

X069/13/01

NATIONAL
QUALIFICATIONS
2013

MONDAY, 27 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.



DATA SHEET
COMMON PHYSICAL QUANTITIES

<i>Quantity</i>	<i>Symbol</i>	<i>Value</i>	<i>Quantity</i>	<i>Symbol</i>	<i>Value</i>
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	$1.673 \times 10^{-27} \text{ kg}$
Radius of Moon	R_M	$1.7 \times 10^6 \text{ m}$	Mass of alpha particle	m_α	$6.645 \times 10^{-27} \text{ kg}$
Mean Radius of Moon Orbit		$3.84 \times 10^8 \text{ m}$	Charge on alpha particle		$3.20 \times 10^{-19} \text{ C}$
Universal constant of gravitation	G	$6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$	Planck's constant	h	$6.63 \times 10^{-34} \text{ J s}$
Speed of light in vacuum	c	$3.0 \times 10^8 \text{ m s}^{-1}$	Permittivity of free space	ϵ_0	$8.85 \times 10^{-12} \text{ F m}^{-1}$
Speed of sound in air	v	$3.4 \times 10^2 \text{ m s}^{-1}$	Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ H m}^{-1}$

REFRACTIVE INDICES

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

<i>Substance</i>	<i>Refractive index</i>	<i>Substance</i>	<i>Refractive index</i>
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

<i>Element</i>	<i>Wavelength/nm</i>	<i>Colour</i>	<i>Element</i>	<i>Wavelength/nm</i>	<i>Colour</i>
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

<i>Substance</i>	<i>Density/</i> kg m^{-3}	<i>Melting Point/</i> K	<i>Boiling Point/</i> K	<i>Specific Heat Capacity/</i> $\text{J kg}^{-1} \text{ K}^{-1}$	<i>Specific Latent Heat of Fusion/</i> J kg^{-1}	<i>Specific Latent Heat of Vaporisation/</i> 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 $1.01 \times 10^5 \text{ Pa}$.

1. A stunt driver is attempting to “loop the loop” in a car as shown in Figure 1. Before entering the loop the car accelerates along a horizontal track.

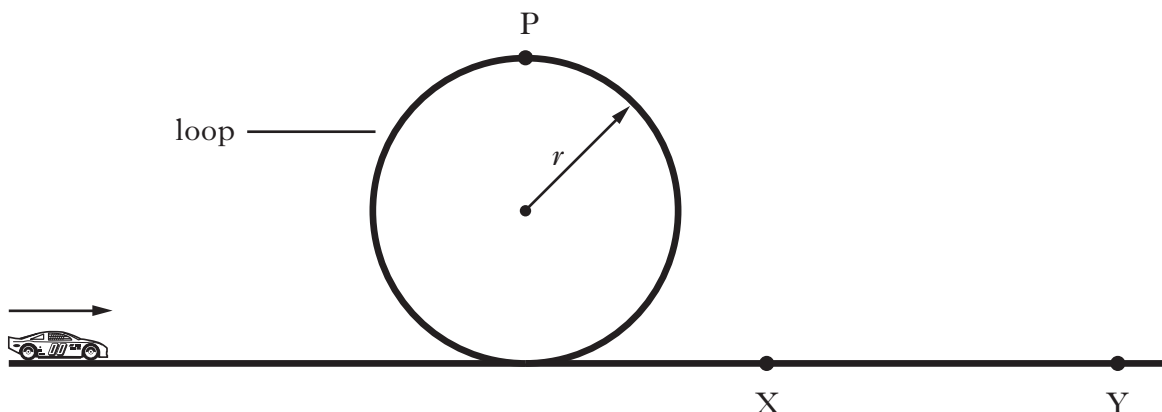


Figure 1

The radius r of the circular loop is 6.2 m.

The total mass of the car and driver is 870 kg.

- (a) Show that the car must have a minimum speed of 7.8 m s^{-1} at point P to avoid losing contact with the track. 2
- (b) During one attempt the car is moving at a speed of 9.0 m s^{-1} at point P.
- (i) Draw a labelled diagram showing the vertical forces acting on the car at point P. 1
- (ii) Calculate the size of each force. 3
- (c) When the car exits the loop the driver starts braking at point X. For one particular run the displacement of the car from point X **until the car comes to rest** at point Y is given by the equation

$$s = 9.1t - 3.2t^2$$

Sketch a graph to show how the displacement of the car varies with time between points X and Y.

Numerical values are required on both axes. 3

(9)

[Turn over

2. The entrance to a building is through a revolving system consisting of 4 doors that rotate around a central axis as shown in Figure 2A.



Figure 2A

The moment of inertia of the system about the axis of rotation is 54 kg m^2 . When it rotates, a constant frictional torque of 25 N m acts on the system.

- (a) The system is initially stationary. On entering the building a person exerts a constant force F perpendicular to a door at a distance of 1.2 m from the axis of rotation as shown in Figure 2B.

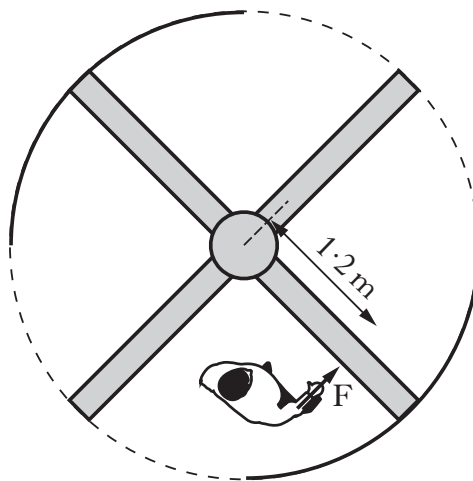


Figure 2B

The angular acceleration of the system is 2.4 rad s^{-2} .

- (i) Calculate the magnitude of the applied force F . 3
- (ii) The applied force is removed and the system comes to rest in 3.6 s . Calculate the angular displacement of the door during this time. 3

2. (continued)

- (b) On exiting the building the person exerts the same magnitude of force F on a door at the same distance from the axis of rotation.

The force is now applied as shown in Figure 2C.

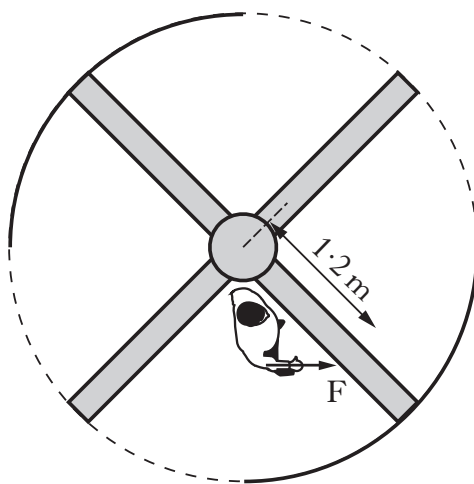


Figure 2C

How does the angular acceleration of the door system compare to that given in part (a)?

Justify your answer.

2

(8)

[Turn over

3. Planets outside our solar system are called exoplanets.

One exoplanet moves in a circular orbit around a star as shown in Figure 3.

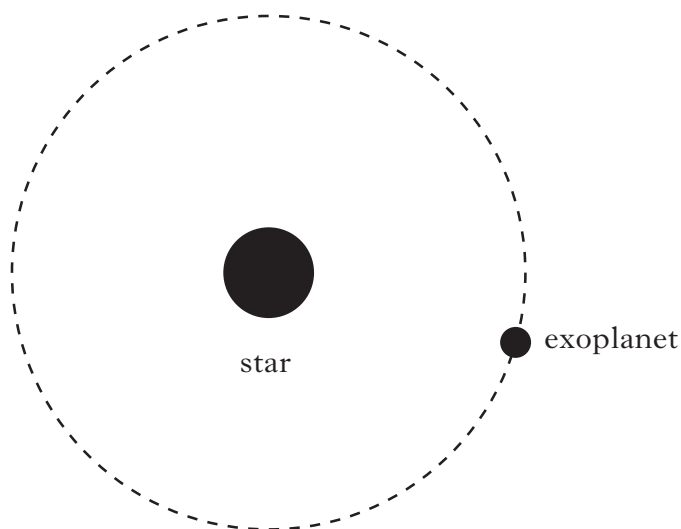


Figure 3

The period of orbit is 14 days. The mass M_s of the star is 1.7×10^{30} kg.

- (a) (i) Show that the radius of the orbit can be given by the relationship

$$r^3 = GM_s \frac{T^2}{4\pi^2}$$

where the symbols have their usual meaning.

2

- (ii) Calculate the radius of this orbit.

1

- (b) The radius of the exoplanet is 1.2×10^8 m and its mass is 5.4×10^{26} kg. Calculate the value of the gravitational field strength g on the surface of the exoplanet.

2

- (c) Astrophysicists have identified many black holes in the universe.

- (i) State what is meant by the term *black hole*.

1

- (ii) A newly discovered object has a mass of 4.2×10^{30} kg and a radius of 2.6×10^4 m.

Show by calculation whether or not this object is a black hole.

2

(8)

4. A “saucer” swing consists of a bowl shaped seat of mass 1.2 kg suspended by four ropes of negligible mass as shown in Figure 4A.



Figure 4A

When the empty seat is pulled back slightly from its rest position and released, its motion approximates to simple harmonic motion.

- (a) Define the term *simple harmonic motion*. 1
- (b) The acceleration-time graph for the seat with no energy loss is shown in Figure 4B.

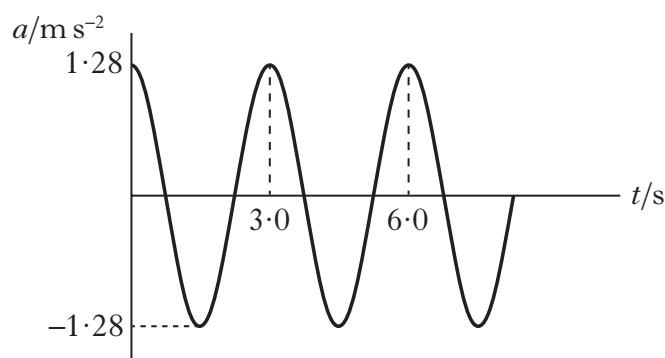


Figure 4B

- (i) Show that the amplitude of the motion is 0.29 m . 3
- (ii) Calculate the velocity of the seat when its displacement is 0.10 m . 2
- (c) Calculate the displacement of the seat when the kinetic energy and potential energy are equal. 3

(9)**[Turn over**

5. The Bohr model of the atom suggests that the angular momentum of an electron orbiting a nucleus is quantised.

A hydrogen atom consists of a single electron orbiting a single proton. Figure 5 shows some of the possible orbits for the electron in a hydrogen atom.

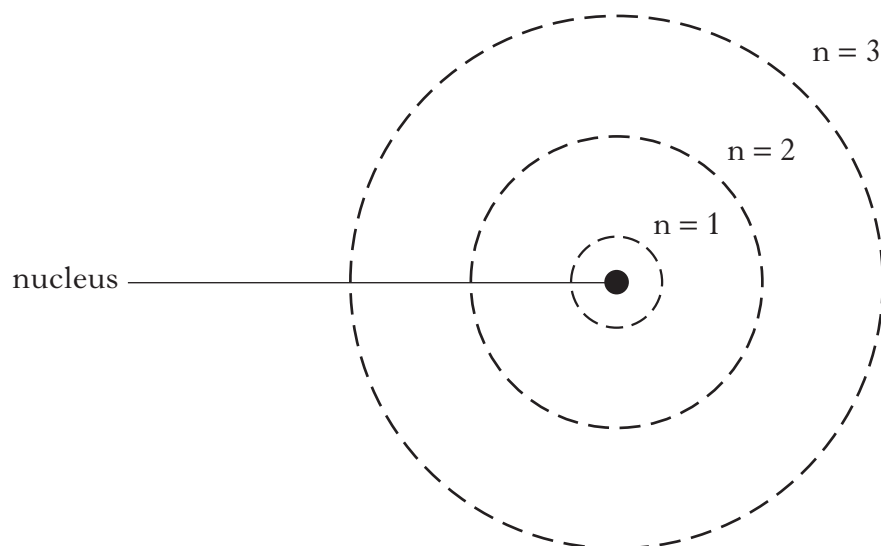


Figure 5

The table shows the values of the radii for the first three orbits.

<i>Orbit number, n</i>	<i>Orbital radius/10⁻¹⁰ m</i>
1	0.53
2	2.1
3	4.8

- (a) (i) Calculate the speed of the electron in orbit number 3. 2
- (ii) Calculate the de Broglie wavelength associated with this electron. 2
- (iii) What is the name given to the branch of physics that treats electrons as waves and predicts their position in terms of probability? 1
- (b) Compare the magnitudes of the electrostatic and gravitational forces between an electron in orbit number 1 and the proton in the nucleus. 3
- Justify your answer by calculation. 3

(8)

[Turn over for Question 6 on *Page ten*

6. A research physicist is investigating collisions between protons and the nuclei of metallic elements. Protons are accelerated **from rest** across a potential difference of 4.0 MV. The protons move through a vacuum and collide with a metal target as shown in Figure 6A.

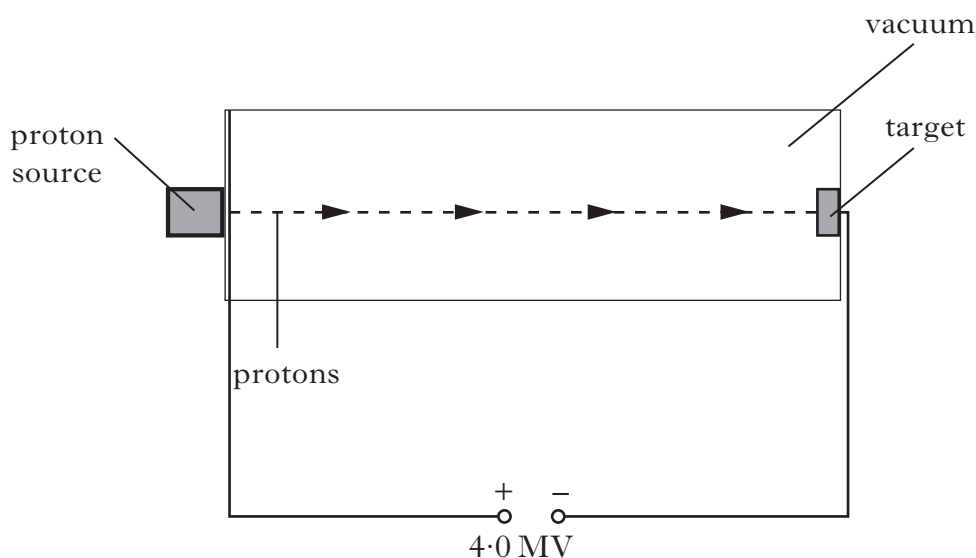


Figure 6A

- (a) (i) Calculate the maximum speed of the protons as they hit the target. 2
- (ii) In one test the researcher uses zirconium as the target. A proton of charge q and velocity v travels directly towards a zirconium nucleus as shown in Figure 6B. The zirconium nucleus has charge Q .



Figure 6B

Show that the distance of closest approach r to the metal target is given by

$$r = \frac{qQ}{2\pi\epsilon_0 mv^2}$$

where the symbols have their usual meaning. 1

- (iii) Calculate the distance of closest approach for a proton travelling towards a zirconium nucleus in the target. 3

6. (continued)

(b) At CERN protons are accelerated to speeds approaching the speed of light. Calculate the relativistic energy of a proton moving at $0.8c$.

4

(c) A student visiting CERN asks why the protons in the nucleus of an atom do not just fly apart. Explain **fully** why protons in a nucleus do not behave in this way.

3

(13)

[Turn over

7. In a nuclear power station liquid sodium is used to cool parts of the reactor. An electromagnetic pump keeps the coolant circulating. The sodium enters a perpendicular magnetic field and an electric current, I , passes through it. A force is experienced by the sodium causing it to flow in the direction shown in Figure 7A.

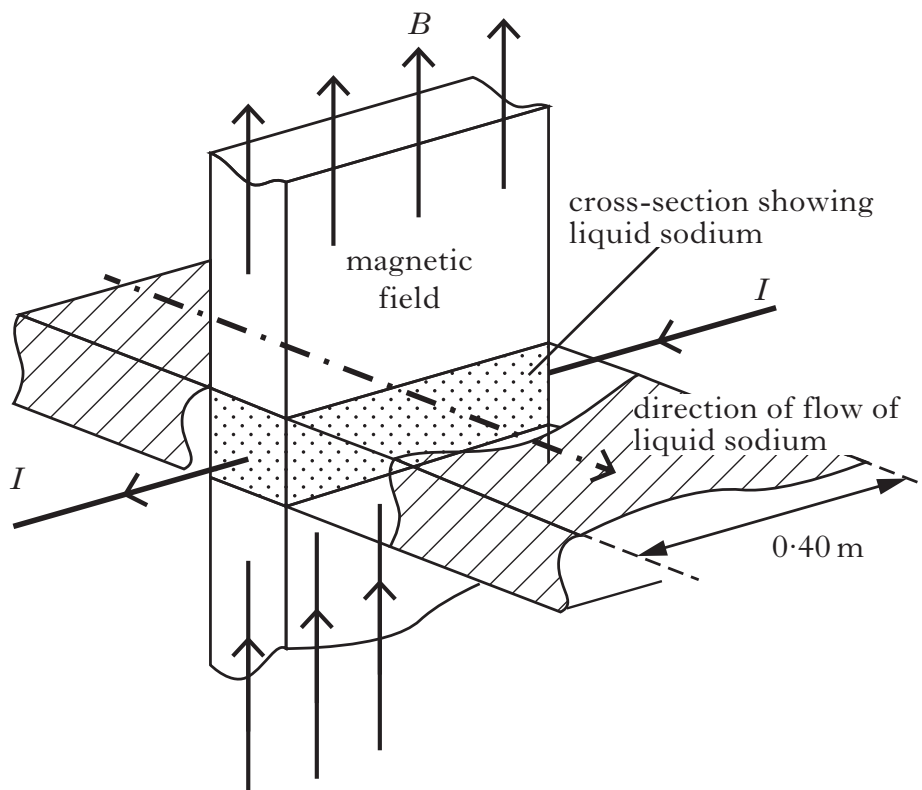


Figure 7A

The magnetic induction B is 0.20 T . The current I in the sodium is 2.5 A and is perpendicular to the magnetic field.

(a) Define one tesla.

1

(b) Calculate the force acting on the 0.40 m length of sodium within the magnetic field.

2

(c) The pump is moved during maintenance and as a result the direction of the magnetic field is changed so that it is no longer perpendicular to the current. What effect does this have on the rate of flow of sodium passing through the pump?

You **must** justify your answer.

2

7. (continued)

- (d) An engineer must install a long, straight, current carrying wire AB close to the pump and is concerned that the magnetic induction produced may interfere with the safe working of the pump.

The wire is 750 mm from the pump and carries a current of 0.60 A.

Show by calculation that the magnetic induction at this distance is negligible. 2

- (e) A second long straight wire CD is installed parallel to the first wire AB as shown in Figure 7B.

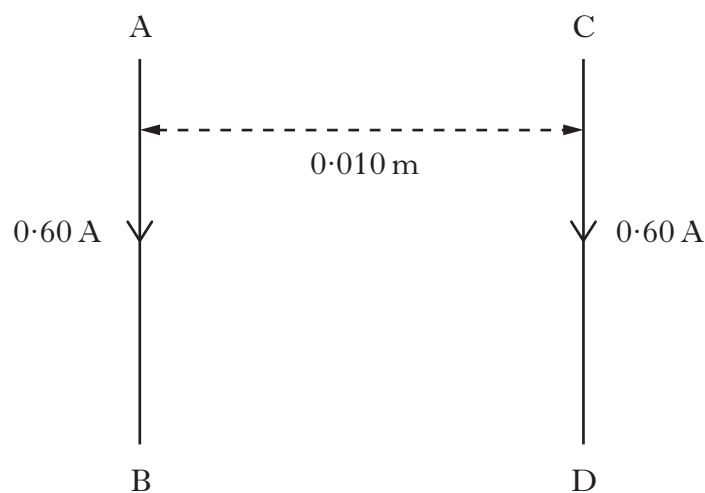


Figure 7B

- (i) It also carries a current of 0.60 A in the same direction as in the first wire AB. Calculate the size of the force per unit length exerted on wire CD by wire AB. 2
- (ii) State the direction of the force on the wire CD.
Justify your answer. 2

(11)

[Turn over

8. In 1909 Robert Millikan devised an experiment to investigate the charge on a small oil drop. Using a variable power supply he adjusted the potential difference between two horizontal parallel metal plates until an oil drop was held stationary between them as shown in Figure 8.

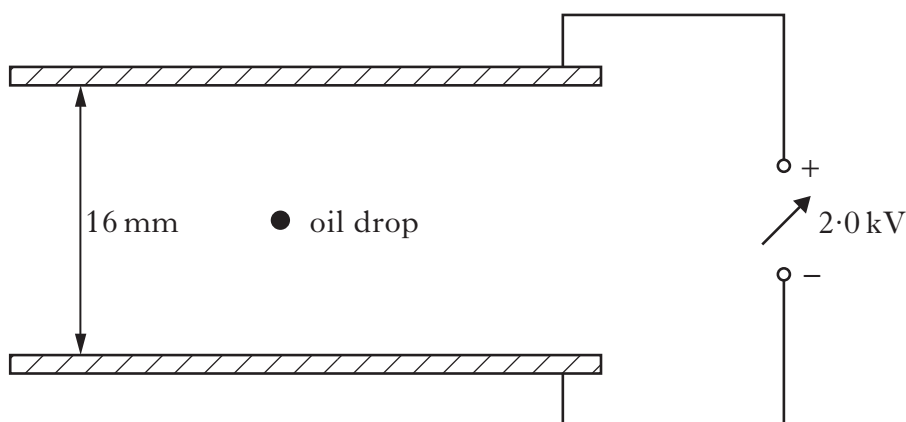


Figure 8

- (a) What was Millikan's main conclusion from this experiment? 1
- (b) Draw a labelled diagram showing the forces acting on the stationary oil drop. 1
- (c) The parallel plates are fixed 16 mm apart. In one experiment the charge on the oil drop was found to be $2.4 \times 10^{-18} \text{ C}$.
Calculate the mass of the oil drop. 3
- (5)**
9. The charge Q on a hollow metal sphere is $(-15.0 \pm 0.4) \mu\text{C}$. The sphere has a radius r of $(0.65 \pm 0.02) \text{ m}$.

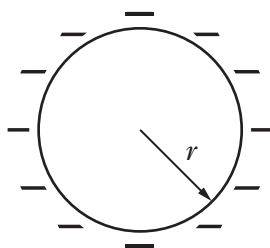


Figure 9

- (a) Calculate the electrostatic potential at the surface of the metal sphere. 2
- (b) Calculate the absolute uncertainty in the electrostatic potential. 2
- (c) State the electrostatic potential at the centre of the sphere. 1
- (5)**

10. A 0.40 H inductor of negligible resistance is connected in a circuit as shown in Figure 10. Switch S is initially open.

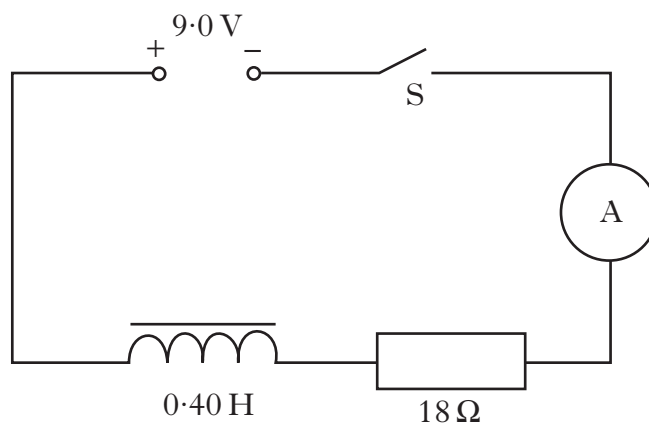


Figure 10

- (a) (i) The switch S is closed. Sketch a graph of current against time giving numerical values on the current axis. 2
- (ii) Explain fully the shape of the graph. 2
- (b) Calculate the initial rate of change of current when switch S is closed. 2
- (6)**

[Turn over

11. High quality *optical flats* made from glass are often used to test components of optical instruments. A high quality optical flat has a very smooth and flat surface.

- (a) During the manufacture of an optical flat, the quality of the surface is tested by placing it on top of a high quality flat. This results in a thin air wedge between the flats as shown in Figure 11A.

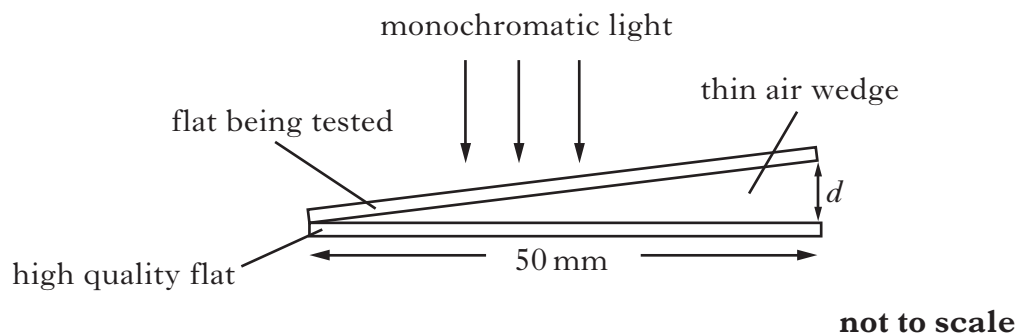


Figure 11A

The thickness d of the air wedge is 6.2×10^{-5} m.

Monochromatic light is used to illuminate the flats from above. When viewed from above using a travelling microscope, a series of interference fringes is observed as shown in Figure 11B.

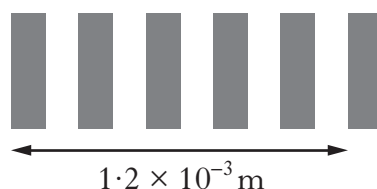


Figure 11B

Calculate the wavelength of the monochromatic light.

3

- (b) A second flat is tested using the same method as in part (a). This flat is slightly curved as shown in Figure 11C.



Figure 11C

Draw the fringe pattern observed.

1

11. (continued)

- (c) Good quality optical flats often have a non-reflecting coating of magnesium fluoride applied to the surface as shown in Figure 11D.

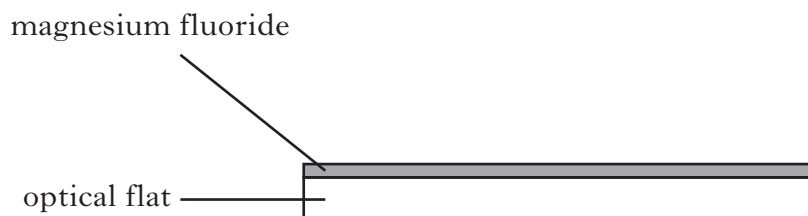


Figure 11D

- (i) With the aid of a diagram explain fully how the coating reduces reflections from the flat for monochromatic light. 2
- (ii) Calculate the minimum thickness of magnesium fluoride required to make the flat non-reflecting for yellow light from a sodium lamp. 2

(8)

[Turn over

12. A water wave of frequency 2.5 Hz travels from left to right.

Figure 12 represents the displacement y of the water at one instant in time.

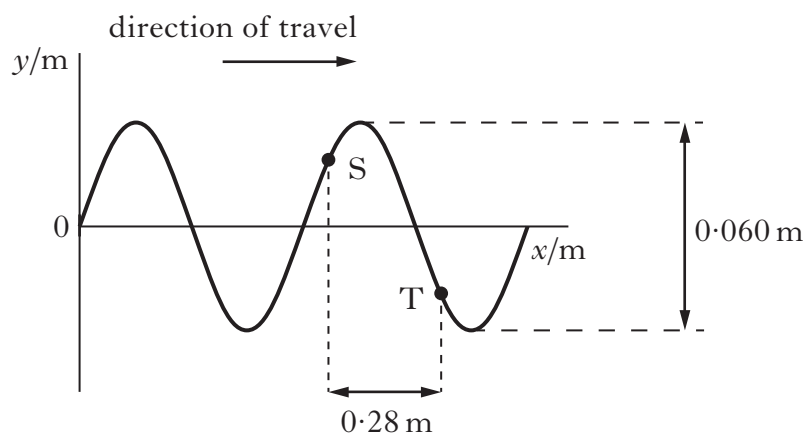


Figure 12

Points S and T are separated by a horizontal distance of 0.28 m.

The phase difference between these two points is 3.5 radians.

(a) Calculate the wavelength of this wave. 2

(b) A second wave with double the frequency travels in the same direction through the water. This wave has five times the intensity of the wave in part (a).

Calculate:

(i) the speed of this wave; 1

(ii) the amplitude of this wave. 2

(5)

13. A student is investigating polarisation of waves.

(a) State what is meant by *plane polarised light*. 1

(b) The student wishes to investigate polarisation of sound waves and asks a teacher for suitable apparatus. The teacher says that sound waves cannot be polarised.

Why can sound waves not be polarised? 1

(c) (i) While doing some background reading the student discovers that the Brewster angle i_p for the liquid solvent triethylamine is given as 54.5° . Explain using a diagram what is meant by the Brewster angle. 2

(ii) Calculate the refractive index of triethylamine. 1

(5)

[END OF QUESTION PAPER]

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