FOR OFFICIAL USE

National Qualifications 2016

Mark

X757/77/01 Physics

TUESDAY, 24 MAY

9:00 AM – 11:30 AM

* X 7 5 7 7 7 0 1 *

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Number of seat

Date of birth

Day Month Year

Scottish candidate number

Total marks — 140

Attempt ALL questions.

Reference may be made to the Physics Relationships Sheet X757/77/11 and the Data Sheet on *Page 02*.

Write your answers clearly in the spaces provided in this booklet. Additional space for answers and rough work is provided at the end of this booklet. If you use this space you must clearly identify the question number you are attempting. Any rough work must be written in this booklet. You should score through your rough work when you have written your final copy.

Care should be taken to give an appropriate number of significant figures in the final answers to calculations.

Use **blue** or **black** ink.

Before leaving the examination room you must give this booklet to the Invigilator; if you do not, you may lose all the marks for this paper.

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DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Gravitational acceleration on Earth	g	9·8 m s^{-2}	Mass of electron	m_e	9·11 × 10^{-31} kg
Radius of Earth	R_E	6·4 × 10^{6} m	Charge on electron	e	−1·60 × 10^{-19} C
Mass of Earth	M_E	6·0 × 10^{24} kg	Mass of neutron	m_n	1·675 × 10^{-27} kg
Mass of Moon	M_M	7·3 × 10^{22} kg	Mass of proton	m_p	1·673 × 10^{-27} kg
Radius of Moon	R_M	1·7 × 10^{6} m	Mass of alpha particle	m_α	6·645 × 10^{-27} kg
Mean Radius of Moon Orbit		3·84 × 10^{8} m	Charge on alpha particle		3·20 × 10^{-19} C
Solar radius		6·955 × 10^{8} m	Planck's constant	h	6·63 × 10^{-34} J s
Mass of Sun		2·0 × 10^{30} kg	Permittivity of free space	ε_0	8·85 × 10^{-12} F m^{-1}
1 AU		1·5 × 10^{11} m	Permeability of free space	μ_0	4π × 10^{-7} H m^{-1}
Stefan-Boltzmann constant	σ	5·67 × 10^{-8} W m^{-2} K^{-4}	Speed of light in vacuum	c	3·0 × 10^{8} m s^{-1}
Universal constant of gravitation	G	6·67 × 10^{-11} m^{3} kg^{-1} s^{-2}	Speed of sound in air	v	3·4 × 10^{2} m s^{-1}

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	*Refractive index*	*Substance*	*Refractive index*
Diamond	2·42	Glycerol	1·47
Glass	1·51	Water	1·33
Ice	1·31	Air	1·00
Perspex	1·49	Magnesium Fluoride	1·38

SPECTRAL LINES

Element	*Wavelength*/nm	*Colour*	*Element*	*Wavelength*/nm	*Colour*
Hydrogen	656	Red	Cadmium	644	Red
	486	Blue-green		509	Green
	434	Blue-violet		480	Blue
	410	Violet	*Lasers*		
	397	Ultraviolet	*Element*	*Wavelength*/nm	*Colour*
	389	Ultraviolet	Carbon dioxide	9550 } 10590 }	Infrared
Sodium	589	Yellow	Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density*/ kg m^{-3}	*Melting Point*/ K	*Boiling Point*/ K	*Specific Heat Capacity*/ J kg^{-1} K^{-1}	*Specific Latent Heat of Fusion*/ J kg^{-1}	*Specific Latent Heat of Vaporisation*/ J kg^{-1}
Aluminium	2·70 × 10^{3}	933	2623	9·02 × 10^{2}	3·95 × 10^{5}	....
Copper	8·96 × 10^{3}	1357	2853	3·86 × 10^{2}	2·05 × 10^{5}	....
Glass	2·60 × 10^{3}	1400	....	6·70 × 10^{2}	....	....
Ice	9·20 × 10^{2}	273	....	2·10 × 10^{3}	3·34 × 10^{5}	....
Glycerol	1·26 × 10^{3}	291	563	2·43 × 10^{3}	1·81 × 10^{5}	8·30 × 10^{5}
Methanol	7·91 × 10^{2}	175	338	2·52 × 10^{3}	9·9 × 10^{4}	1·12 × 10^{6}
Sea Water	1·02 × 10^{3}	264	377	3·93 × 10^{3}	....	....
Water	1·00 × 10^{3}	273	373	4·19 × 10^{3}	3·34 × 10^{5}	2·26 × 10^{6}
Air	1·29	....	....	....	....	....
Hydrogen	9·0 × 10^{-2}	14	20	1·43 × 10^{4}	....	4·50 × 10^{5}
Nitrogen	1·25	63	77	1·04 × 10^{3}	....	2·00 × 10^{5}
Oxygen	1·43	55	90	9·18 × 10^{2}	....	2·40 × 10^{4}

The gas densities refer to a temperature of 273 K and a pressure of 1·01 × 10^{5} Pa.

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Total marks — 140 marks

Attempt ALL questions

MARKS | DO NOT WRITE IN THIS MARGIN

1.

Calvin Chan/shutterstock.com

A car on a long straight track accelerates from rest. The car's run begins at time $t = 0$.

Its velocity v at time t is given by the equation

$$v = 0{\cdot}135t^2 + 1{\cdot}26t$$

where v is measured in m s^{-1} and t is measured in s.

Using **calculus** methods:

(a) determine the acceleration of the car at $t = 15{\cdot}0\,\text{s}$; **3**

Space for working and answer

(b) determine the displacement of the car from its original position at this time. **3**

Space for working and answer

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2. (a) An ideal conical pendulum consists of a mass moving with constant speed in a circular path, as shown in Figure 2A.

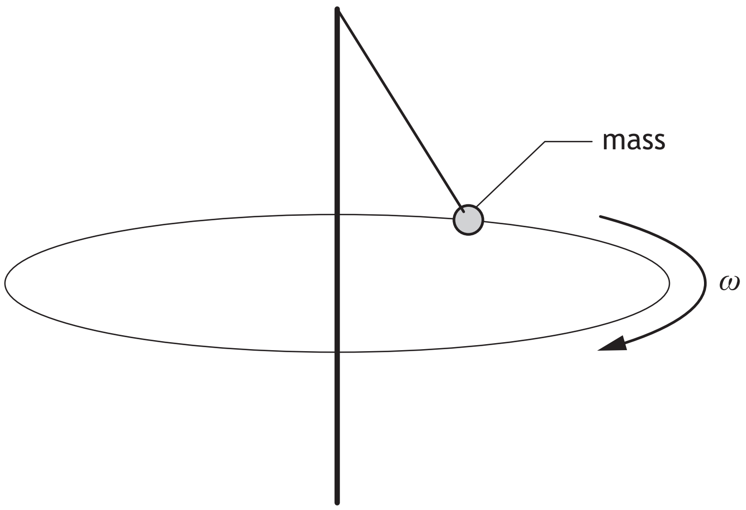


Figure 2A

(i) Explain why the mass is accelerating despite moving with constant speed. **1**

(ii) State the direction of this acceleration. **1**

(b) Swingball is a garden game in which a ball is attached to a light string connected to a vertical pole as shown in Figure 2B.

The motion of the ball can be modelled as a conical pendulum.

The ball has a mass of 0·059 kg.

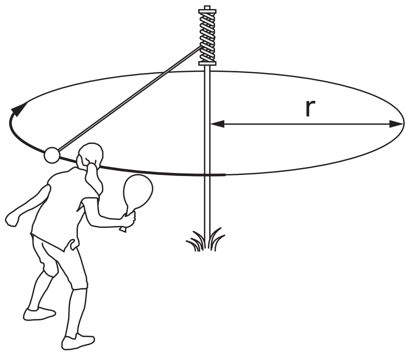


Figure 2B

(i) The ball is hit such that it moves with constant speed in a horizontal circle of radius 0·48 m.

The ball completes 1·5 revolutions in 2·69 s.

(A) Show that the angular velocity of the ball is 3·5 rad s^{-1}. **2**

Space for working and answer

(B) Calculate the magnitude of the centripetal force acting on the ball. **3**

Space for working and answer

(C) The horizontal component of the tension in the string provides this centripetal force and the vertical component balances the weight of the ball.

Calculate the magnitude of the tension in the string. **3**

Space for working and answer

(ii) The string breaks whilst the ball is at the position shown in Figure 2C.

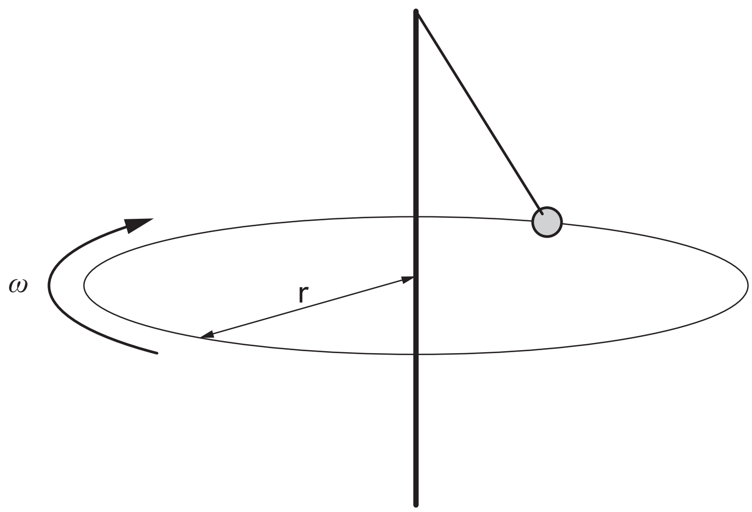


Figure 2C

On Figure 2C, draw the direction of the ball's velocity **immediately** after the string breaks. **1**

(An additional diagram, if required, can be found on *Page 39*.)

3. A spacecraft is orbiting a comet as shown in Figure 3.

The comet can be considered as a sphere with a radius of $2{\cdot}1 \times 10^3$ m and a mass of $9{\cdot}5 \times 10^{12}$ kg.

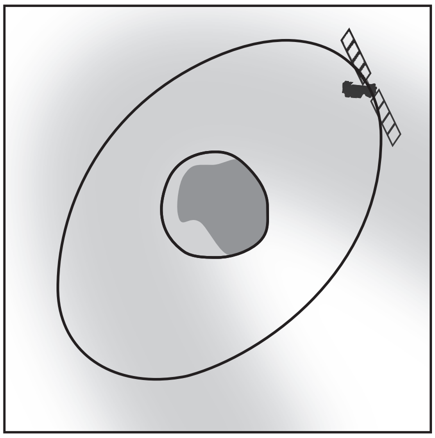


Figure 3 (not to scale)

(a) A lander was released by the spacecraft to land on the surface of the comet. After impact with the comet, the lander bounced back from the surface with an initial upward vertical velocity of $0{\cdot}38\,\mathrm{m\,s^{-1}}$.

By calculating the escape velocity of the comet, show that the lander returned to the surface for a second time. **4**

Space for working and answer

[Turn over

3. (continued)

(b) (i) Show that the gravitational field strength at the surface of the comet is $1{\cdot}4 \times 10^{-4}\,\mathrm{N\,kg^{-1}}$. **3**

Space for working and answer

(ii) Using the data from the space mission, a student tries to calculate the maximum height reached by the lander after its first bounce.

The student's working is shown below

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

$$0 = 0{\cdot}38^2 + 2 \times \left(-1{\cdot}4 \times 10^{-4}\right) \times s$$

$$s = 515{\cdot}7\,\mathrm{m}$$

The actual maximum height reached by the lander was **not** as calculated by the student.

State whether the actual maximum height reached would be greater or smaller than calculated by the student.

You must justify your answer. **3**

4. Epsilon Eridani is a star $9{\cdot}94 \times 10^{16}$ m from Earth. It has a diameter of $1{\cdot}02 \times 10^{9}$ m. The apparent brightness of Epsilon Eridani is measured on Earth to be $1{\cdot}05 \times 10^{-9}\,\mathrm{W\,m^{-2}}$.

(a) Calculate the luminosity of Epsilon Eridani. **3**

Space for working and answer

(b) Calculate the surface temperature of Epsilon Eridani. **3**

Space for working and answer

(c) State an assumption made in your calculation in (b). **1**

5. Einstein's theory of general relativity can be used to describe the motion of objects in non-inertial frames of reference. The equivalence principle is a key assumption of general relativity.

(a) Explain what is meant by the terms:

(i) *non-inertial frames of reference*; **1**

(ii) *the equivalence principle*. **1**

(b) Two astronauts are on board a spacecraft in deep space far away from any large masses. When the spacecraft is accelerating one astronaut throws a ball towards the other.

(i) On Figure 5A sketch the path that the ball would follow in the astronauts' frame of reference. **1**

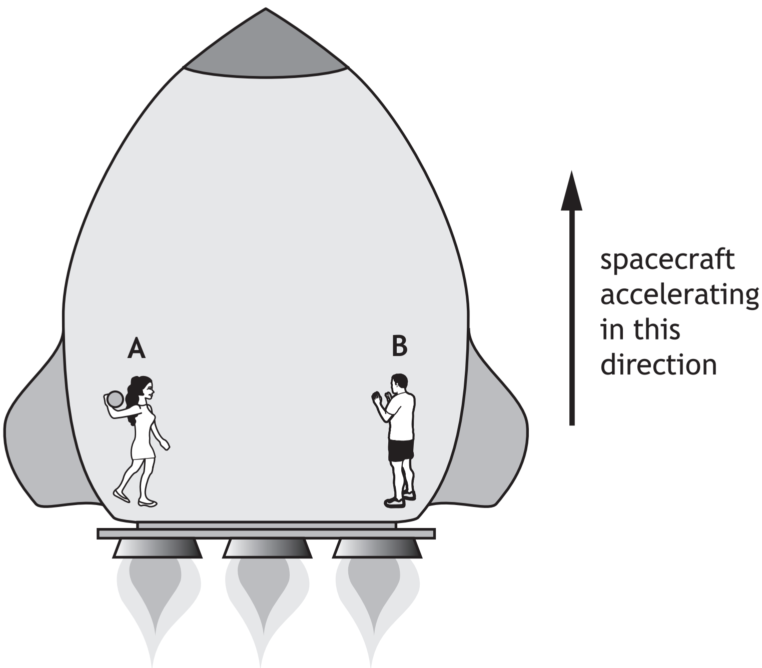


Figure 5A

(An additional diagram, if required, can be found on *Page 39*.)

5. (b) (continued)

(ii) The experiment is repeated when the spacecraft is travelling at constant speed.

On Figure 5B sketch the path that the ball would follow in the astronauts' frame of reference. **1**

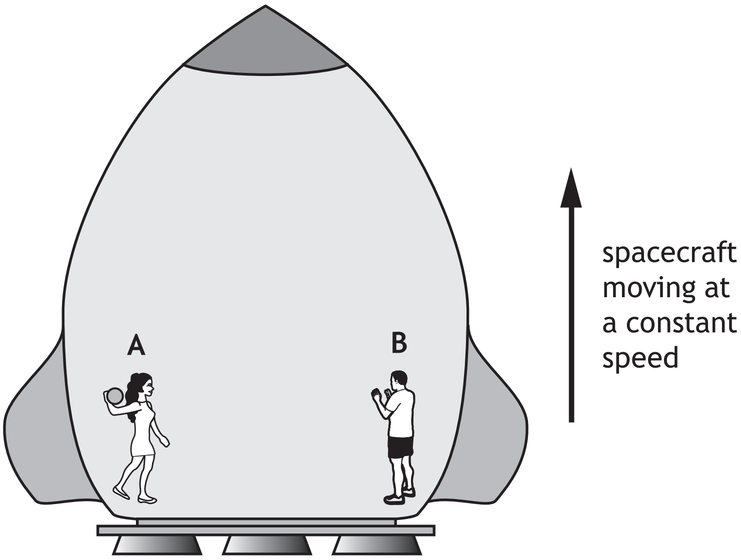


Figure 5B

(An additional diagram, if required, can be found on *Page 40*.)

(c) A clock is on the surface of the Earth and an identical clock is on board a spacecraft which is accelerating in deep space at $8\,m\,s^{-2}$.

State which clock runs slower.

Justify your answer in terms of the equivalence principle. **2**

[Turn over

6. A student makes the following statement.

"Quantum theory — I don't understand it. I don't really know what it is. I believe that classical physics can explain everything."

Use your knowledge of physics to comment on the statement. **3**

7. (a) The Earth can be modelled as a black body radiator.

The average surface temperature of the Earth can be estimated using the relationship

$$T = \frac{b}{\lambda_{\text{peak}}}$$

where

T is the average surface temperature of the Earth in kelvin;

b is Wien's Displacement Constant equal to $2{\cdot}89 \times 10^{-3}$ K m;

λ_{peak} is the peak wavelength of the radiation emitted by a black body radiator.

The average surface temperature of Earth is 15 °C.

(i) Estimate the peak wavelength of the radiation emitted by Earth. **3**

Space for working and answer

(ii) To which part of the electromagnetic spectrum does this peak wavelength correspond? **1**

[Turn over

7. **(continued)** **MARKS** DO NOT WRITE IN THIS MARGIN

(b) In order to investigate the properties of black body radiators a student makes measurements from the spectra produced by a filament lamp. Measurements are made when the lamp is operated at its rated voltage and when it is operated at a lower voltage.

The filament lamp can be considered to be a black body radiator.

A graph of the results obtained is shown in Figure 7.

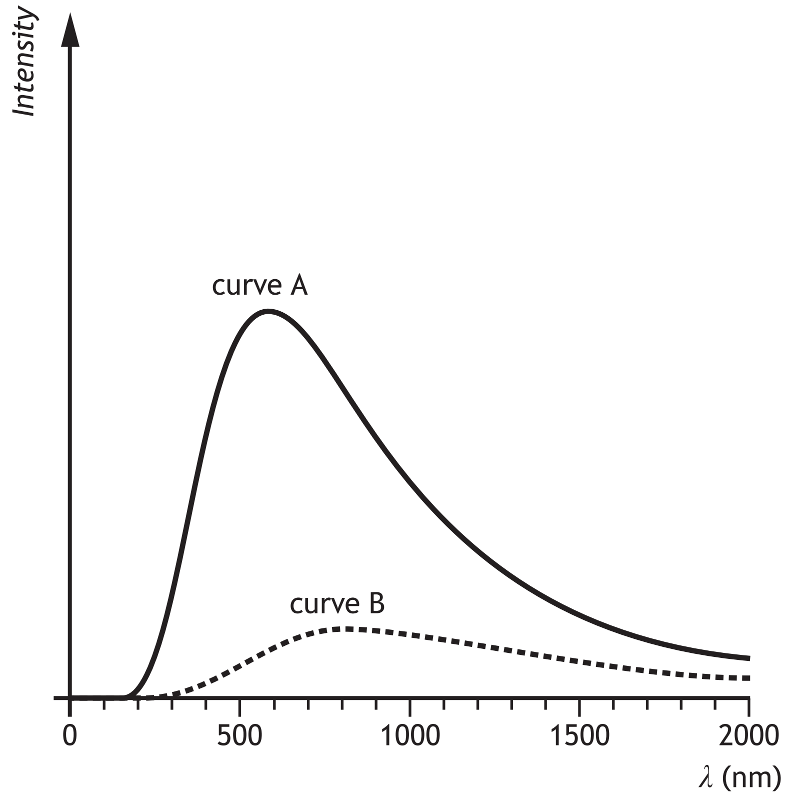


Figure 7

(i) State which curve corresponds to the radiation emitted when the filament lamp is operating at its rated voltage.

You must justify your answer. **2**

(ii) The shape of the curves on the graph on Figure 7 is not as predicted by classical physics.

On Figure 7, sketch a curve to show the result predicted by classical physics. **1**

(An additional graph, if required, can be found on *Page 40*.)

* X 7 5 7 7 7 0 1 1 4 *

8. Werner Heisenberg is considered to be one of the pioneers of quantum mechanics.

He is most famous for his uncertainty principle which can be expressed in the equation

$$\Delta x \Delta p_x \geq \frac{h}{4\pi}$$

(a) (i) State what quantity is represented by the term Δp_x. **1**

(ii) Explain the implications of the Heisenberg uncertainty principle for experimental measurements. **1**

[Turn over

MARKS

DO NOT WRITE IN THIS MARGIN

(b) In an experiment to investigate the nature of particles, individual electrons were fired one at a time from an electron gun through a narrow double slit. The position where each electron struck the detector was recorded and displayed on a computer screen.

The experiment continued until a clear pattern emerged on the screen as shown in Figure 8.

The momentum of each electron at the double slit is $6{\cdot}5 \times 10^{-24}\,\mathrm{kg\,m\,s^{-1}}$.

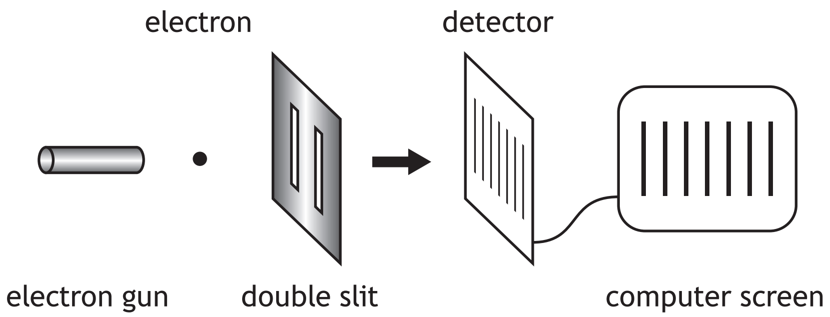


Figure 8 not to scale

(i) The experimenter had three different double slits with slit separations $0{\cdot}1\,\mathrm{mm}$, $0{\cdot}1\,\mu\mathrm{m}$ and $0{\cdot}1\,\mathrm{nm}$.

State which double slit was used to produce the image on the screen.

You must justify your answer by calculation of the de Broglie wavelength. **4**

Space for working and answer

8. (b) (continued)

(ii) The uncertainty in the momentum of an electron at the double slit is $6{\cdot}5 \times 10^{-26}\,\text{kg m s}^{-1}$.

Calculate the minimum absolute uncertainty in the position of the electron. **3**

Space for working and answer

(iii) Explain fully how the experimental result shown in Figure 8 can be interpreted. **3**

[Turn over

9. A particle with charge q and mass m is travelling with constant speed v. The particle enters a uniform magnetic field at 90° and is forced to move in a circle of radius r as shown in Figure 9.

The magnetic induction of the field is B.

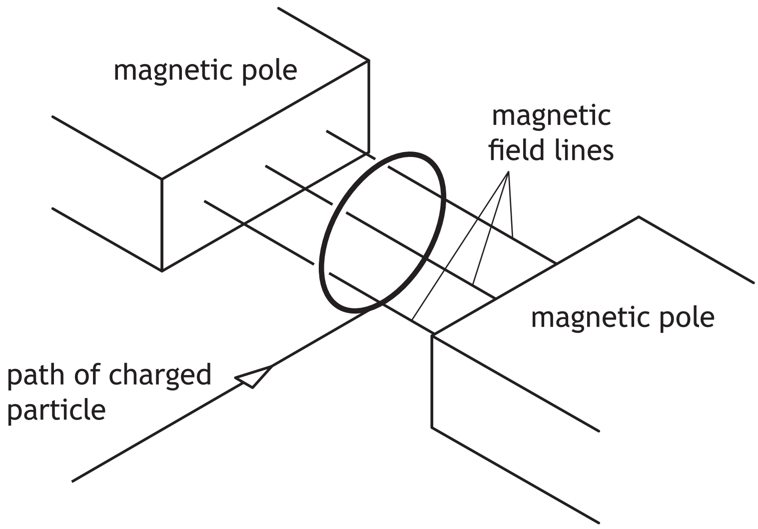


Figure 9

(a) Show that the radius of the circular path of the particle is given by

$$r = \frac{mv}{Bq}$$

2

9. **(continued)**

MARKS DO NOT WRITE IN THIS MARGIN

(b) In an experimental nuclear reactor, charged particles are contained in a magnetic field. One such particle is a deuteron consisting of one proton and one neutron.

The kinetic energy of each deuteron is 1·50 MeV.

The mass of the deuteron is $3{\cdot}34 \times 10^{-27}$ kg.

Relativistic effects can be ignored.

(i) Calculate the speed of the deuteron. **4**

Space for working and answer

(ii) Calculate the magnetic induction required to keep the deuteron moving in a circular path of radius 2·50 m. **2**

Space for working and answer

[Turn over

* X 7 5 7 7 7 0 1 1 9 *

(iii) Deuterons are fused together in the reactor to produce isotopes of helium.

$^{3}_{2}He$ nuclei, each comprising 2 protons and 1 neutron, are present in the reactor.

A $^{3}_{2}He$ nucleus also moves in a circular path in the same magnetic field.

The $^{3}_{2}He$ nucleus moves at the same speed as the deuteron.

State whether the radius of the circular path of the $^{3}_{2}He$ nucleus is greater than, equal to or less than 2·50 m.

You must justify your answer. **2**

10. (a) (i) State what is meant by *simple harmonic motion*. **1**

(ii) The displacement of an oscillating object can be described by the expression

$$y = A\cos\omega t$$

where the symbols have their usual meaning.

Show that this expression is a solution to the equation

$$\frac{d^2y}{dt^2} + \omega^2 y = 0$$

2

[Turn over

(b) A mass of 1·5 kg is suspended from a spring of negligible mass as shown in Figure 10. The mass is displaced downwards 0·040 m from its equilibrium position.

The mass is then released from this position and begins to oscillate. The mass completes ten oscillations in a time of 12 s.

Frictional forces can be considered to be negligible.

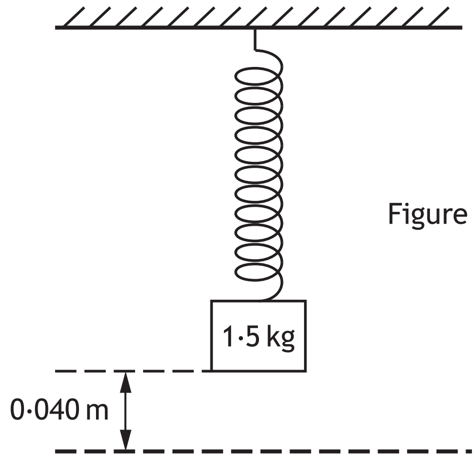


Figure 10

(i) Show that the angular frequency ω of the mass is $5{\cdot}2\ \text{rad s}^{-1}$. **3**

Space for working and answer

(ii) Calculate the maximum velocity of the mass. **3**

Space for working and answer

* X 7 5 7 7 7 0 1 2 2 *

10. (b) (continued)

(iii) Determine the potential energy stored in the spring when the mass is at its maximum displacement. **3**

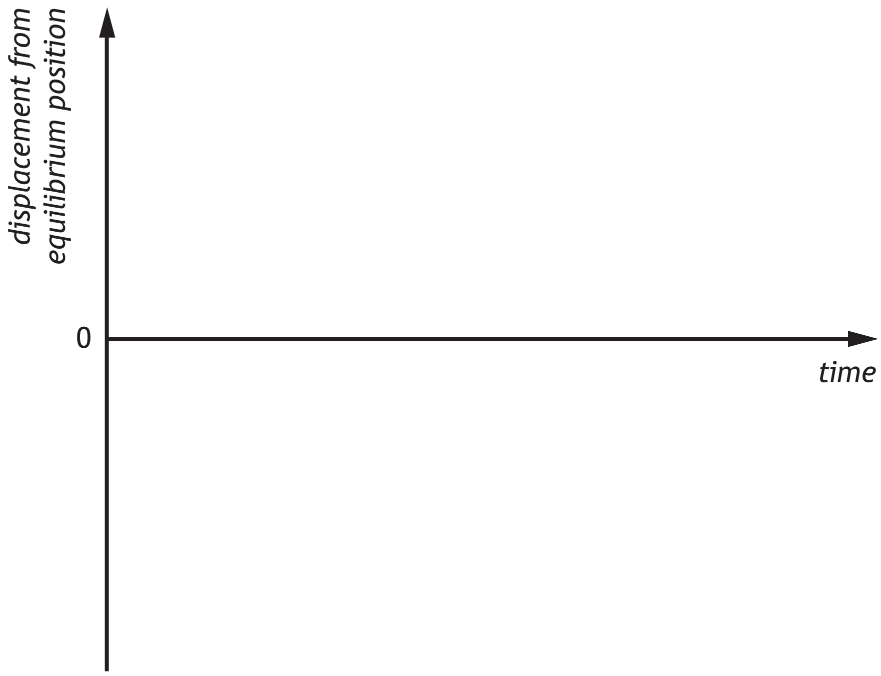
Space for working and answer

(c) The system is now modified so that a damping force acts on the oscillating mass.

(i) Describe how this modification may be achieved. **1**

(ii) Using the axes below sketch a graph showing, for the modified system, how the displacement of the mass varies with time after release.

Numerical values are **not** required on the axes. **1**



(An additional graph, if required, can be found on *Page 41*.)

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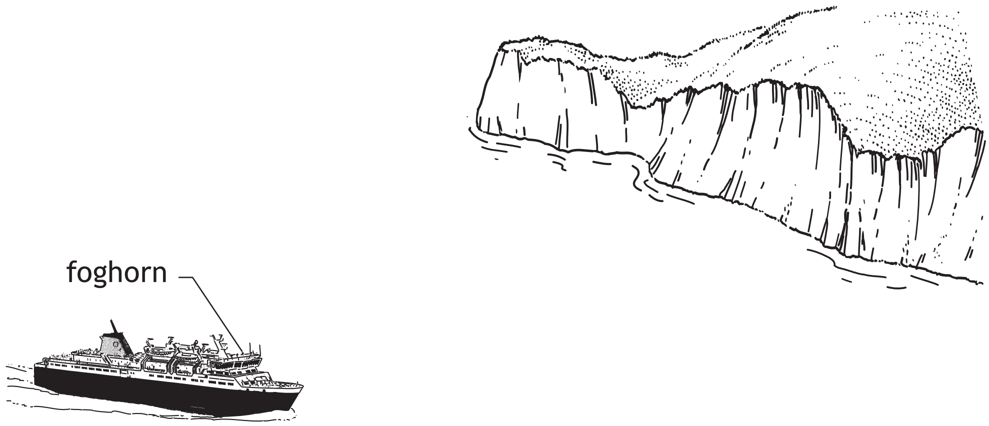
11.



A ship emits a blast of sound from its foghorn. The sound wave is described by the equation

$$y = 0 \cdot 250 \sin 2\pi (118t - 0 \cdot 357x)$$

where the symbols have their usual meaning.

(a) Determine the speed of the sound wave. **4**

Space for working and answer

11. **(continued)** **MARKS** DO NOT WRITE IN THIS MARGIN

(b) The sound from the ship's foghorn reflects from a cliff. When it reaches the ship this reflected sound has half the energy of the original sound.

Write an equation describing the reflected sound wave at this point. **4**

[Turn over

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12. Some early 3D video cameras recorded two separate images at the same time to create two almost identical movies.

Cinemas showed 3D films by projecting these two images simultaneously onto the same screen using two projectors. Each projector had a polarising filter through which the light passed as shown in Figure 12.

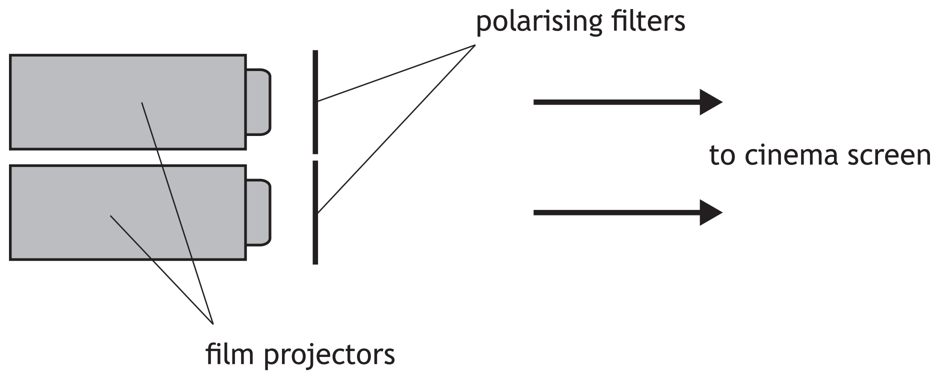

Figure 12

(a) Describe how the transmission axes of the two polarising filters should be arranged so that the two images on the screen do not interfere with each other. **1**

(b) A student watches a 3D movie using a pair of glasses which contains two polarising filters, one for each eye.

Explain how this arrangement enables a different image to be seen by each eye. **2**

12. (continued) **MARKS** DO NOT WRITE IN THIS MARGIN

(c) Before the film starts, the student looks at a ceiling lamp through one of the filters in the glasses. While looking at the lamp, the student then rotates the filter through 90°.

State what effect, if any, this rotation will have on the observed brightness of the lamp.

Justify your answer. **2**

(d) During the film, the student looks at the screen through only one of the filters in the glasses. The student then rotates the filter through 90° and does not observe any change in brightness.

Explain this observation. **1**

[Turn over

13. (a) Q_1 is a point charge of +12 nC. Point Y is 0·30 m from Q_1 as shown in Figure 13A.

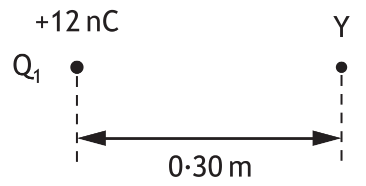

Figure 13A

Show that the electrical potential at point Y is +360 V. **2**

Space for working and answer

(b) A second point charge Q_2 is placed at a distance of 0·40 m from point Y as shown in Figure 13B . The electrical potential at point Y is now zero.

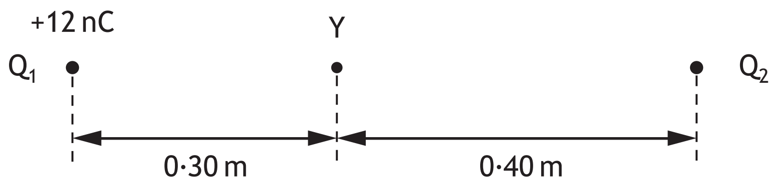

Figure 13B

(i) Determine the charge of Q_2. **3**

Space for working and answer

13. (b) (continued)

(ii) Determine the electric field strength at point Y. **4**

Space for working and answer

(iii) On Figure 13C, sketch the electric field pattern for this system of charges. **2**

Figure 13C

(An additional diagram, if required, can be found on *Page 41*)

[Turn over

14. A student measures the magnetic induction at a distance r from a long straight current carrying wire using the apparatus shown in Figure 14.

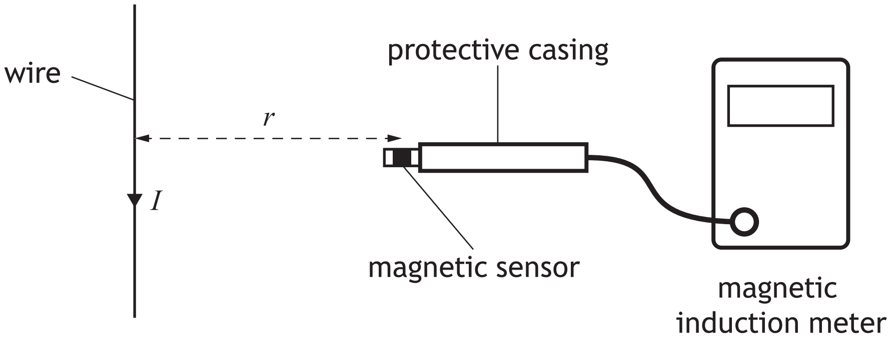

Figure 14

The following data are obtained.

Distance from wire $r = 0{\cdot}10\,\text{m}$
Magnetic induction $B = 5{\cdot}0\,\mu\text{T}$

(a) Use the data to calculate the current I in the wire. **3**

Space for working and answer

(b) The student estimates the following uncertainties in the measurements of B and r.

Uncertainties in r		Uncertainties in B	
reading	$\pm 0{\cdot}002\,\text{m}$	reading	$\pm 0{\cdot}1\,\mu\text{T}$
calibration	$\pm 0{\cdot}0005\,\text{m}$	calibration	$\pm 1{\cdot}5\%$ of reading

(i) Calculate the percentage uncertainty in the measurement of r. **1**

Space for working and answer

14. (b) (continued)

(ii) Calculate the percentage uncertainty in the measurement of B. **3**

Space for working and answer

(iii) Calculate the absolute uncertainty in the value of the current in the wire. **2**

Space for working and answer

(c) The student measures distance r, as shown in Figure 14, using a metre stick. The smallest scale division on the metre stick is 1 mm.

Suggest a reason why the student's estimate of the reading uncertainty in r is not $\pm 0{\cdot}5$ mm. **1**

[Turn over

15. A student constructs a simple air-insulated capacitor using two parallel metal plates, each of area A, separated by a distance d. The plates are separated using small insulating spacers as shown in Figure 15A.

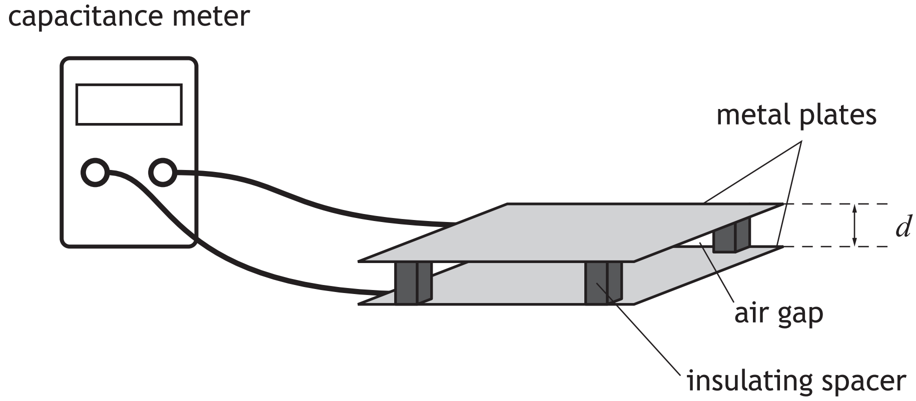

Figure 15A

The capacitance C of the capacitor is given by

$$C = \varepsilon_0 \frac{A}{d}$$

The student investigates how the capacitance depends on the separation of the plates. The student uses a capacitance meter to measure the capacitance for different plate separations. The plate separation is measured using a ruler.

The results are used to plot the graph shown in Figure 15B.

The area of each metal plate is $9{\cdot}0 \times 10^{-2}\ \mathrm{m}^2$.

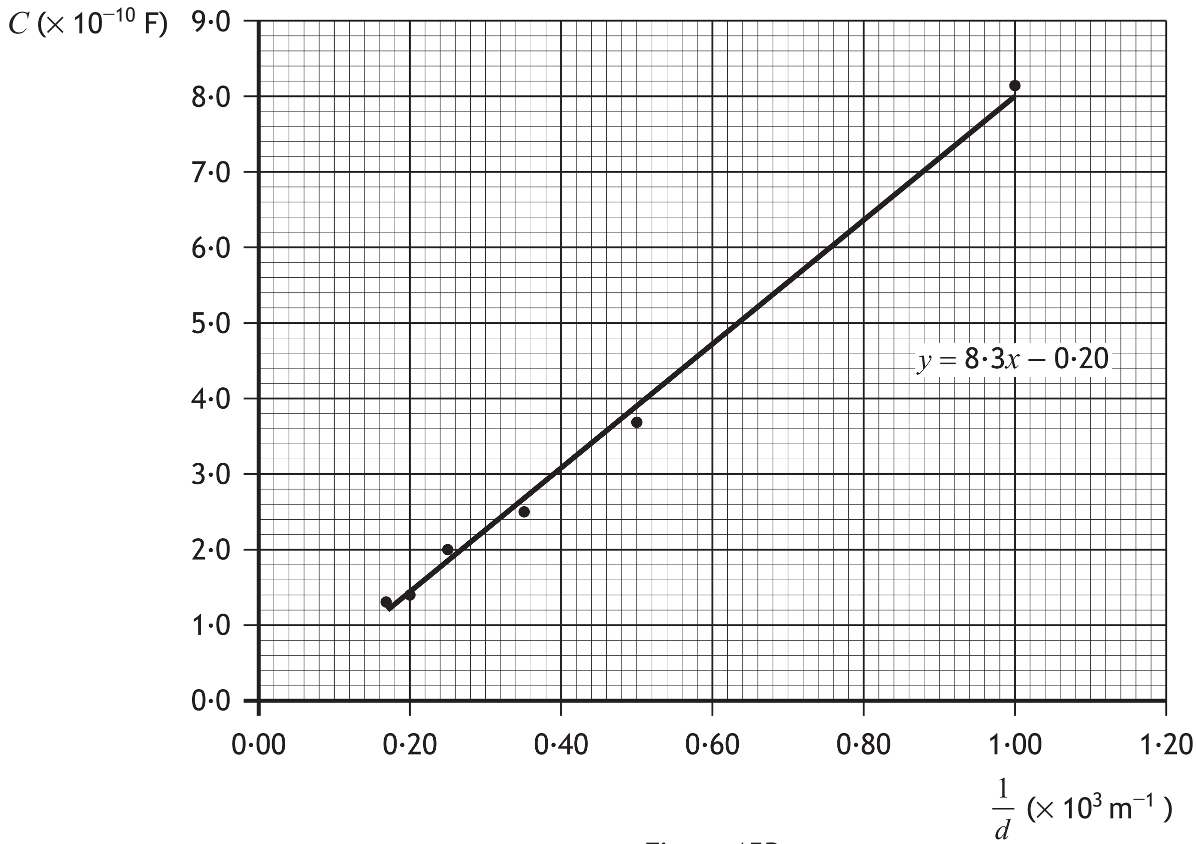

Figure 15B

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15. (continued)

(a) (i) Use information from the graph to determine a value for ε_o, the permittivity of free space. **3**

Space for working and answer

(ii) Use your calculated value for the permittivity of free space to determine a value for the speed of light in air. **3**

Space for working and answer

(b) The best fit line on the graph does not pass through the origin as theory predicts.

Suggest a reason for this. **1**

[Turn over

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16. A student uses two methods to determine the moment of inertia of a solid sphere about an axis through its centre.

(a) In the first method the student measures the mass of the sphere to be 3·8 kg and the radius to be 0·053 m.

Calculate the moment of inertia of the sphere. **3**

Space for working and answer

(b) In the second method, the student uses conservation of energy to determine the moment of inertia of the sphere.

The following equation describes the conservation of energy as the sphere rolls down the slope

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

where the symbols have their usual meanings.

The equation can be rearranged to give the following expression

$$2gh = \left(\frac{I}{mr^2} + 1\right)v^2$$

This expression is in the form of the equation of a straight line through the origin,

$$y = gradient \times x$$

[Turn over

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The student measures the height of the slope h. The student then allows the sphere to roll down the slope and measures the final speed of the sphere v at the bottom of the slope as shown in Figure 16.

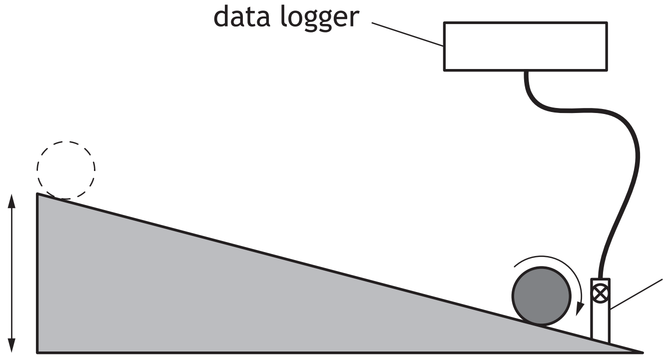

Figure 16

The following is an extract from the student's notebook.

h (m)	v ($m\,s^{-1}$)	$2gh$ ($m^2\,s^{-2}$)	v^2 ($m^2\,s^{-2}$)
0·020	0·42	0·39	0·18
0·040	0·63	0·78	0·40
0·060	0·68	1·18	0·46
0·080	0·95	1·57	0·90
0·100	1·05	1·96	1·10

$m = 3{\cdot}8\,kg$ $\qquad$ $r = 0{\cdot}053\,m$

(i) On the square-ruled paper on *Page 37*, draw a graph that would allow the student to determine the moment of inertia of the sphere. **3**

(ii) Use the gradient of your line to determine the moment of inertia of the sphere. **3**

Space for working and answer

(An additional square-ruled paper, if required, can be found on *Page 42*.)

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(c) The student states that more confidence should be placed in the value obtained for the moment of inertia in the second method.

Use your knowledge of experimental physics to comment on the student's statement. **3**

[END OF QUESTION PAPER]

ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK

Additional diagram for Question 2 (b) (ii)

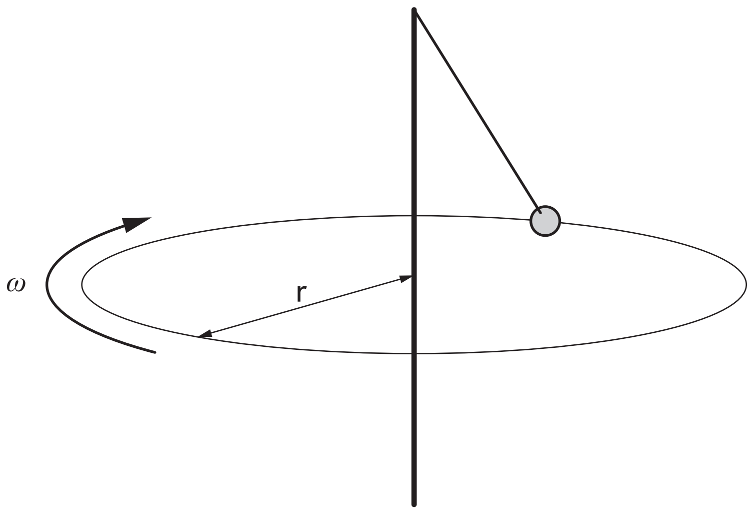


Figure 2C

Additional diagram for Question 5 (b) (i)

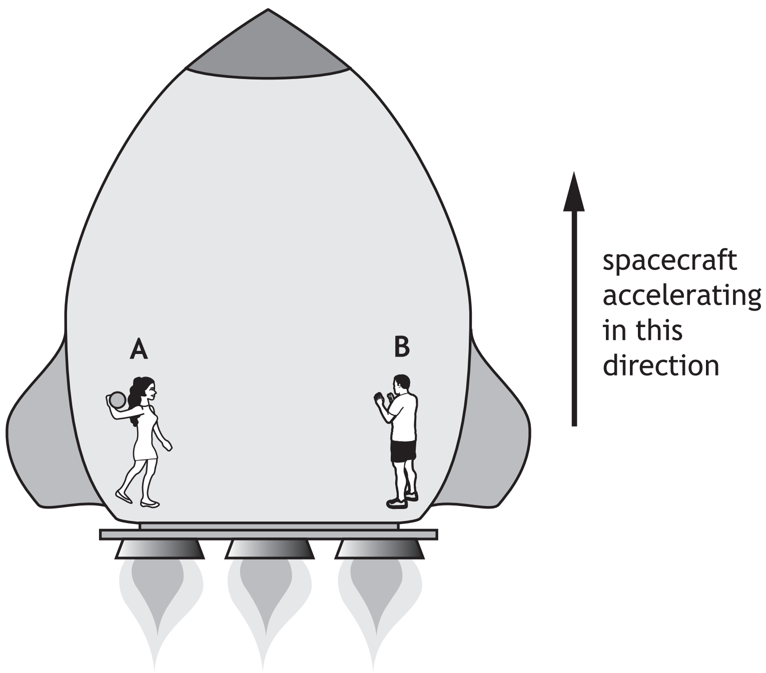


Figure 5A

ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK

Additional diagram for Question 5 (b) (ii)

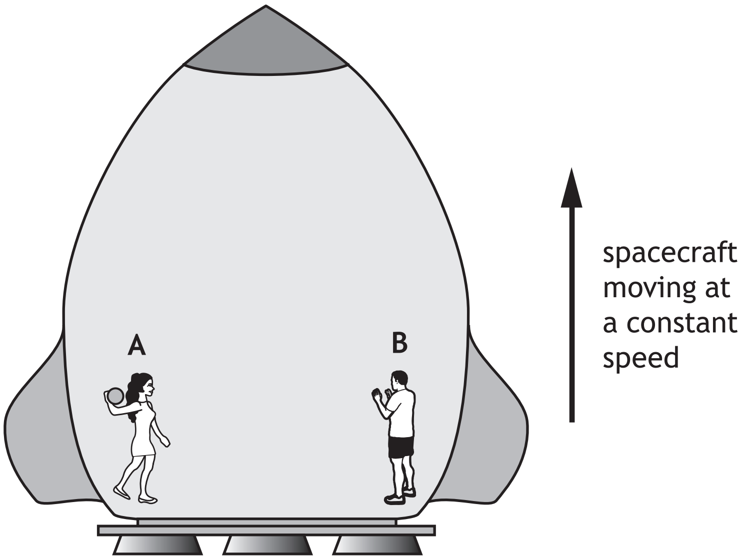


Figure 5B

Additional diagram for Question 7 (b) (ii)

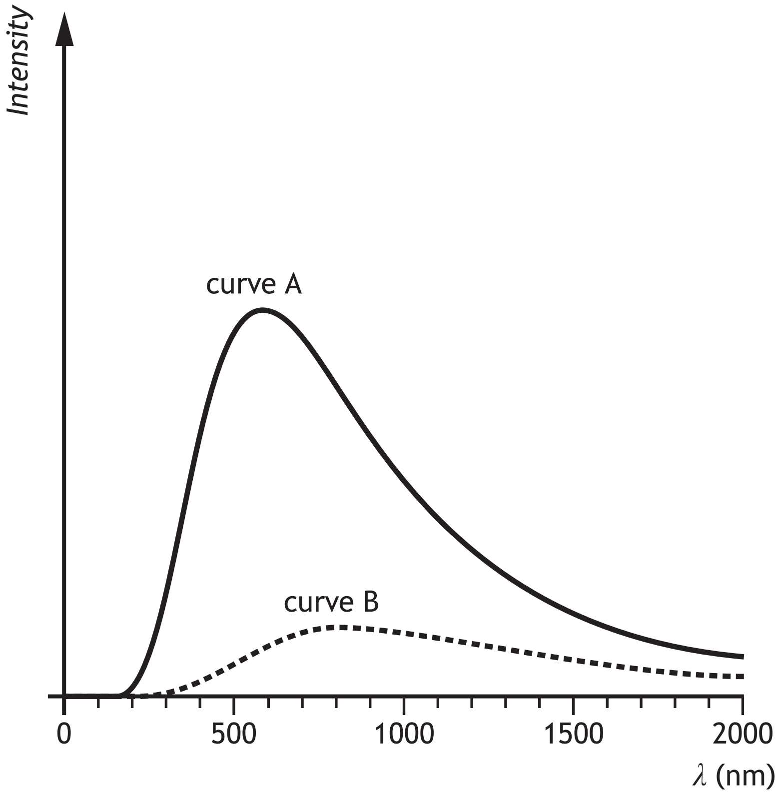
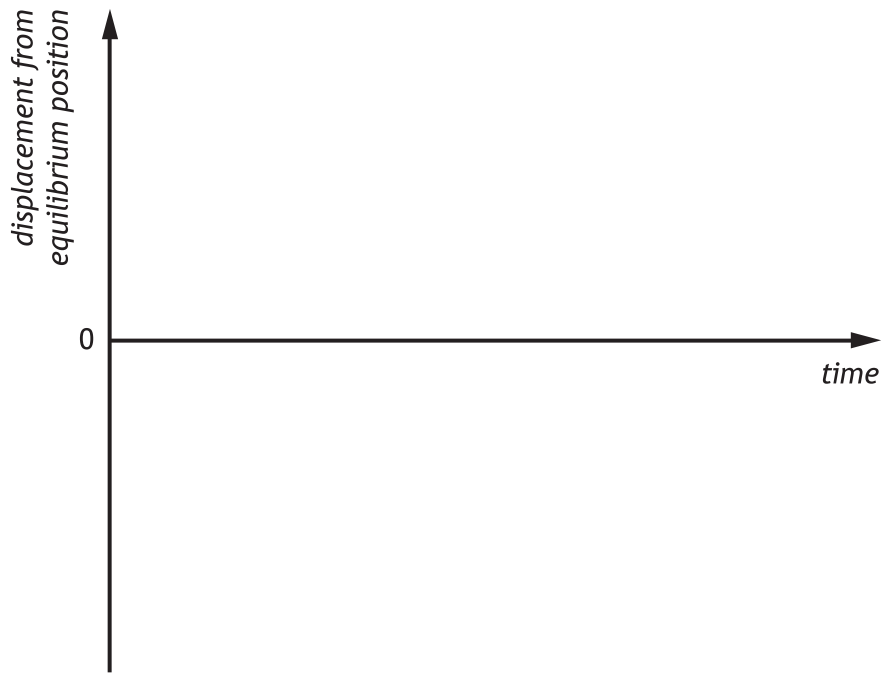


Figure 7

ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK

Additional diagram for Question 10 (c) (ii)



Additional diagram for Question 13 (b) (iii)

Figure 13C

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ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK

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ADDITIONAL SPACE FOR ANSWERS AND ROUGH WORK

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ACKNOWLEDGEMENT

Question 1 – Calvin Chan/shutterstock.com