

X069/701

NATIONAL
QUALIFICATIONS
2004

FRIDAY, 28 MAY
1.00 PM – 3.30 PM

PHYSICS
ADVANCED HIGHER

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.



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	$9.11 \times 10^{-31} \text{ kg}$
Radius of Earth	R_E	$6.4 \times 10^6 \text{ m}$	Charge on electron	e	$-1.60 \times 10^{-19} \text{ C}$
Mass of Earth	M_E	$6.0 \times 10^{24} \text{ kg}$	Mass of neutron	m_n	$1.675 \times 10^{-27} \text{ kg}$
Mass of Moon	M_M	$7.3 \times 10^{22} \text{ kg}$	Mass of proton	m_p	$1.673 \times 10^{-27} \text{ kg}$
Mean Radius of Moon Orbit		$3.84 \times 10^8 \text{ m}$	Planck's constant	h	$6.63 \times 10^{-34} \text{ J s}$
Universal constant of gravitation	G	$6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$	Permittivity of free space	ϵ_0	$8.85 \times 10^{-12} \text{ F m}^{-1}$
Speed of light in vacuum	c	$3.0 \times 10^8 \text{ m s}^{-1}$	Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ H m}^{-1}$
Speed of sound in air	v	$3.4 \times 10^2 \text{ m s}^{-1}$			

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	<i>Lasers</i>		
	397	Ultraviolet	<i>Element</i>	<i>Wavelength/nm</i>	<i>Colour</i>
	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/ $\text{J kg}^{-1} \text{ K}^{-1}$	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	....	2.40×10^5

The gas densities refer to a temperature of 273 K and a pressure of $1.01 \times 10^5 \text{ Pa}$.

1. The relativistic mass m of a moving object is given by

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

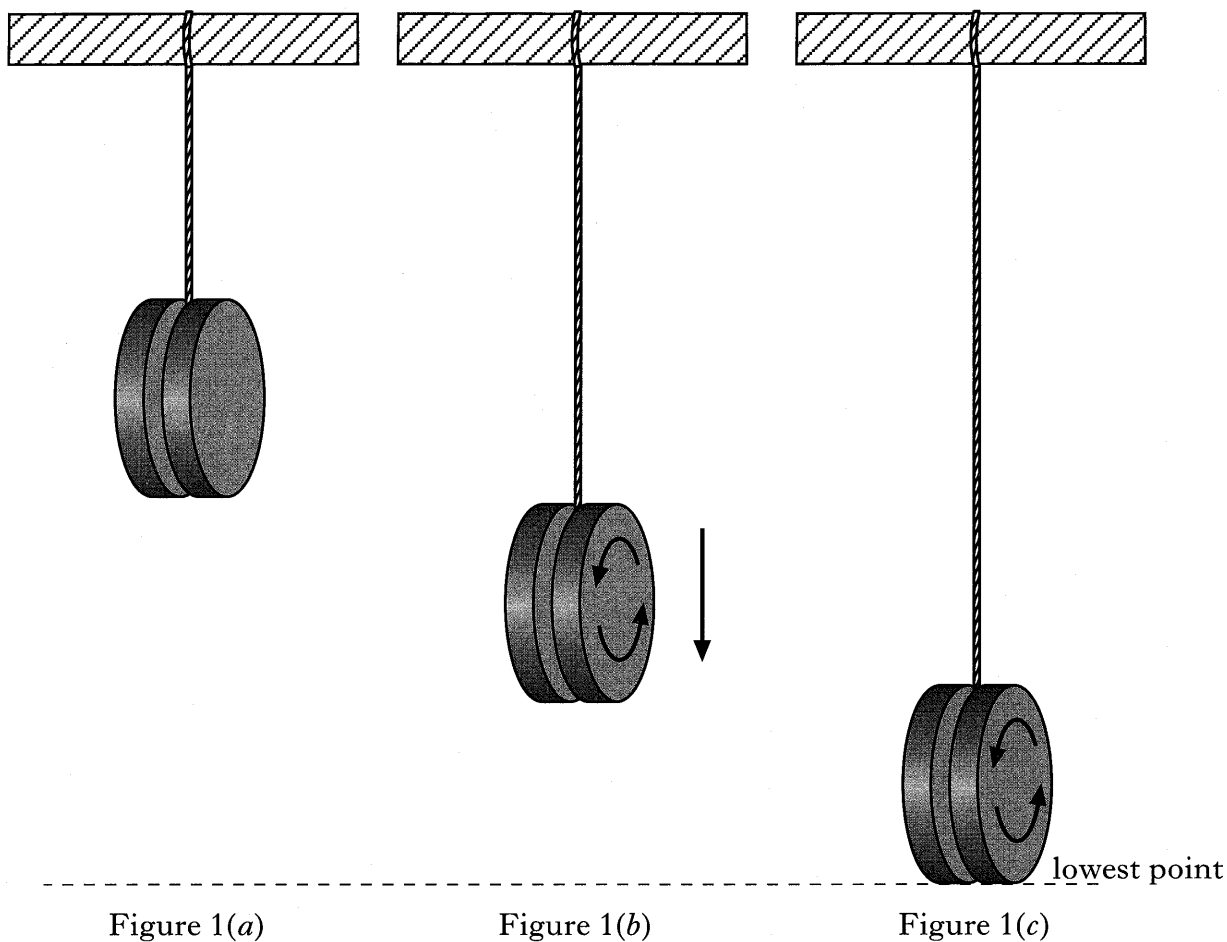
where the symbols have their usual meanings.

- (a) Calculate the speed at which the relativistic mass of an object is equal to three times its rest mass. 2
- (b) An electron is emitted with a speed of $0.90c$ from a radioactive nucleus. Calculate the relativistic energy of this electron. 3

(5)

[Turn over

2. A yo-yo consists of two discs mounted on an axle.
 A length of string is attached to the axle and wound round the axle.
 With the string fully wound, the yo-yo is suspended from a horizontal support as shown in Figure 1(a).



The yo-yo is released from rest and rotates as it falls, as shown in Figure 1(b).
 The string is fully unwound at the yo-yo's lowest point, as shown in Figure 1(c).
 The yo-yo then rises, rewinding the string.

- (a) State the type(s) of energy which the yo-yo has when it is at the position shown in:
- (i) Figure 1(b);
 - (ii) Figure 1(c). 2
- (b) Each disc has a mass m of 0.100 kg and a radius r of 0.050 m.
 The moment of inertia of a disc is given by $\frac{1}{2}mr^2$.
 The moment of inertia of the axle is negligible.
 Calculate the moment of inertia of the yo-yo. 2
- (c) When the yo-yo is at the position shown in Figure 1(c) it has an angular velocity of 120 rad s^{-1} .
 Calculate the maximum height to which the yo-yo could rise as it rewinds the string. 2

2. (continued)

- (d) One type of yo-yo has four friction pads inside each disc. Each friction pad is held in place by a spring which exerts a force of 5.00 N . At low angular velocities the friction pads grip the axle as shown in Figure 2.

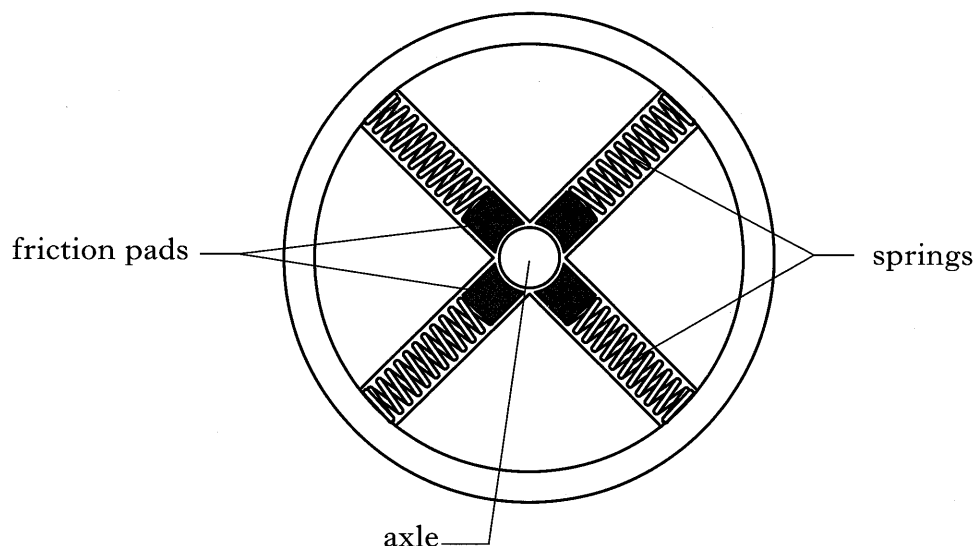


Figure 2

At higher angular velocities the pads move away from the axle and compress the springs. This releases the axle and allows the discs to spin freely.

- (i) Explain why the friction pads move away from the axle.
- ~~*~~ii) Each friction pad can be considered as a point mass of 12.0 g at a radius of 10.0 mm from the centre of the axle.

Calculate the minimum angular velocity at which the axle is released from the friction pads.

3
(9)

[Turn over

3. A grinder is used for cutting paving slabs.

The grinder has a motor and a disc with an abrasive edge as shown in Figure 3.

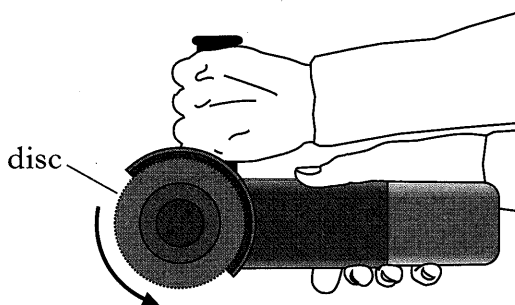


Figure 3

The motor is switched on and the disc reaches a maximum angular velocity of 600 revolutions per minute.

The motor is switched off and the disc slows uniformly to rest in 30 s.

- (a) Calculate the maximum angular velocity of the disc in rad s^{-1} . 1
- (b) Calculate the angular acceleration of the disc as it slows. 2
- (c) How many revolutions does the disc make during this time? 3
- (d) The moment of inertia of the disc is $2.16 \times 10^{-3} \text{ kg m}^2$.
Calculate the torque acting on the disc as it slows. 2
- (e) The disc is replaced by a disc of **half** the radius and **double** the mass. The motor is switched on and this disc also reaches a maximum angular velocity of 600 revolutions per minute. The grinder is switched off and a torque equal to that in part (d) acts on the disc.

Explain whether this disc comes to rest in a time greater than, equal to or less than 30 s.

The moment of inertia of a disc is given by $\frac{1}{2}mr^2$. 2

(10)

4. The gravitational pull of the Earth keeps a satellite in a circular orbit.

(a) Show that for an orbit of radius r the period T is given by

$$T = 2\pi \sqrt{\frac{r^3}{GM_E}}$$

where the symbols have their usual meanings.

2

(b) A polar orbiting satellite is used to map the Earth by photographing strips of the surface as it orbits, as shown in Figure 4.

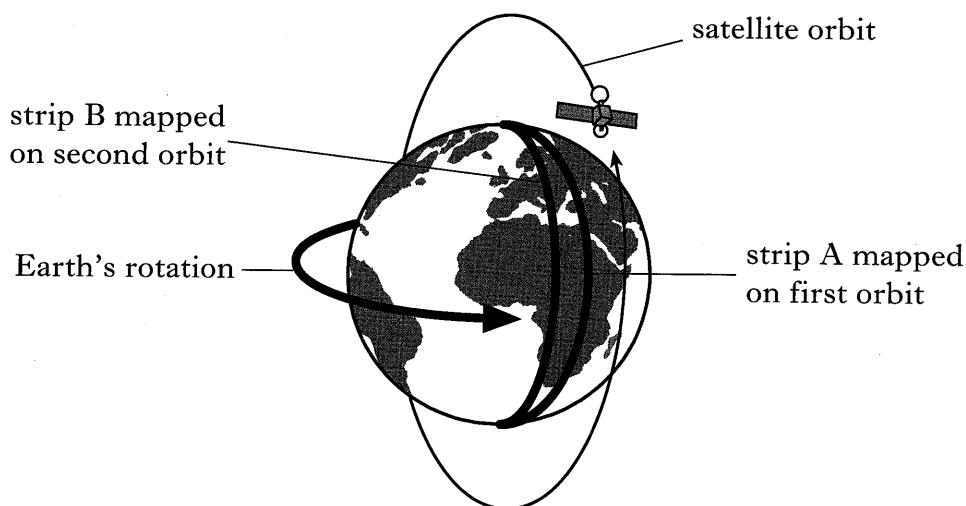


Figure 4

The plane of the satellite orbit is fixed. The Earth rotates and so the satellite maps a different strip on each orbit.

- (i) The satellite orbits at a height of 80 km above the surface of the Earth. Assuming the Earth to be spherical, show that the period of the orbit is approximately 86 minutes.
- ~~XX~~(ii) The Earth's angular velocity is $7.3 \times 10^{-5} \text{ rad s}^{-1}$. Calculate the distance along the equator between strips A and B which are mapped on consecutive orbits.

4

(6)

[Turn over

5. A mass of 0.50 kg is suspended from a spring of negligible mass, as shown in Figure 5(a).

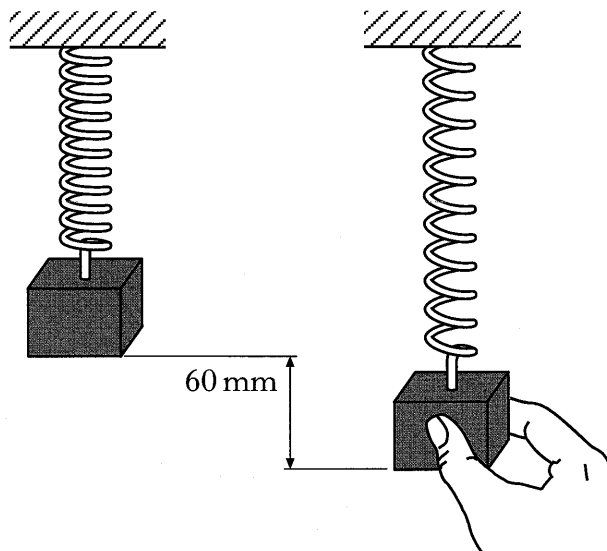


Figure 5(a)

Figure 5(b)

A student pulls the mass down a distance of 60 mm and holds it in the position shown in Figure 5(b).

The tension in the spring is now 7.0 N.

- (a) By considering the vertical forces acting on the mass, calculate the force applied by the student to hold the mass in this position. 1
- (b) The student releases the mass, which performs simple harmonic motion.
- (i) State the relationship between the unbalanced force acting on the mass and the displacement of the mass.
 - (ii) Calculate the acceleration of the mass immediately after its release.
 - (iii) State the initial amplitude of the oscillations. 4
- (c) The oscillations of the mass are described by the equation

$$\frac{d^2y}{dt^2} = -\omega^2 y.$$

- (i) Name the physical quantity represented by the term $\frac{d^2y}{dt^2}$.
- (ii) Calculate the frequency of the oscillations. 3

(8)

6. (a) (i) Define the term *electric field strength*.
 (ii) Two parallel plates are separated by distance d . The potential difference between the plates is V .
 Derive the expression for the electric field strength E between the plates in terms of V and d .

3

- (b) The electric field pattern between two parallel metal plates is shown in Figure 6.

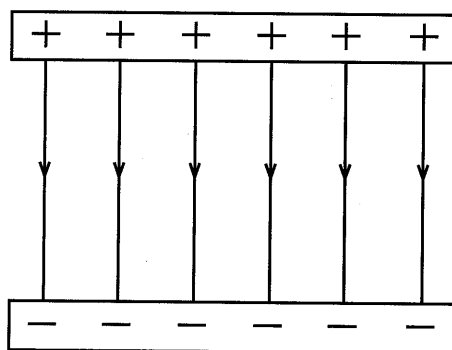


Figure 6

An uncharged, conducting sphere is placed between the plates as shown in Figure 7.

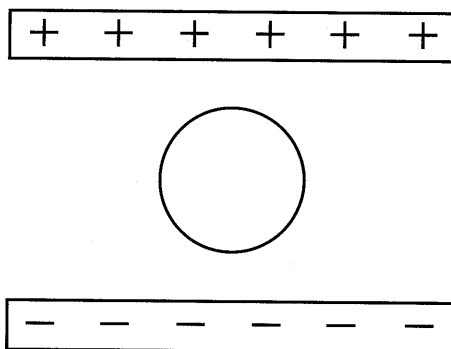


Figure 7

- (i) Copy and complete Figure 7 to show the electric field pattern between the plates.
 (ii) On your diagram, show the charge distribution on the sphere.
 (iii) State the value of the electric field strength inside the sphere.

4
(7)

[Turn over

7. (a) State Coulomb's law for the electrostatic force between two point charges. 1

~~(b)~~ The two identical conducting spheres R and S, shown in Figure 8, are initially uncharged.

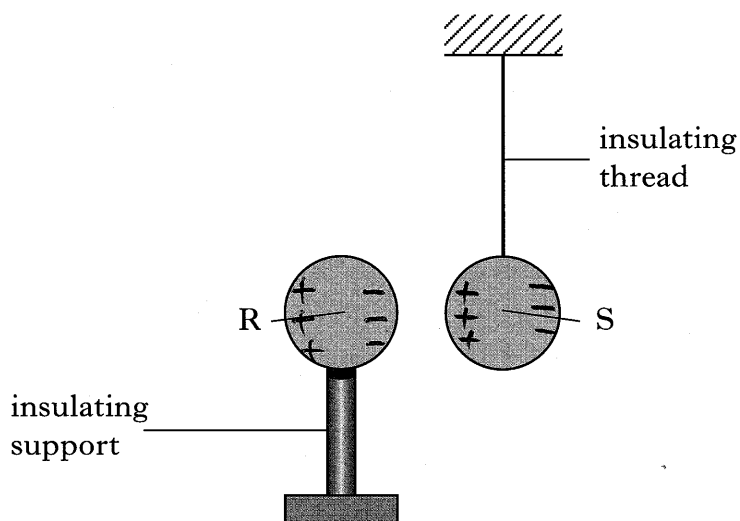


Figure 8

Describe how sphere R can be given a positive charge and sphere S an equal negative charge by induction, using a positively charged insulating rod. 2

(c) Two identical conducting spheres X and Y shown in Figure 9 have equal and opposite charges.

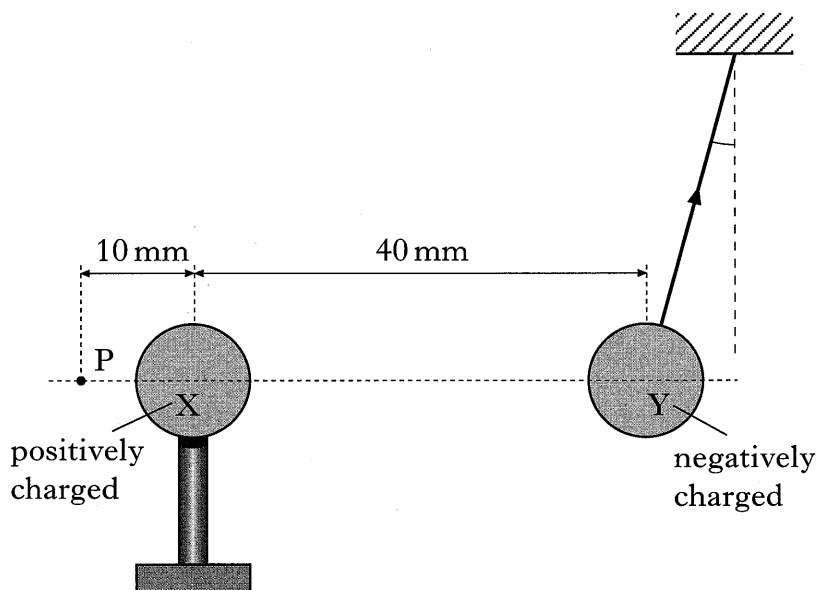


Figure 9

- (i) The force between the spheres is 3.0×10^{-5} N.
By considering the spheres as point charges separated by a distance of 40 mm, show that the charge on each sphere is 2.3 nC.
- (ii) Calculate the electrostatic potential at point P, 10 mm from X, as shown in Figure 9.

7. (c) (continued)

(iii) In reality, the spheres are not point charges.

Draw a sketch to show how charge is distributed on each sphere when the spheres are in the positions shown in Figure 9.

6

(d) Sphere Y has mass 2.5×10^{-5} kg and hangs at an angle α to the vertical, as shown in Figure 10. The horizontal force acting on the sphere is 3.0×10^{-5} N.

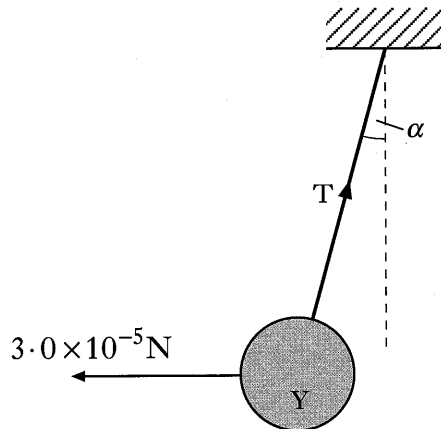


Figure 10

The mass of the thread is negligible.

- (i) Calculate the tension T in the thread.
- (ii) Calculate the size of angle α .

4

(13)

[Turn over

8. A particle of mass m and charge q is fired with speed v into a magnetic field of uniform magnetic induction B . The particle enters the field at point X and follows a semicircular path, before leaving the field at point Y, as shown in Figure 11.

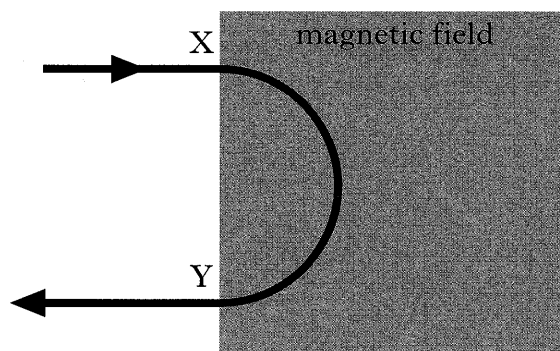


Figure 11

- (a) Show that the radius r of the semicircular path is given by

$$r = \frac{mv}{qB}. \quad 2$$

- (b) Using the above relationship, show that the time taken for the particle to follow the semicircular path in the magnetic field is independent of the speed of the particle. 2
- (c) An electron with speed $2.0 \times 10^6 \text{ m s}^{-1}$ is fired, as shown in Figure 11, into a magnetic field of uniform magnetic induction 5.0 mT . Calculate the time during which the electron is in the magnetic field. 2

(6)

9. An inductor of negligible resistance is connected in the circuit shown in Figure 12.

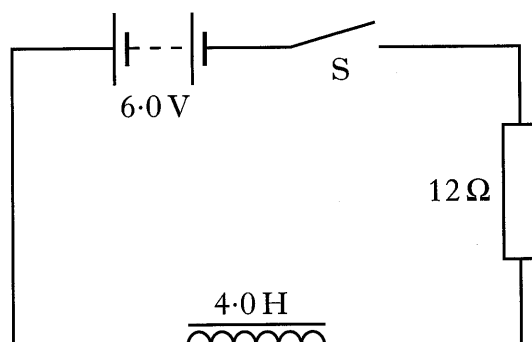


Figure 12

- ~~(a)~~ Sketch a graph to show how the potential difference across the resistor varies with time after switch S is closed. A numerical scale is required on the potential difference axis.
- (b) At a point in time after switch S is closed, the current in the circuit is 0.20 A. Calculate the rate of change of current at this time.

2

3

(5)

[Turn over

10. Two long parallel conductors, distance r apart, carry currents I_1 and I_2 .

(a) Show that the force per unit length acting on each conductor is given by

$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

where the symbols have their usual meanings.

2

(b) In some countries direct current is used for transmitting power over long distances. Two direct current transmission cables each carry a current of 850 A. The currents are in opposite directions as shown in Figure 13.

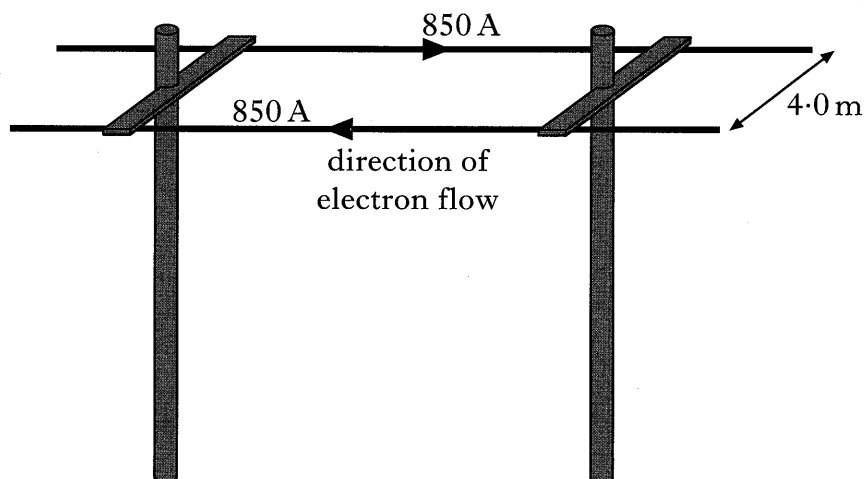


Figure 13

The cables are parallel and are separated by a distance of 4.0 m.

- (i) Calculate the force per unit length between the cables due to the currents in the cables.
- (ii) Does this force tend to move the cables together or apart?
- (iii) Determine the magnitude **and** direction of the resultant magnetic induction, due to both cables, at a point midway between the cables.

5

10. (continued)

- (c) The direction of the Earth's magnetic field is at an angle of 60 degrees to one cable, as shown in Figure 14.

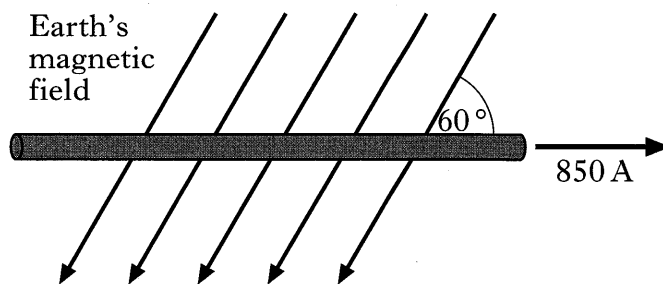


Figure 14

In the region of the cable, the magnetic induction of the Earth's field is $52\mu\text{T}$. Calculate the force per unit length on this cable due to the Earth's magnetic field and the current in this cable.

2
(9)

[Turn over

11. A transverse wave is described by the expression

$$y = 8.0 \sin(12t - 0.50x)$$

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

(a) For this wave, calculate the:

(i) frequency;

(ii) wavelength.

2

(b) (i) Calculate the phase difference, in radians, between the point at $x = 3.0$ m and the point at $x = 4.0$ m.

~~(ii)~~ (ii) Calculate the time for the wave to travel between these two points.

4

(c) The wave is reflected and loses some energy.

State a possible equation for the reflected wave.

2

(8)

12. A television aerial is shown in Figure 15.

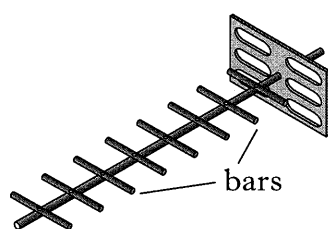


Figure 15

(a) Instructions for installing the aerial state

“The television waves received are plane polarised. The aerial does not pick up a strong signal unless the plane of the bars is the same as the plane of polarisation of the television waves.”

- (i) Explain the term *plane polarised*.
- (ii) The aerial is installed and connected to a television.

The television has a clear picture when the bars of the aerial are horizontal as shown in Figure 15.

The aerial is now slowly rotated until the bars are vertical as shown in Figure 16.

Describe what happens to the television picture during this rotation.

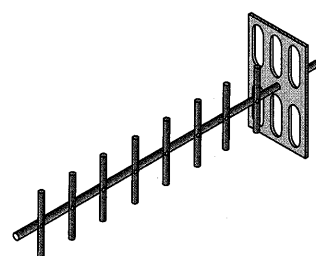


Figure 16

(b) Unpolarised light strikes the surface of a transparent material at the Brewster angle i_p , as shown in Figure 17. The reflected light is plane polarised.

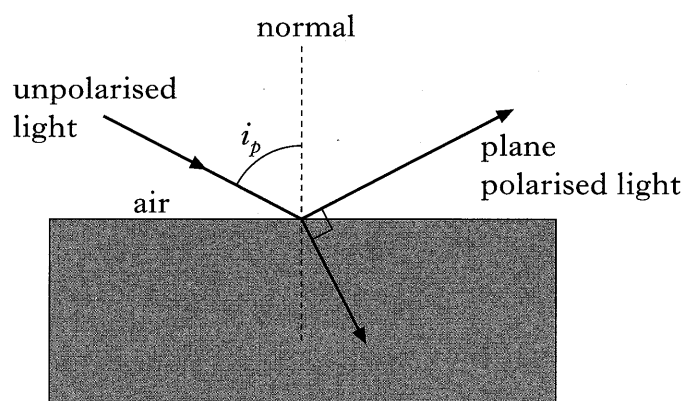


Figure 17

(i) Derive the expression

$$n = \tan i_p$$

where n is the refractive index of the transparent material.

(ii) Calculate the Brewster angle for perspex.

4

(6)

13. A student sets up a “Young’s double slit” experiment, as shown in Figure 18, to measure the wavelength of laser light.

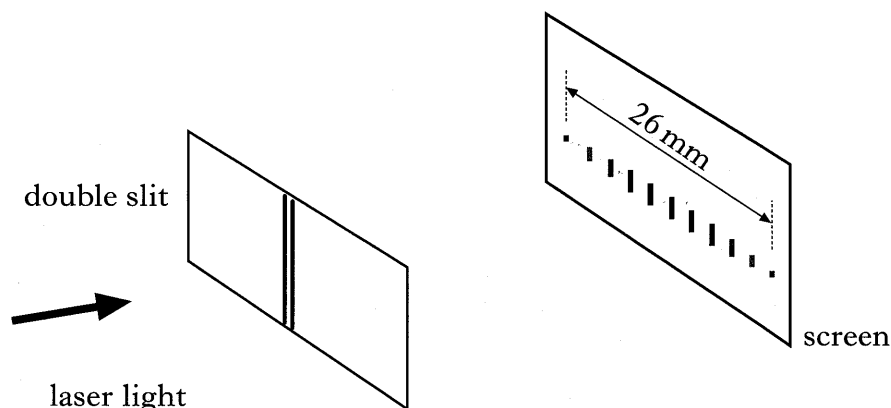


Figure 18

The student obtains the following results.

Separation of 11 fringes	26 (± 2) mm
Distance to screen from slits	2.00 (± 0.01) m
Separation of slits	0.52 (± 0.02) mm

- (a) Calculate the wavelength of the laser light. 2
- (b) Calculate the percentage uncertainty in this wavelength. 3
- (c) Suggest an improvement to the experiment that would reduce the uncertainty in the calculated value of the wavelength.
Justify your answer. 2
- (d) Which principle does this experiment illustrate, interference by division of wavefront or by division of amplitude? 1

(8)

[END OF QUESTION PAPER]

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