

.....

.....

(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)

.....

.....

.....

.....

.....

.....

**(Total for Question 10 = 8 marks)**

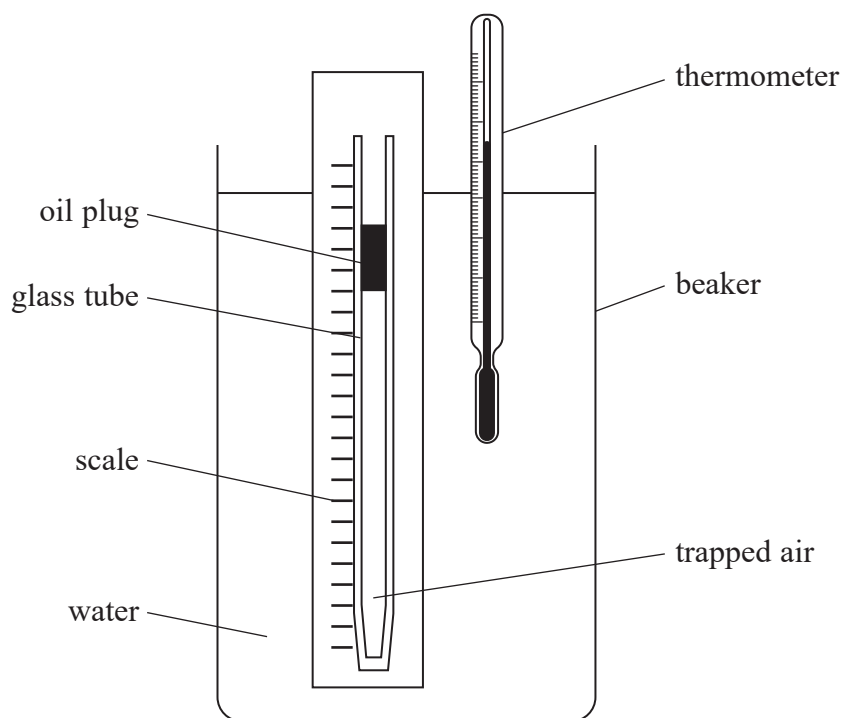
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



- 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  $\theta$ . The corresponding value of  $l$  was measured. This was repeated for a range of temperatures.

The thermometer had a resolution of  $0.5^\circ\text{C}$ . The scale had mm divisions.

The student's results are shown in the table.

| $\theta / ^\circ\text{C}$ | $l / \text{cm}$ |
|---------------------------|-----------------|
| 24                        | 8.8             |
| 60                        | 9.8             |
| 78.5                      | 10.3            |
| 95.5                      | 10.9            |

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

(3)



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

(4)

.....

.....

.....

.....

.....

.....

.....

.....

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

(2)

.....

.....

.....

.....

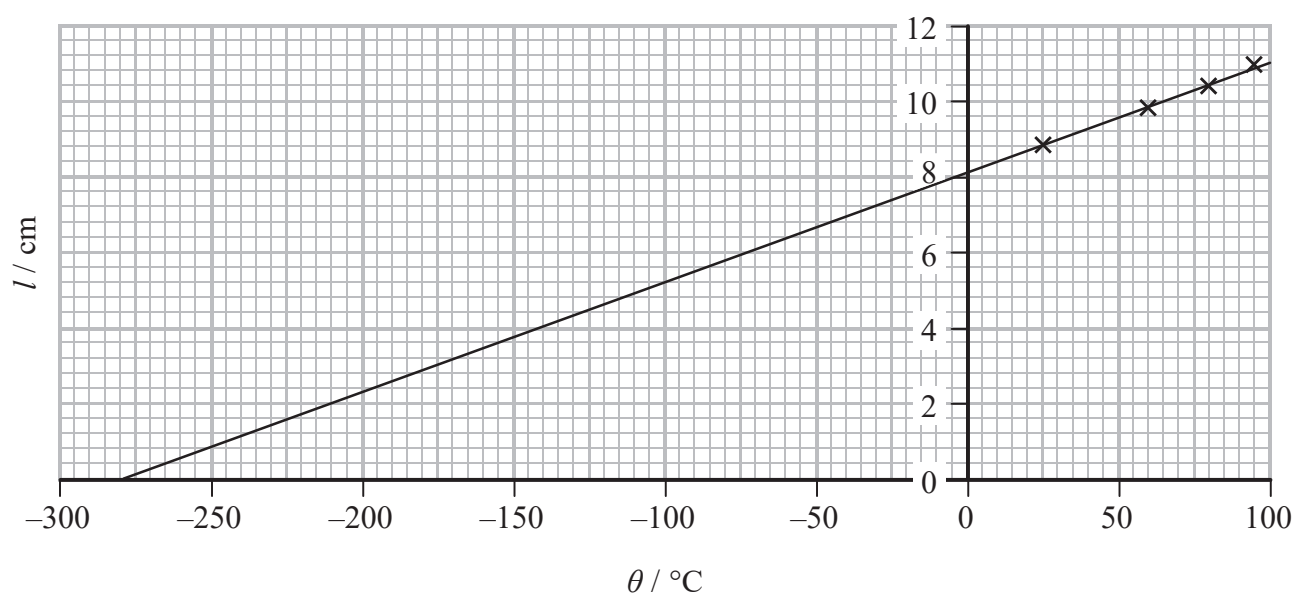
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



(b) The student plotted a graph of  $l$  against  $\theta$  as shown.



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

(3)



- (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)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

**(Total for Question 11 = 16 marks)**

---

DO NOT WRITE IN THIS AREA

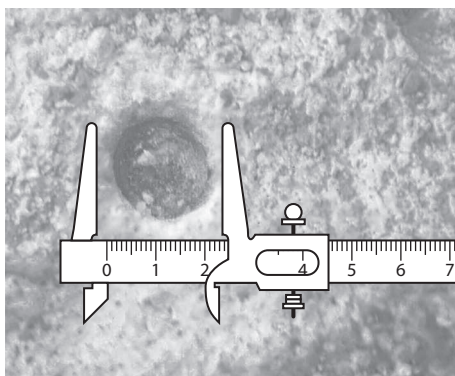
DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



- 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)

Factor = .....

- \*(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                  |





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)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

---

**(Total for Question 12 = 9 marks)**

---

**TOTAL FOR PAPER = 120 MARKS**

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**BLANK PAGE**



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**BLANK PAGE**



DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

**BLANK PAGE**



### 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         | $k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$ |                            |
| 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   | $\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$                           |                            |
| 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

#### Work, energy and power

##### 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

$$p = mv$$

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

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

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

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

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

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

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



## 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

$$F = 6\pi\eta r v$$

### 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

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

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

### 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

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

### 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

$$F = k \frac{Q_1 Q_2}{r^2}$$

$$\text{where } k = \frac{1}{4\pi\epsilon_0}$$

#### 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

$$\mathcal{E} = \frac{-d(N\phi)}{dt}$$

#### 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

$$A = \lambda N$$

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

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

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

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

## Gravitational fields

### Gravitational force

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

### Gravitational field strength

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

### Gravitational potential

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

## 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

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

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

