X069/701

NATIONAL
QUALIFICATIONS
2010

FRIDAY, 28 MAY
1.00 PM – 3.30 PM

PHYSICS
ADVANCED HIGHER

Reference may be made to the Physics Data Booklet.

Answer **all** questions.

Any necessary data may be found in the Data Sheet on page two.

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

Square-ruled paper (if used) should be placed inside the front cover of the answer book for return to the Scottish Qualifications Authority.

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DATA SHEET

COMMON PHYSICAL QUANTITIES

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

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*
Hydrogen	656	Red
	486	Blue-green
	434	Blue-violet
	410	Violet
	397	Ultraviolet
	389	Ultraviolet
Sodium	589	Yellow

Element	*Wavelength*/nm	*Colour*
Cadmium	644	Red
	509	Green
	480	Blue

Lasers

Element	*Wavelength*/nm	*Colour*
Carbon dioxide	9550 } 10590 }	Infrared
Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

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

The gas densities refer to a temperature of 273 K and a pressure of $1{\cdot}01 \times 10^{5}$ Pa.

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Marks

1. A turntable, radius r, rotates with a constant angular velocity ω about an axis of rotation. Point X on the circumference of the turntable is moving with a tangential speed v, as shown in Figure 1A.

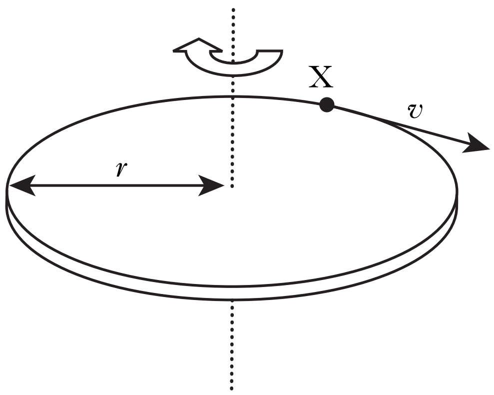

Figure 1A

(*a*) Derive the relationship

$$v = r w.$$ **2**

(*b*) Data recorded for the turntable is shown below.

Angle of rotation	(3·1 ± 0·1) rad
Time taken for angle of rotation	(4·5 ± 0·1) s
Radius of disk	(0·148 ± 0·001) m

(i) Calculate the tangential speed v. **2**

(ii) Calculate the percentage uncertainty in this value of v. **2**

(iii) As the disk rotates, v remains constant.

(A) Explain why point X is accelerating. **1**

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

(8)

Marks

2. A motorised model plane is attached to a light string anchored to a ceiling.

The plane follows a circular path of radius 0·35 m as shown in Figure 2A.

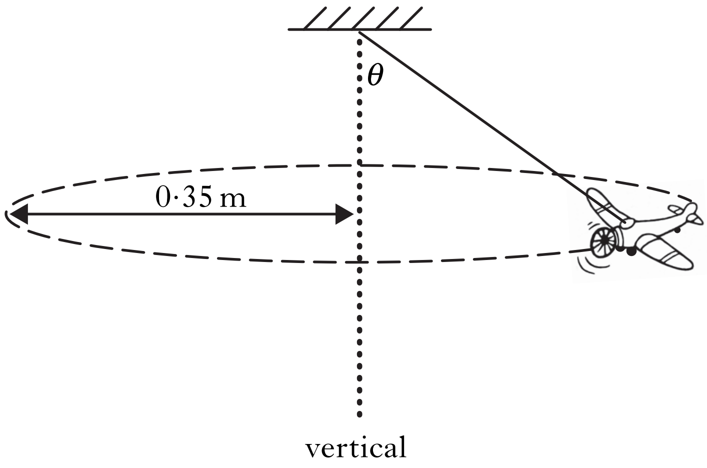

Figure 2A

The plane has a mass of 0·20 kg and moves with a constant angular velocity of 6·0 rad s^{-1}.

(*a*) Calculate the central force acting on the plane. **2**

(*b*) Calculate angle θ of the string to the vertical. **2**

(*c*) What effect would a decrease in the plane's speed have on angle θ?

Justify your answer. **2**

(6)

[Turn over

3. A mass of 2·5 kg is attached to a string of negligible mass. The string is wound round a flywheel of radius 0·14 m. A motion sensor, connected to a computer, is placed below the mass as shown in Figure 3A.

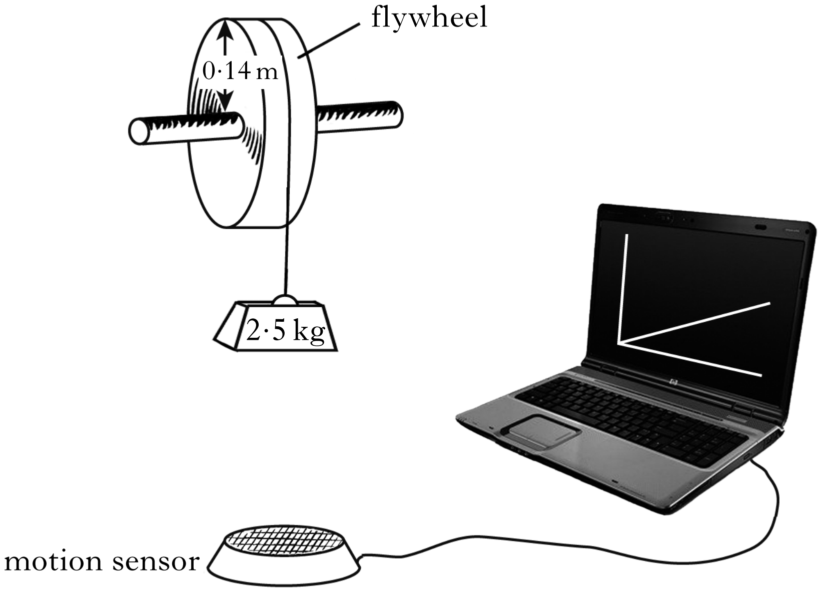

Figure 3A

The mass is released from rest. The computer calculates the linear velocity of the mass as it falls and the angular velocity of the flywheel.

The graph of the angular velocity of the flywheel against time, as displayed on the computer, is shown in Figure 3B.

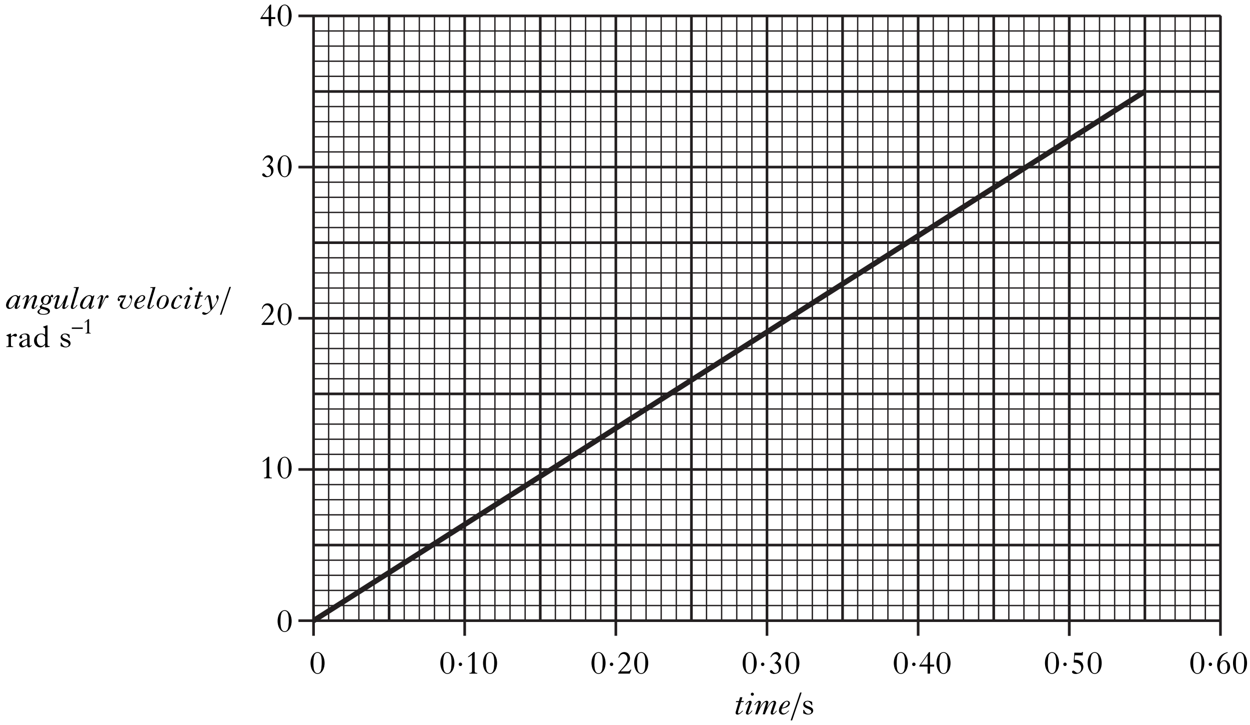

Figure 3B

Marks

3. (continued)

(*a*) Calculate the angular acceleration of the flywheel. **2**

(*b*) Show that the mass falls a distance of 1·3 m in the first 0·55 seconds. **3**

(*c*) Use the conservation of energy to calculate the moment of inertia of the flywheel. Assume the frictional force to be negligible. **4**

(9)

[Turn over

Marks

4. (*a*) State the law of conservation of angular momentum. **1**

(*b*) A student sits on a platform that is free to rotate on a frictionless bearing. The angular velocity of the rotating platform is displayed on a computer.

The student rotates with a hand outstretched at 0·60 m from the axis of rotation as shown in Figure 4A.

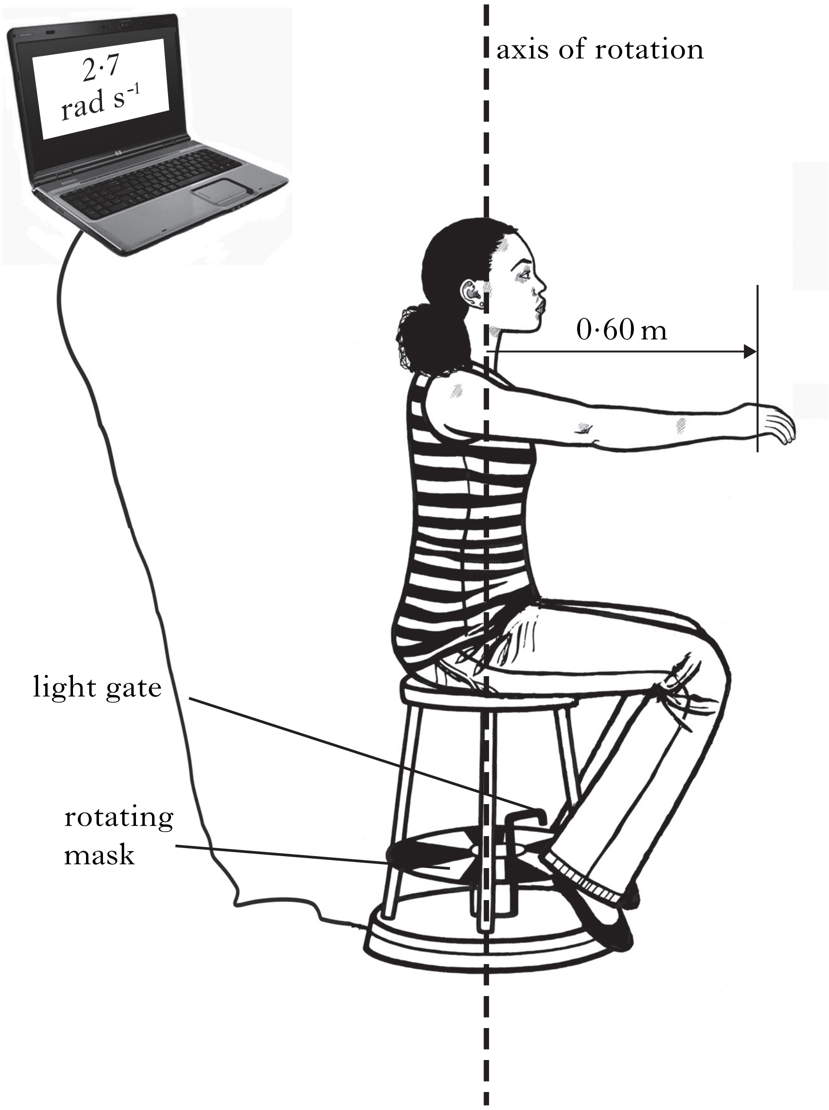

Figure 4A

The moment of inertia of the student and rotating platform is $4{\cdot}1\,\text{kg}\,\text{m}^2$. The angular velocity is $2{\cdot}7\,\text{rad}\,\text{s}^{-1}$.

(i) Calculate the angular momentum of the student and rotating platform. **2**

(ii) As the student rotates, she grasps a $2 \cdot 5$ kg mass from a stand as shown in Figure 4B.

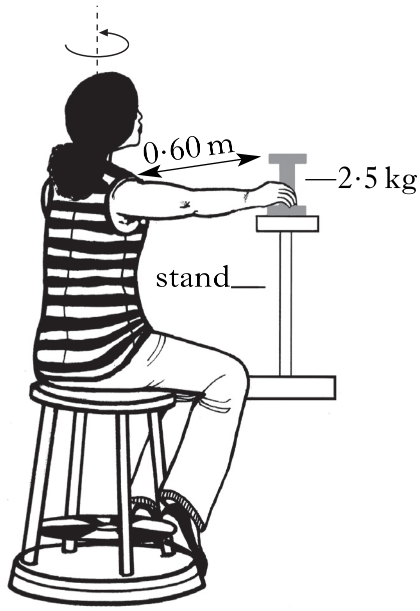

Figure 4B

Calculate the angular velocity of the student and platform just after the mass has been grasped. **3**

(iii) The student then pulls the mass towards her body.

Explain the effect this has on the angular velocity of the student and the platform. **2**

(*c*) In another investigation the student and platform rotate at $1 \cdot 5\ \text{rad s}^{-1}$. The student puts one foot on the floor as shown in Figure 4C.

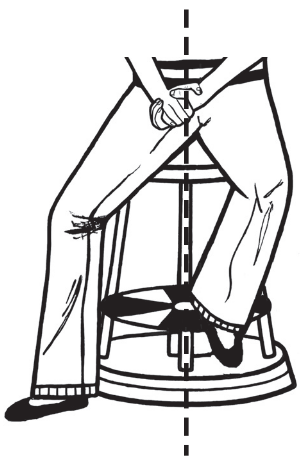

Figure 4C

The frictional force between the student's shoe and the floor brings the student and platform to rest in $0 \cdot 75$ seconds. The new moment of inertia of the student and platform is $4 \cdot 5\ \text{kg m}^2$.

Calculate the average frictional torque. **3**

(11)

5. A motorised mixer in a DIY store is used to mix different coloured paints.

Paints are placed in a tin and the tin is clamped to the base as shown in Figure 5A.

Figure 5A

The oscillation of the tin in the vertical plane closely approximates to simple harmonic motion.

The amplitude of the oscillation is 0·012 m.

The mass of the tin of paint is 1·4 kg.

Figure 5B shows the graph of the acceleration against displacement for the tin of paint.

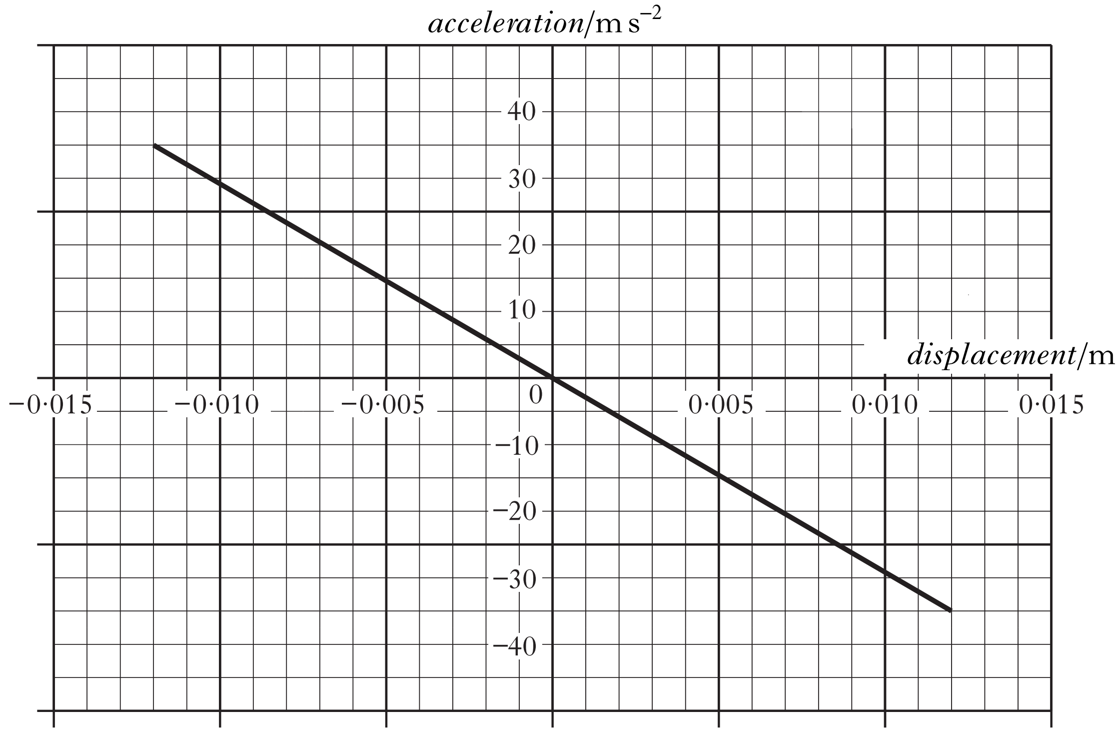

Figure 5B

Marks

5. (continued)

(*a*) Show that the angular frequency ω of the oscillation is $54\,\text{rad s}^{-1}$. **1**

(*b*) Write an expression for the displacement y of the tin as a function of time. Include appropriate numerical values. **2**

(*c*) Derive an expression for the velocity v of the tin as a function of time. Numerical values should again be included. **2**

(*d*) Calculate the maximum kinetic energy of the tin of paint as it oscillates. **2**

(7)

[Turn over

6. A hollow metal sphere, radius 1·00 mm, carries a charge of $-1{\cdot}92 \times 10^{-12}$ C.

(*a*) Calculate the electric field strength, E, at the surface of the sphere. **2**

(*b*) Four students sketch graphs of the variation of electric field strength with distance from the centre of the sphere as shown in Figure 6A.

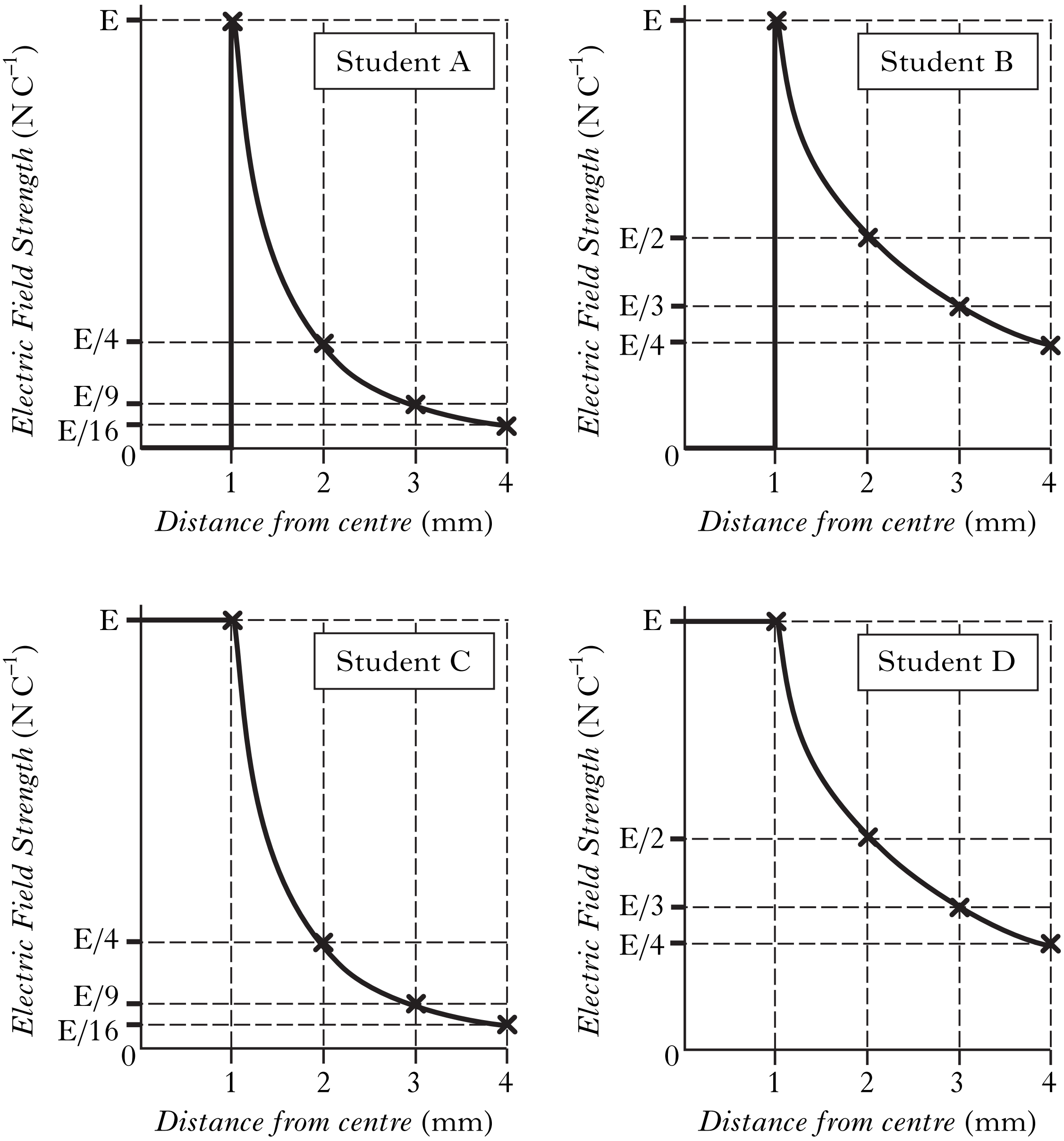

Figure 6A

(i) Which student has drawn the correct graph? **1**

(ii) Give **two** reasons to support your choice. **2**

6. (continued)

(*c*) Four point charges, Q_1, Q_2, Q_3 and Q_4, each of value $-2{\cdot}97 \times 10^{-8}$ C, are held in a square array. The hollow sphere with charge $-1{\cdot}92 \times 10^{-12}$ C is placed 30·0 mm above the centre of the array where it is held stationary by an electrostatic force.
The hollow sphere is 41·2 mm from each of the four charges as shown in Figure 6B.

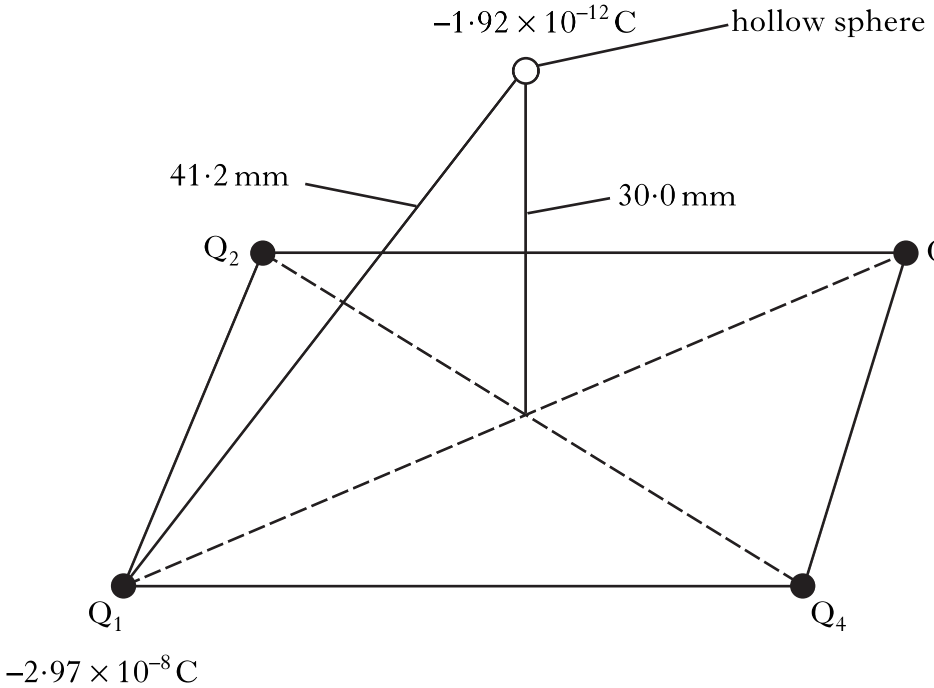

Figure 6B

(i) Calculate the magnitude of the force acting on the sphere due to charge Q_1. **2**

(ii) Calculate the vertical component of this force. **2**

(iii) Calculate the resultant electrostatic force on the sphere due to the whole array. **1**

(iv) Calculate the mass of the sphere. **2**

(12)

[Turn over

Marks

7. A beam of protons enters a region of uniform magnetic field, at right angles to the field.

The protons follow a circular path in the magnetic field until a potential difference is applied across the deflecting plates. The deflected protons hit a copper target. The protons travel through a vacuum. A simplified diagram is shown in Figure 7A.

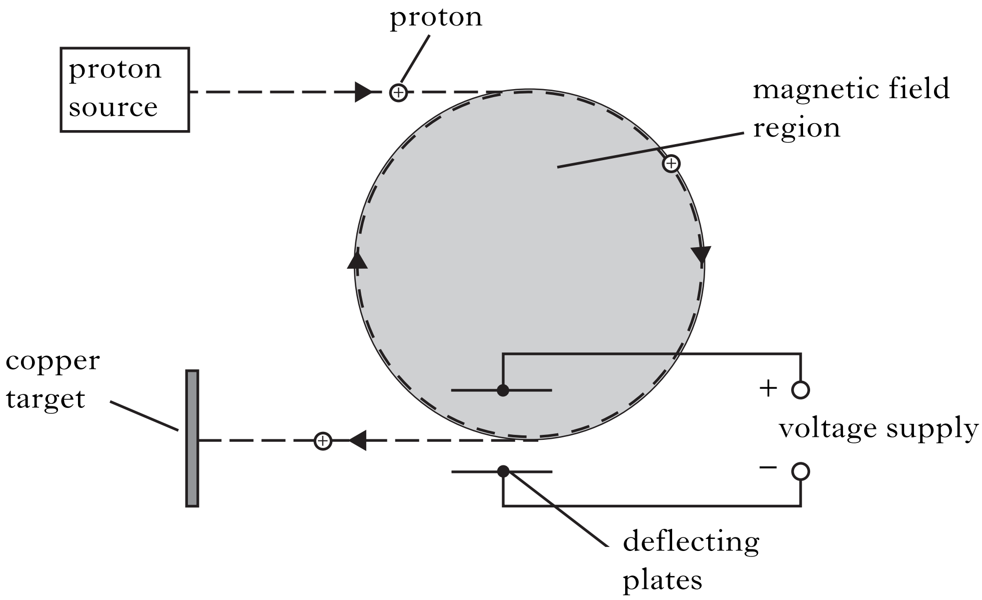

Figure 7A

(*a*) State the direction of the magnetic field, *B*. **1**

(*b*) The speed of the protons is $6{\cdot}0 \times 10^6\,\mathrm{m\,s^{-1}}$ and the magnetic induction is $0{\cdot}75\,\mathrm{T}$. Calculate the radius of the circular path followed by the protons. **3**

(*c*) Calculate the electric field strength required to make the protons move off at a tangent to the circle. **2**

Marks

7. (continued)

(*d*) A proton of charge q initially travels at speed v directly towards a copper nucleus as shown in Figure 7B. The copper nucleus has charge Q.

Figure 7B

(i) Show that the distance of closest approach, r, to the copper nucleus is given by

$$\frac{qQ}{2\pi\varepsilon_0 mv^2}.$$ **1**

(ii) Calculate the distance of closest approach for a proton initially travelling at $6{\cdot}0 \times 10^6\,\mathrm{m\,s^{-1}}$. **3**

(iii) Name the force that holds the protons together in the copper nucleus. **1**

(*e*) The beam of protons in Figure 7A is replaced by a beam of electrons. The speed of the electrons is the same as the speed of the protons.

State **two** changes that must be made to the magnetic field to allow the electrons to follow the same circular path as the protons. **2**

(13)

[Turn over

Marks

8. Identification of elements in a semiconductor sample can be carried out using an electron scanner to release atoms from the surface of the sample for analysis. Electrons are accelerated from rest between a cathode and anode by a potential difference of 2·40 kV.

A variable voltage supply connected to the deflection plates enables the beam to scan the sample between points A and B shown in Figure 8A.

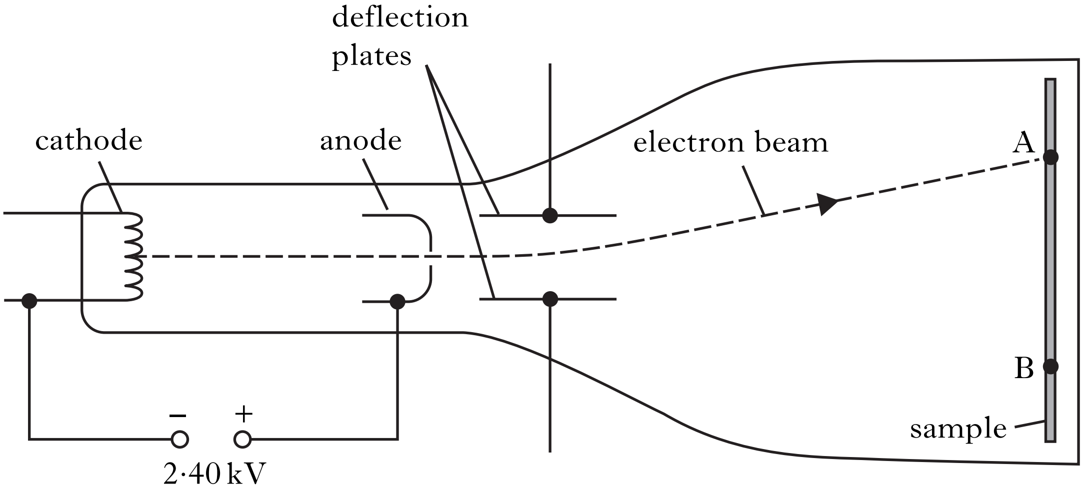

Figure 8A

(*a*) Calculate the speed of the electrons as they pass through the anode. **2**

(*b*) Explain why the electron beam follows

(i) a curved path between the plates; **1**

(ii) a straight path beyond the plates. **1**

When the potential difference across the deflection plates is 100 V, the electron beam strikes the sample at position A.

(*c*) The deflection plates are 15·0 mm long and separated by 10·0 mm.

(i) Show that the vertical acceleration between the plates is $1{\cdot}76 \times 10^{15}\,\mathrm{m\,s^{-2}}$. **2**

(ii) Calculate the vertical velocity of an electron as it emerges from between the plates. **3**

(*d*) The anode voltage is now increased. State what happens to the length of the sample scanned by the electron beam.

You must justify your answer. **2**

(11)

9. A transverse wave travels along a string as shown in Figure 9A.

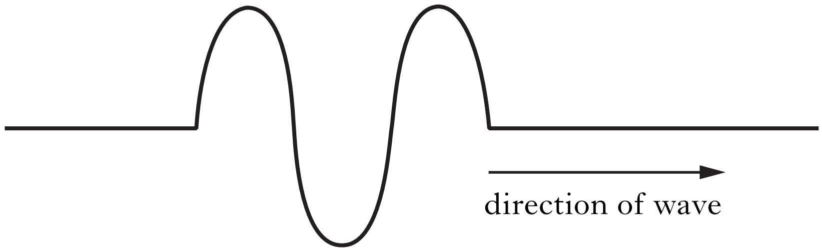

Figure 9A

The equation representing the travelling wave on the string is

$$y = 8{\cdot}6 \times 10^{-2} \sin 2\pi\,(2{\cdot}4t - 2{\cdot}0x)$$

where x and y are in metres and t is in seconds.

(*a*) State the frequency of the wave. **1**

(*b*) Calculate the velocity of the wave. **2**

(*c*) Attached to the end of the string is a very light ring. The ring is free to move up and down a fixed vertical rod.

Figure 9B shows the string after the wave reflects from the vertical rod.

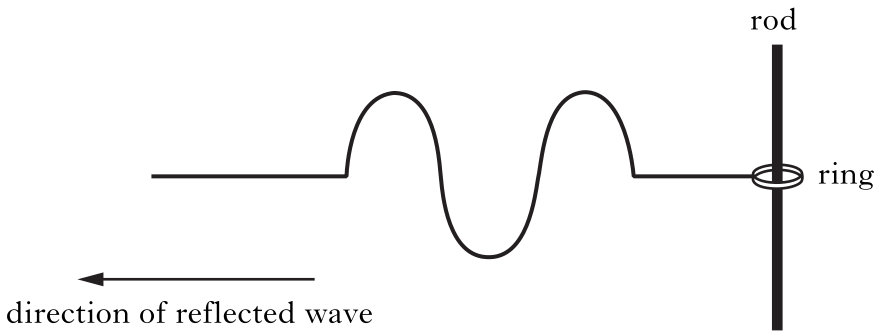

Figure 9B

When the wave reflects, its intensity falls to one quarter of its original value. The frequency and wavelength are constant.

Write the equation that represents this reflected wave. **2**

(5)

[Turn over

Marks

10. (*a*) Explain the formation of coloured fringes when white light illuminates a thin film of oil on a water surface. **2**

(*b*) Thin film coatings deposited on glass can be used to make the glass non-reflecting for certain wavelengths of light, as shown in Figure 10A.

The refractive index of the coating is less than glass, but greater than air.

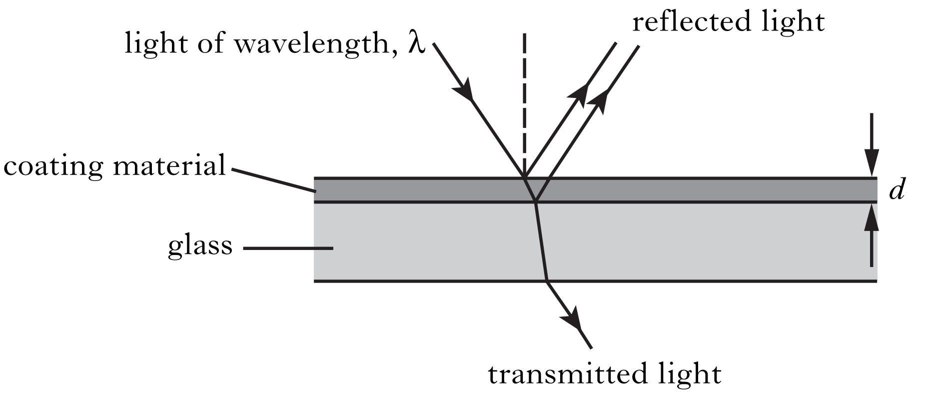

Figure 10A

Show that for near normal incidence

$$d = \frac{\lambda}{4n}$$

where n is the refractive index of the coating material and d is the thinnest coating that will be non-reflecting for light of wavelength, λ. **2**

(*c*) The relationship in (*b*) also applies to radiation of wavelength 780 nm.

A thin film coating has a refractive index of 1·30. For radiation of wavelength 780 nm the minimum thickness for a thin film that is non-reflecting is 0·150 μm. In practice, this thickness is too thin to manufacture.

Calculate the thickness of the next thinnest coating that would be non-reflecting for this wavelength. **2**

10. (continued)

(*d*) Six laser beams provide photons of wavelength 780 nm. These photons collide with rubidium atoms and cause the atoms to come to rest, as shown in Figure 10B.

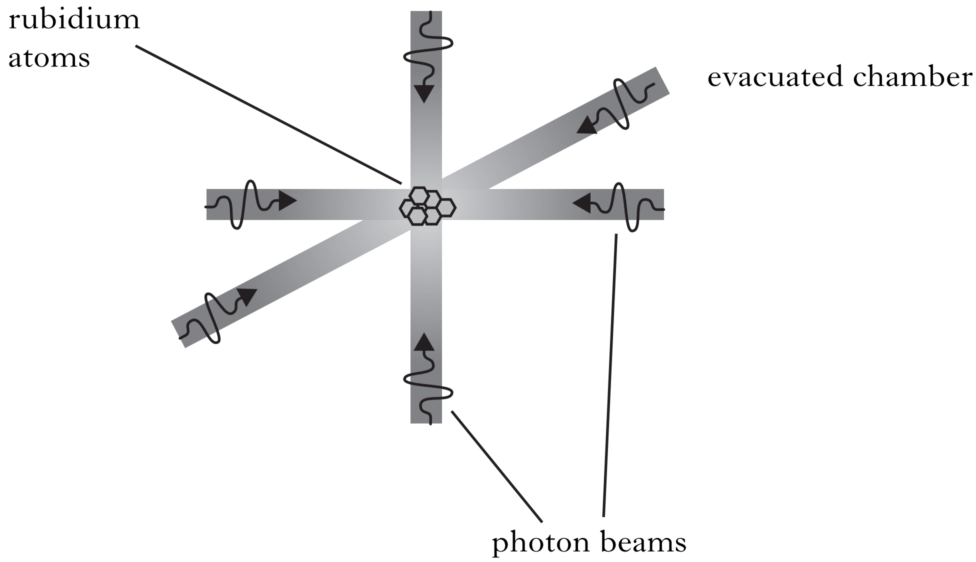

Figure 10B

Each rubidium atom has a mass of $1{\cdot}43 \times 10^{-25}$ kg and kinetic energy of $4{\cdot}12 \times 10^{-21}$ J before the lasers are switched on.

(i) Calculate the momentum of a rubidium atom before the lasers are switched on. **3**

(ii) Calculate the momentum of each photon in the laser beams. **2**

(iii) Assuming that all of the momentum of the photons is transferred to a rubidium atom, calculate the number of photons required to bring the atom to rest. **1**

(12)

[Turn over

Marks

11. A light source produces a beam of unpolarised light. The beam of light passes through a polarising filter called a polariser. The transmission axis of the polariser is shown in Figure 11A.

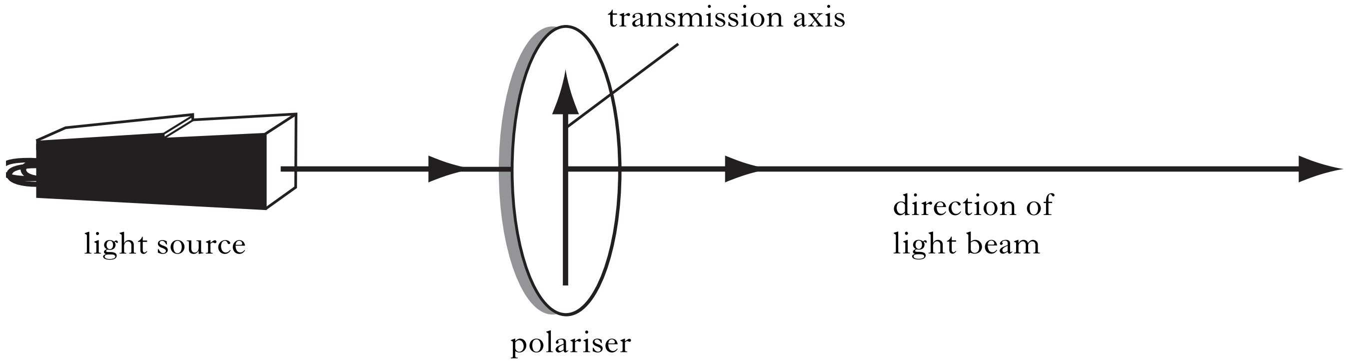

Figure 11A

(*a*) Explain the difference between the unpolarised light entering the polariser and the plane polarised light leaving the polariser. **1**

(*b*) The plane polarised light passes through a second polarising filter called an analyser.

The irradiance of the light passing through the analyser is measured by a light meter.

The transmission axis of the analyser can be rotated and its angle of rotation measured using a scale as shown in Figure 11B.

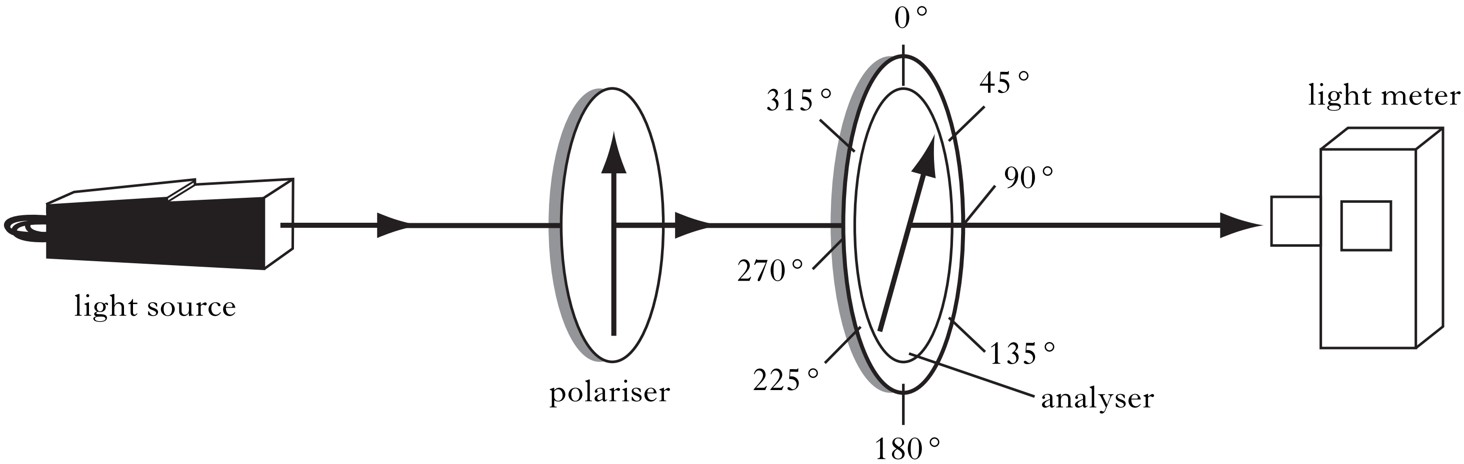

Figure 11B

(i) The analyser is rotated.

State the **two** positions on the analyser scale that will produce a maximum reading of irradiance, I_0, on the light meter. **2**

Marks

11. (*b*) (continued)

(ii) The relationship between the irradiance I detected by the light meter and the angle of rotation θ is given by

$$I = I_0 \cos^2\theta.$$

Explain how the equipment shown in Figure 11B could be used to establish this relationship.

Your answer should include:

- the measurements required;
- a description of how the relationship would be verified. **3**

(6)

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