

X069/701

NATIONAL
QUALIFICATIONS
2009

TUESDAY, 26 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

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	$1.673 \times 10^{-27} \text{ kg}$
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.

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. Figure 1A shows a space shuttle shortly after take-off.

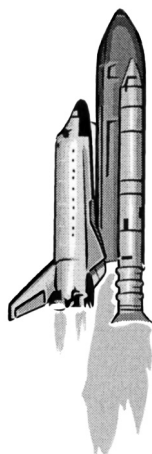


Figure 1A

- (a) Immediately after take off, the vertical displacement of the shuttle for part of its journey can be described using the equation

$$s = 3.1t^2 + 4.1t.$$

- (i) Find, by differentiation, the equation for the vertical velocity of the shuttle. 1
- (ii) At what time will the vertical velocity be 72 m s^{-1} ? 2
- (iii) Calculate the vertical linear acceleration during this time. 1
- (b) A theory suggests that a burned out star can collapse to form a black hole.
- (i) Explain why a *black hole* appears black. 1
- (ii) Explain the term *escape velocity*. 1
- (iii) Derive an expression for the escape velocity at the surface of a star of mass M and radius r . 2
- (iv) A star collapses to form a black hole of mass $4.58 \times 10^{30} \text{ kg}$. Even in these extreme conditions the expression in part (iii) applies. Calculate the maximum radius of the black hole. 2
- (v) Calculate the minimum density ρ of this black hole. 3
- (13)**

[Turn over

2. An anemometer is an instrument to measure windspeed and is shown in *Marks* Figure 2A.



Figure 2A

The anemometer is tested in a wind tunnel.

The calibration graph of the angular velocity, in **revolutions per minute**, against windspeed, in m s^{-1} , is shown in Figure 2B.

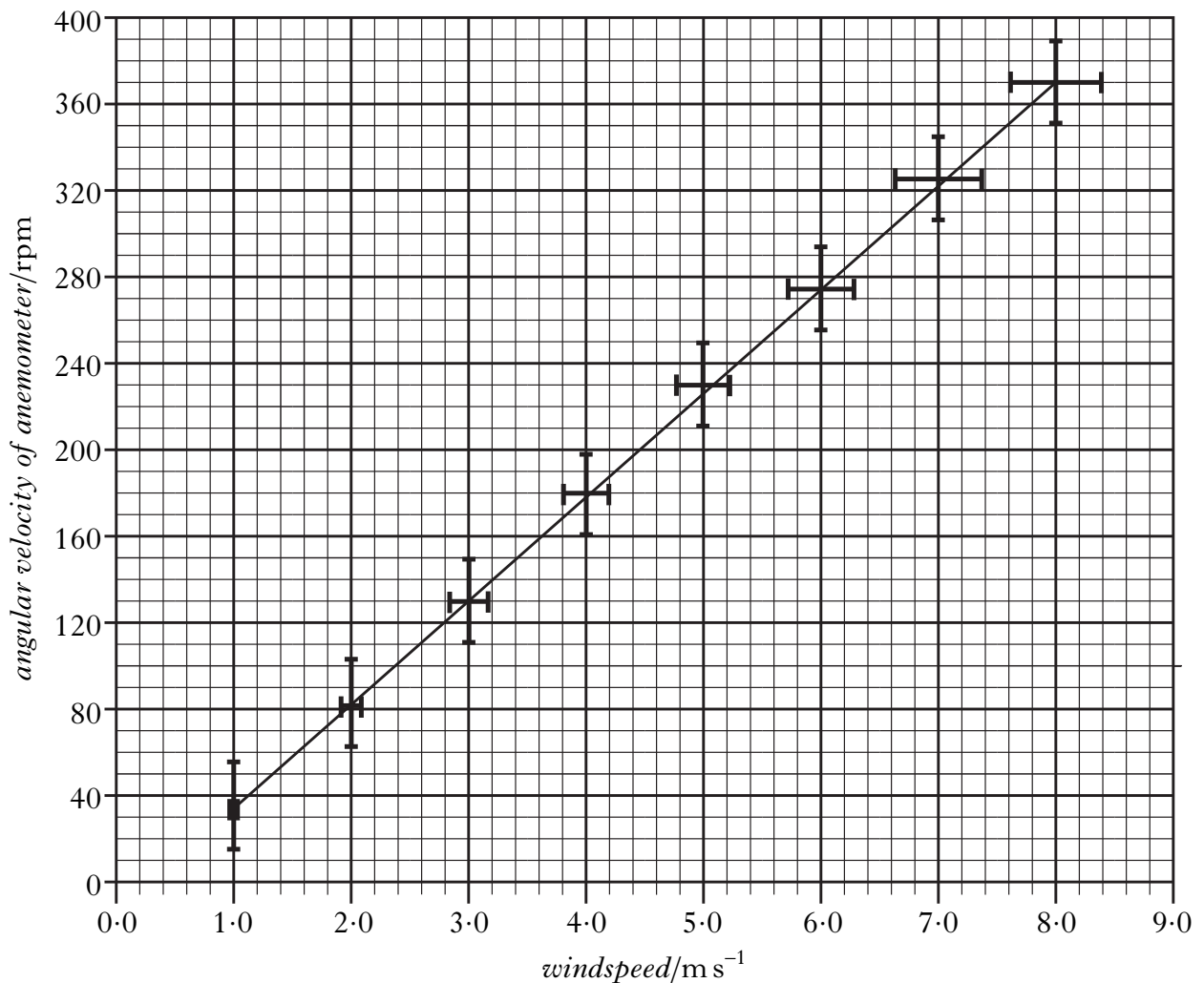


Figure 2B

The calibration graph is found not to go through the origin.

The equation for the line is $y = 48x - 12$.

- (a) (i) During one test there is a constant windspeed of 5.8 m s^{-1} . Show that the angular velocity of the anemometer at this windspeed is 28 rad s^{-1} . 1
- (ii) In a **second** test the windspeed is reduced from 5.8 m s^{-1} to 1.6 m s^{-1} in a time of 8.0 seconds. Calculate the angular acceleration of the anemometer. 3

2. (continued)

- (b) The rotating part of the anemometer is made up of a central cylinder and three arms as shown in Figure 2C.

Plan view of rotating parts of anemometer

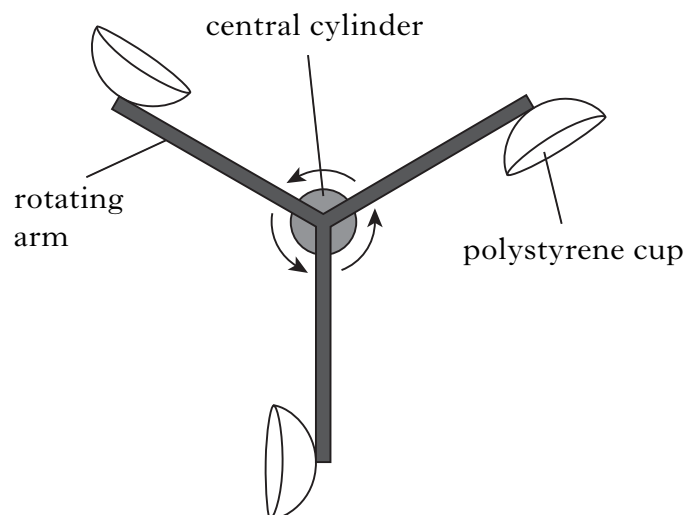


Figure 2C

Each arm consists of a rod of length 76 mm and mass 11 g with a polystyrene cup of negligible mass on the end of the rod. One arm of the anemometer is shown in Figure 2D.

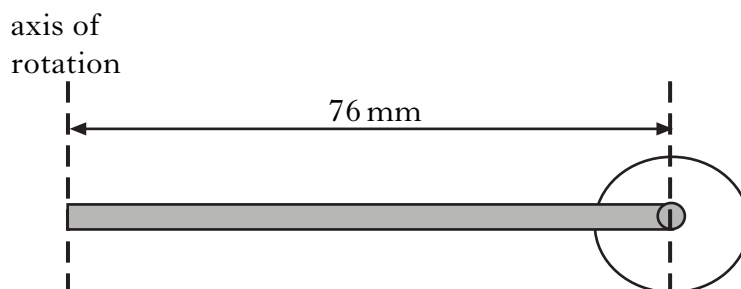


Figure 2D

- (i) Calculate the moment of inertia of the rod about the axis shown. 2
- (ii) The moment of inertia of the central cylinder is $1.1 \times 10^{-6} \text{ kg m}^2$. Calculate the total moment of inertia of all the rotating parts. 2
- (c) Calculate the average torque acting on the rotating system during the **second** test. 2
- (d) The anemometer is set up at a field site to record wind speed. Freezing rain deposits a layer of ice evenly over the cups. Explain the effect this might have on the motion of the arm. 2

(12)

3. An electric toothbrush has a circular brush head, diameter 12 mm, as shown in Figure 3A.

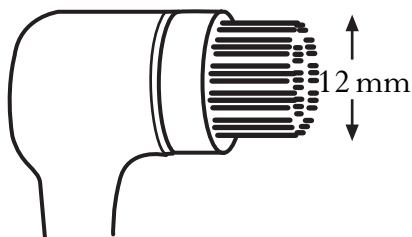


Figure 3A

The toothbrush has two settings.

On setting 1, the brush head vibrates with simple harmonic motion. On this setting, the head vibrates with a frequency of 33 Hz and moves a maximum distance of 4.2 mm as shown in Figure 3B.

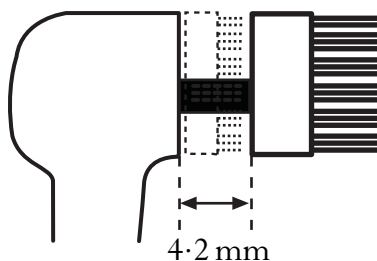


Figure 3B

- (a) (i) Write an expression for the displacement, in metres, of the brush head. 2
- (ii) Calculate the maximum speed of the brush head. 2

3. (continued)

- (b) On setting 2, the brush head can be considered to oscillate with simple harmonic motion with amplitude A as shown in Figure 3C.

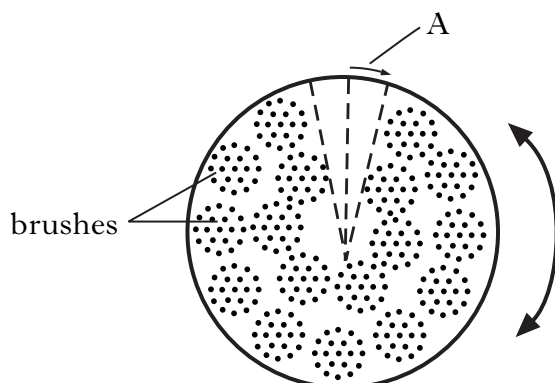


Figure 3C

The velocity, in ms^{-1} , of a point on the circumference of the head can be given by the equation

$$v = 9.2 \times 10^{-2} \cos 77t.$$

Calculate the amplitude of the oscillation on setting 2.

2

- (c) A particle of toothpaste of mass $2.5 \times 10^{-6} \text{ kg}$ on the outer edge of the brush head is shown in Figure 3D.

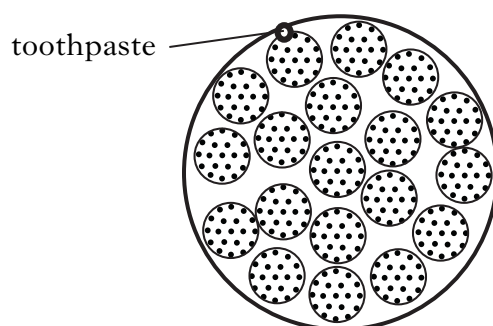


Figure 3D

The switch is on setting 2.

- (i) Calculate the maximum kinetic energy of the particle of toothpaste. 2
- (ii) Sketch a graph of the kinetic energy of the particle of toothpaste against its displacement. Appropriate numerical values are required on both axes. 2

(10)

[Turn over

4. (a) A point charge of $+4.0\ \mu\text{C}$ is shown in Figure 4A.

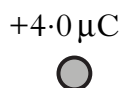


Figure 4A

- (i) Copy Figure 4A and draw the electric field lines around this point charge. 1
- (ii) A point charge of $-2.0\ \mu\text{C}$ is now placed at a distance of $0.10\ \text{m}$ from the first charge as shown in Figure 4B.

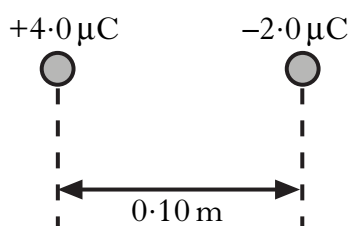


Figure 4B

Explain why the electric field strength **is not** zero at any point between these two charges. 2

- (iii) Point P is $0.24\ \text{m}$ to the right of the second charge as shown in Figure 4C.

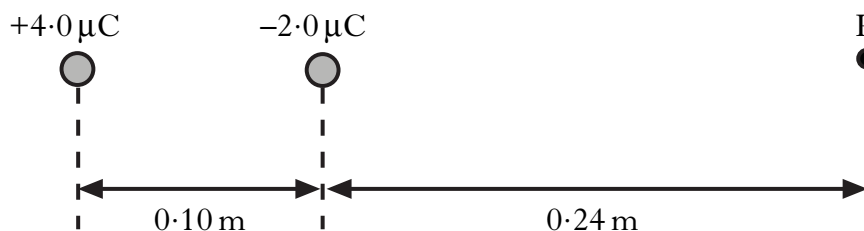


Figure 4C

Calculate the electric field strength at point P. 3

- (b) Two like charges experience a repulsive electrostatic force.

Explain why two protons in a nucleus do not fly apart. 2

4. (continued)

- (c) Information on the properties of three elementary particles together with two types of quarks and their corresponding antiquarks is shown in Figure 4D.

Properties of elementary particles			
Particle	Number of quarks	Charge	Baryon number
Proton	3	+e	1
Antiproton	3	-e	-1
Pi-meson	2	-e	0

Properties of quarks and antiquarks		
Particle	Charge	Baryon number
Up quark	$+\frac{2}{3}e$	$+\frac{1}{3}$
Down quark	$-\frac{1}{3}e$	$+\frac{1}{3}$
Anti-up quark	$-\frac{2}{3}e$	$-\frac{1}{3}$
Anti-down quark	$+\frac{1}{3}e$	$-\frac{1}{3}$

Figure 4D

- (i) Using information from Figure 4D, show that a proton consists of two up quarks and one down quark. 1
- (ii) State the combination of quarks that forms a pi-meson. 1
- (10)**

[Turn over

5. An alpha particle passes through a region that has perpendicular electric and magnetic fields, as shown in Figure 5A.

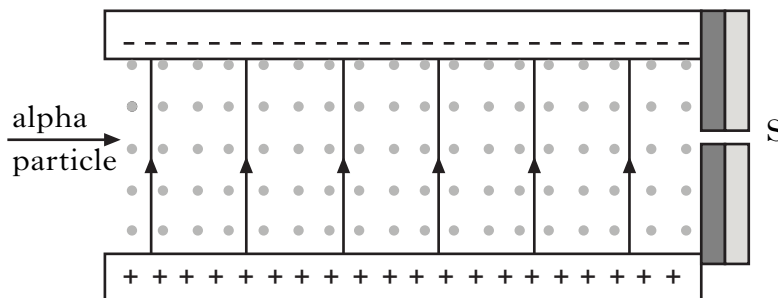


Figure 5A

The magnetic induction is 6.8 T and is directed out of the page.

The force on the alpha particle due to the magnetic field is $5.0 \times 10^{-11} \text{ N}$.

- (a) Show that the velocity of the alpha particle is $2.3 \times 10^7 \text{ m s}^{-1}$. 2

- (b) In order that the alpha particle exits through slit S, it must pass through the region undeflected.

Calculate the strength of the electric field that ensures the alpha particle exits through slit S. 2

5. (continued)

- (c) After passing through slit S, the alpha particle enters a region where there is the same uniform perpendicular magnetic field but no electric field as shown in Figure 5B.

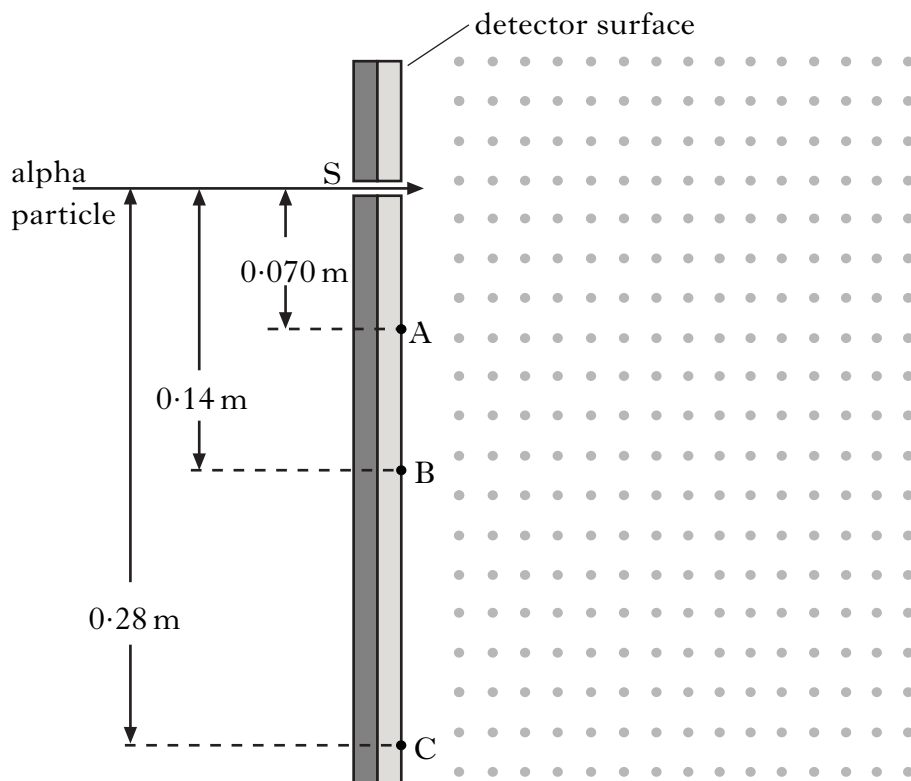


Figure 5B

This magnetic field causes the alpha particle to travel in a semi-circular path and hit the detector surface.

Points A, B and C are at distances of 0.070 m, 0.14 m and 0.28 m respectively from slit S.

Show, by calculation, which point on the detector surface is hit by the alpha particle.

3

- (d) An electron travelling at the same speed as the alpha particle passes through slit S into the region of uniform magnetic field.

State **two** differences in the semi-circular path of the electron compared to the path of the alpha particle. **Justify** your answer.

3

(10)

[Turn over

6. (a) A 3.0 V battery is connected in series with a switch, a resistor and an inductor of negligible resistance. A neon lamp is connected across the inductor as shown in Figure 6A.

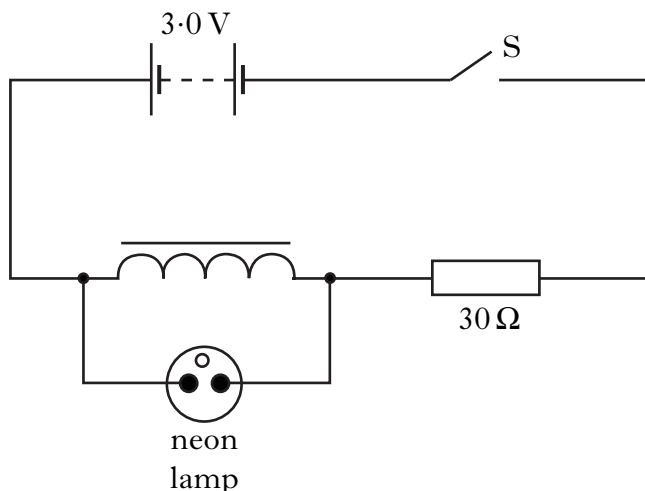


Figure 6A

- (i) Sketch a graph to show how the current in the inductor varies with time from the instant the switch is closed.

Appropriate numerical values are required on the current axis.

2

- (ii) The neon lamp requires a potential difference of at least 110 V across it before it lights.

Explain why the lamp does not light when the switch is closed.

1

- (iii) After a few seconds the switch is opened and the lamp flashes.

Explain, in terms of the magnetic field, why the lamp flashes as the switch is opened.

2

- (iv) The neon lamp has an average power of 1.2 mW and a flash that lasts 0.25 s.

Assuming all the energy stored by the inductor is transferred to the lamp, calculate the inductance of the inductor.

3

6. (continued)

- (b) Figure 6B shows a circuit used to investigate the relationship between the current in an inductive circuit and the supply frequency.

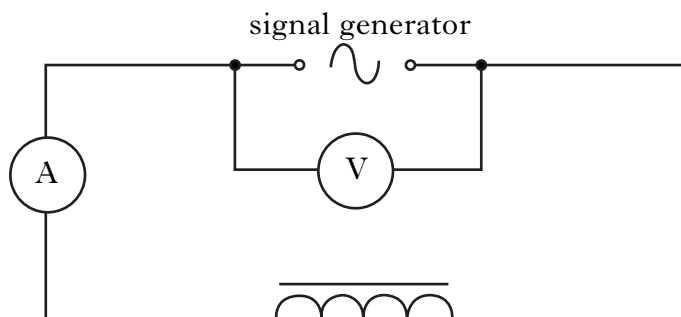


Figure 6B

The reading on the ammeter is noted for different values of supply frequency.

- (i) State the purpose of the voltmeter. 1
 - (ii) Describe how the data obtained should be analysed to determine the relationship between the current in the inductive circuit and the supply frequency. 1
 - (iii) State the expected relationship. 1
- (c) A loudspeaker system is connected to a music amplifier. The system contains a capacitor, inductor and two loudspeakers, LS1 and LS2, as shown in Figure 6C.

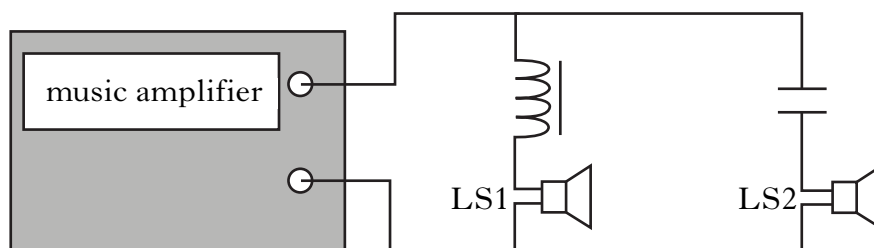


Figure 6C

The circuit is designed so that one loudspeaker emits low frequency sounds while the other emits high frequency sounds.

By comparing the capacitive and inductive reactances, describe the operation of this system.

2
(13)

[Turn over

7. The Bohr model of the hydrogen atom states that the angular momentum of an electron is quantised.
- (a) (i) Calculate the minimum angular momentum of the electron in a hydrogen atom. 2
- (ii) When the electron has its minimum angular momentum it is in an orbit of radius 5.3×10^{-11} m. Calculate the linear momentum of the electron in this orbit. 2
- (iii) Calculate the de Broglie wavelength of the electron in this orbit. 2
- (b) One of the limitations of the Bohr model is that an orbiting electron is constantly accelerating and therefore should continuously emit electromagnetic radiation.
- (i) What would happen to the orbit of the electron if electromagnetic radiation were to be continuously emitted? 1
- (ii) What is the name of the branch of physics that provides methods to determine the electron's position in terms of probability? 1
- (8)**

8. A student uses a probe to measure the magnetic induction near a long straight current carrying conductor PQ, as shown in Figure 8A.

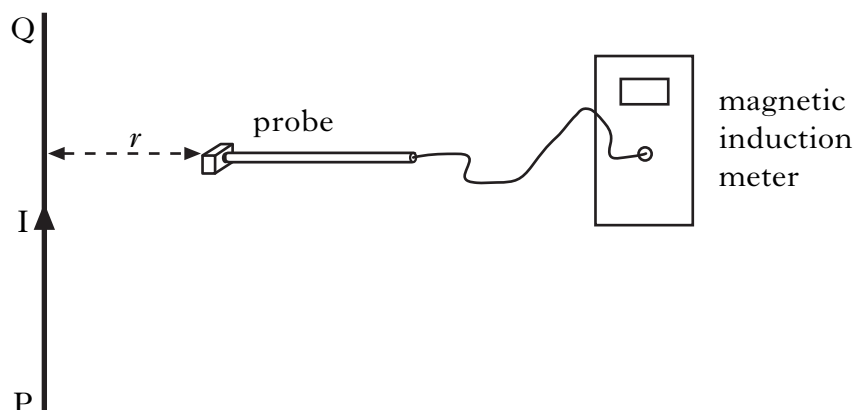


Figure 8A

The following data is obtained.

Distance r/m	Magnetic induction B/T
0.25	1.7×10^{-7}

- (a) Calculate the current in the conductor PQ. 2
- (b) The unit of magnetic induction is the tesla. Define *one tesla*. 1
- (c) A second long straight conductor RS carrying a current of 2 A is placed at a distance of 0.25 m from the first conductor PQ, as shown in Figure 8B.

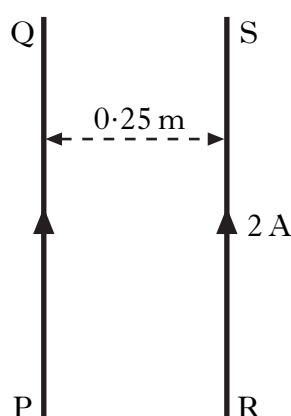


Figure 8B

- Calculate the magnitude of the force per metre acting on conductor RS. 2
- (5)

[Turn over

9. (a) A student is measuring the thickness of a piece of paper using a thin air wedge. The air wedge is formed between two glass plates that are in contact at one end and separated by a sheet of paper at the other end.

Monochromatic light is reflected down onto the air wedge. A travelling microscope is used to view the resulting interference pattern as shown in Figure 9A.

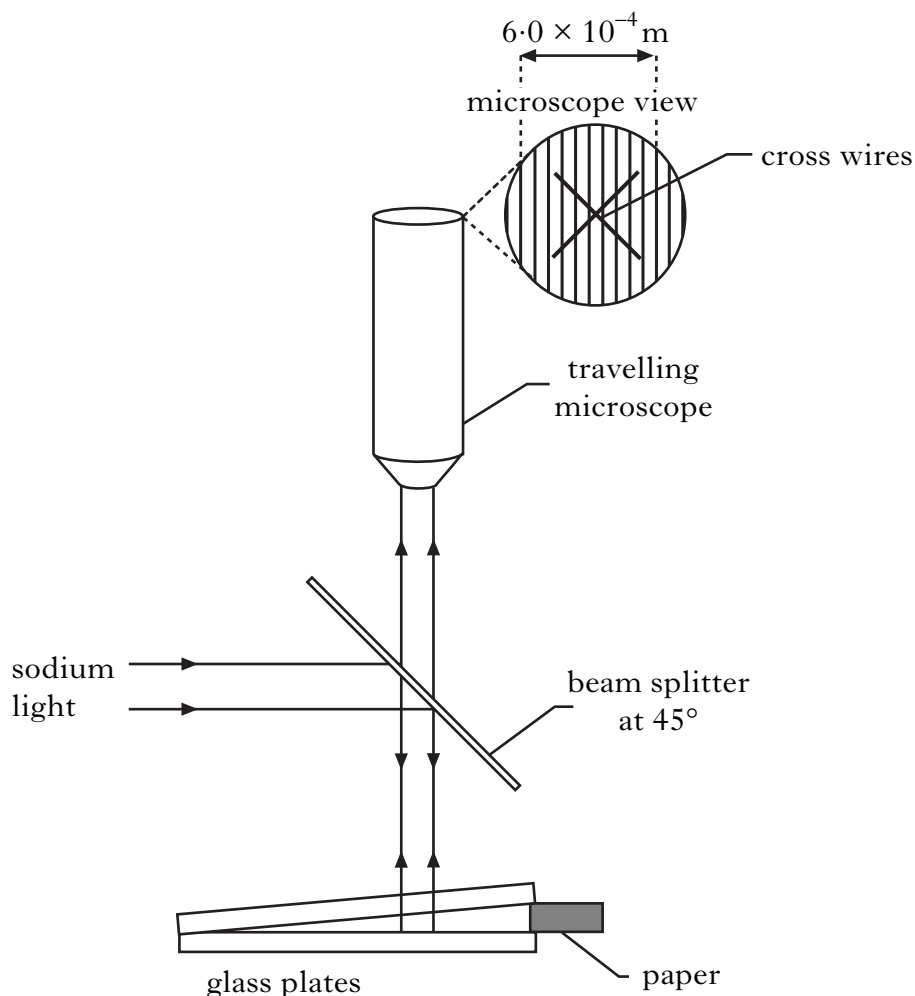


Figure 9A

- (i) The air wedge produces interference by division of amplitude.
State what is meant by the term *division of amplitude*. 1
- (ii) The following data is obtained.
10 fringe separations = $(6.0 \pm 0.5) \times 10^{-4}$ m
Wavelength, $\lambda = 580 \text{ nm} \pm 10 \text{ nm}$
Length of glass plate, $l = (4.0 \pm 0.1) \times 10^{-2}$ m
Calculate the thickness of the paper. 3
- (iii) Calculate the percentage uncertainty in the thickness. 2

9. (continued)

- (b) A beam of monochromatic light of wavelength 580 nm illuminates a film of soap that is held in a wire loop. An interference pattern is produced as shown in Figure 9B.

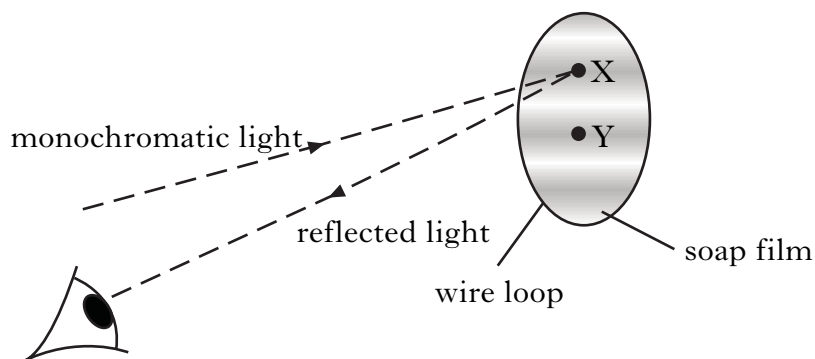


Figure 9B

An expanded view of part of the film is shown in Figure 9C.

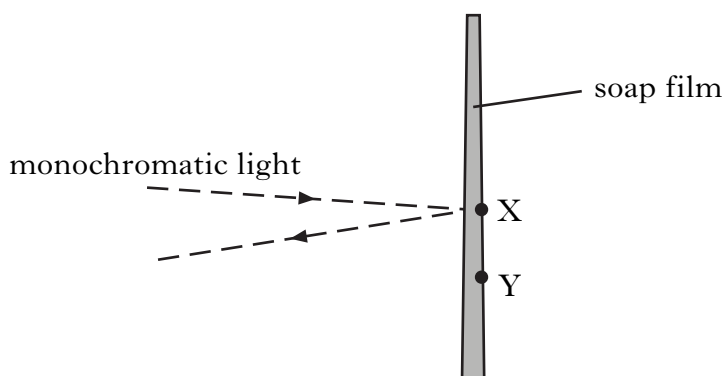


Figure 9C

- (i) Destructive interference occurs when light is reflected at position X.

Explain why destructive interference occurs. You may include a diagram as part of your answer.

2

- (ii) At position X the thickness of the film is $4.00\ \mu\text{m}$.

The refractive index of the film of soap is 1.45.

Calculate the optical path difference produced by this film at position X.

2

- (iii) The **next** position where destructive interference occurs is position Y where the film is slightly thicker.

Calculate the optical path difference produced by the film at position Y.

2

(12)

10. A long pipe containing polystyrene beads is closed by a plunger. A loudspeaker at the other end is connected to a signal generator as shown in Figure 10A.



Figure 10A

The loudspeaker is switched on and the frequency is adjusted until a stationary sound wave is set up in the tube. The polystyrene beads form the pattern shown in Figure 10B. The distance between successive piles of beads is 85 mm.

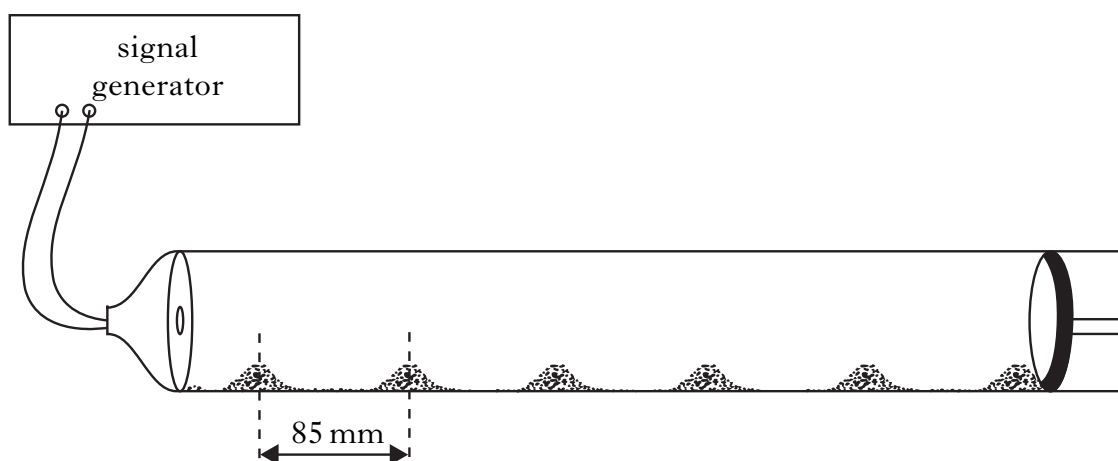


Figure 10B

- (a) Explain how sound waves in the tube produce the stationary wave. 1
- (b) Define the terms node and antinode. 1
- (c) Do the polystyrene beads collect at nodes or antinodes? Justify your answer. 2
- (d) The signal generator is set to 1.95 kHz. Calculate the speed of sound in air. 3
- (7)**

[END OF QUESTION PAPER]

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