X069/701

NATIONAL QUALIFICATIONS 2002

WEDNESDAY, 22 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	g	$9{\cdot}8\ \text{m s}^{-2}$	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
Mean Radius of Moon Orbit		$3{\cdot}84 \times 10^{8}$ m	Planck's constant	h	$6{\cdot}63 \times 10^{-34}$ J s
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}\ \text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}\ \text{F m}^{-1}$
Speed of light in vacuum	c	$3{\cdot}0 \times 10^{8}\ \text{m s}^{-1}$	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \text{H m}^{-1}$
Speed of sound in air	v	$3{\cdot}4 \times 10^{2}\ \text{m s}^{-1}$			

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*
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*/ 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	$2{\cdot}70 \times 10^{3}$	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.

Marks

1. (*a*) An object moves with constant acceleration a.

At time $t = 0$ its displacement s is zero.

The velocity v of the object is given by $v = u + at$.

Derive the equation

$$s = ut + \tfrac{1}{2}at^2$$

where the symbols have their usual meanings. **2**

(*b*) Relativistic mass is given by the equation

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

where the symbols have their usual meanings.

In a particle accelerator electrons reach a velocity of $2{\cdot}0 \times 10^8\,\mathrm{m\,s^{-1}}$.

Calculate the relativistic energy of an electron at this velocity. **3**

(5)

[Turn over

Marks

2. The flywheel shown in Figure 1 consists of a uniform disc of diameter 0·80 m and moment of inertia 180 kg m^2.

The flywheel is spinning at 2500 revolutions per minute on a friction-free bearing.

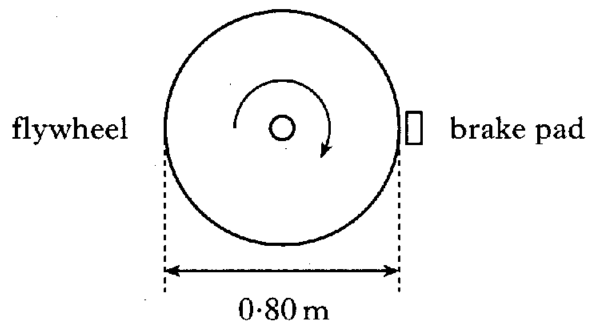

Figure 1

(*a*) (i) Show that the angular velocity of the flywheel is 260 rad s^{-1}.

(ii) Calculate the rotational kinetic energy of the flywheel. **4**

(*b*) A brake pad now applies a constant force to the rim of the flywheel, bringing it to rest in 40 s.

Calculate:

(i) the angular deceleration of the flywheel;

(ii) the force between the brake pad and the flywheel. **5**

(*c*) The flywheel is replaced with one of the same mass and diameter, but with most of the mass concentrated near the rim. This new flywheel also spins at 2500 revolutions per minute.

The same braking force is applied.

Is the time taken for this flywheel to come to rest less than, equal to or greater than 40 s? **You must justify your answer**. **2**

(11)

3. (*a*) The gravitational force exerted by the Earth maintains a satellite in a circular orbit of radius *r*.

By equating the expressions for gravitational force and centripetal force, show that

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

where the symbols have their usual meanings. **2**

(*b*) The orbital period of a geostationary satellite is equal to the period of rotation of the Earth about its axis.

Calculate:

(i) the height of the satellite above the Earth's surface;

(ii) the speed of the satellite in its orbit. **5**

(*c*) Another satellite is in an orbit of radius $6{\cdot}7 \times 10^6$ m around the Earth. This satellite is to be boosted to escape velocity.

(i) Explain the term "escape velocity".

(ii) Use the expression

$$v = \sqrt{\frac{2GM}{r}}$$

to calculate the escape velocity. **3**

(10)

[Turn over

4. A mass of 0·40 kg is suspended from a spring as shown in Figure 2. The mass is then displaced vertically and released. Its subsequent motion is recorded using a motion sensor linked to a computer.

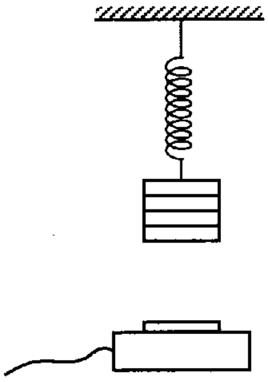

Figure 2

The mass moves with simple harmonic motion. The displacement-time graph of the mass is shown in Figure 3.

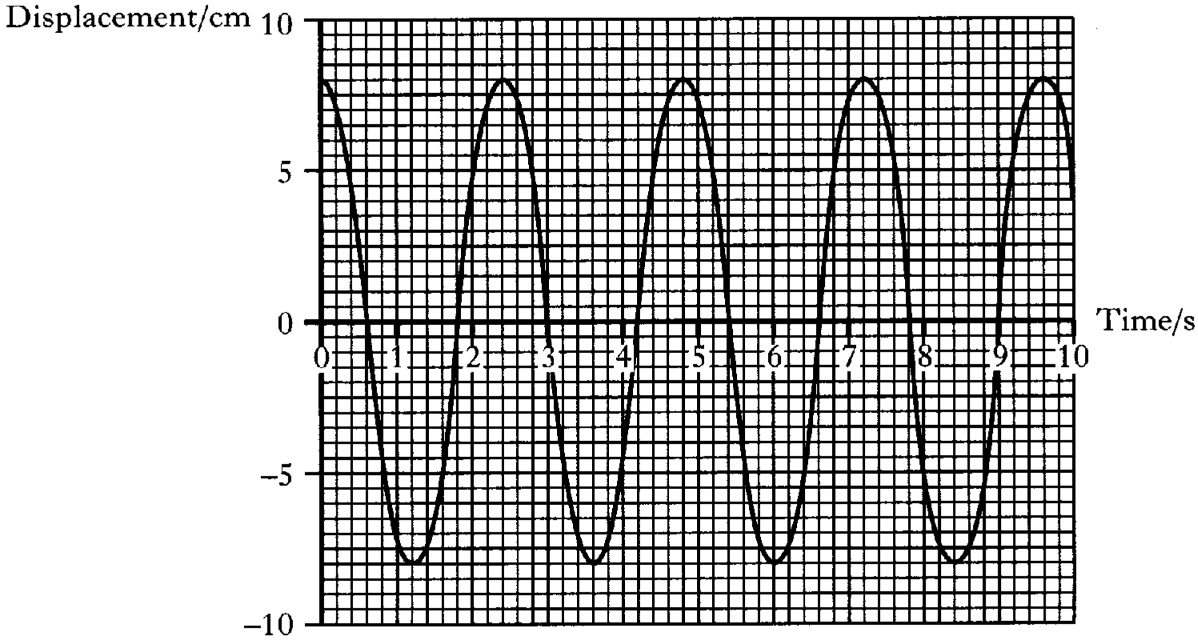

Figure 3

(*a*) Find:

(i) the amplitude of the oscillation;

(ii) the period of the oscillation. **2**

(*b*) Using the values from part (*a*), obtain an expression, in the form $y = A\cos\omega t$, for the vertical displacement y of the mass. **2**

(*c*) (i) Using the solution to part (*b*), derive an expression which gives the relationship between the acceleration a of the mass and time t.

(ii) Calculate the maximum kinetic energy of the mass. **5**

(9)

Marks

5. (*a*) (i) Electrons exhibit wave-like behaviour.

Give **one** example of experimental evidence which supports this statement.

(ii) Electrons can also exhibit particle-like behaviour.

Give **one** example of experimental evidence which supports this statement. **2**

(*b*) De Broglie showed that it is possible to calculate a wavelength for a moving object.

A tennis ball of mass 60 g is served at $55\ m\ s^{-1}$.

(i) Calculate the de Broglie wavelength for this ball.

(ii) Explain why wave-like properties are not observed for this ball. **3**

(5)

[Turn over

Marks

6. (*a*) Calculate the magnitude of the electrostatic force between two protons separated by a distance of 0·010 mm. **2**

(*b*) Despite the electrostatic force of repulsion, the protons in an atomic nucleus do not fly apart.

(i) Name the force which holds protons together in a nucleus.

(ii) Explain why this force has negligible effect on the protons in part (*a*). **2**

(*c*) In a Rutherford scattering experiment, an alpha particle with a velocity of $2{\cdot}0 \times 10^{6}\,\mathrm{m\,s^{-1}}$ is fired at a target of gold foil in a vacuum. The mass of an alpha particle is $6{\cdot}7 \times 10^{-27}\,\mathrm{kg}$ and the atomic number of gold is 79.

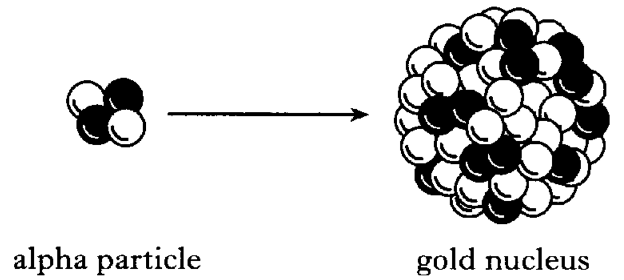

Figure 4

Calculate the distance of closest approach for a head-on collision between the alpha particle and a gold nucleus. **4**

(8)

7. In a cathode ray tube, electrons emitted from the cathode are accelerated from rest through a potential difference of 2·0 kV, as shown in Figure 5.

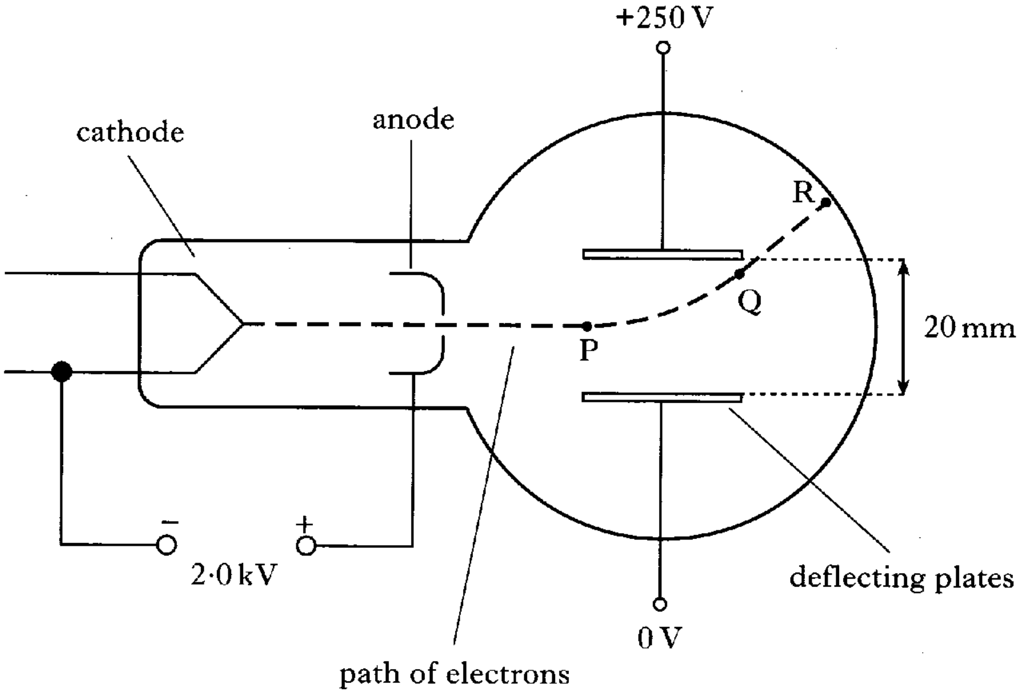

Figure 5

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

(*b*) After leaving the anode, the electrons pass between two parallel deflecting plates separated by 20 mm. The potential difference between the deflecting plates is 250 V.

The electrons follow path PQR.

(i) By considering the forces acting on the electrons, explain the shape of the path between:

(A) P and Q;

(B) Q and R.

Assume gravitational effects to be negligible.

(ii) Calculate the acceleration of the electrons between the deflecting plates. **6**

(*c*) The moving electrons can also be deflected by a magnetic field.

(i) Explain why electrons travelling perpendicularly to a uniform magnetic field follow a circular path.

(ii) Find the magnitude **and** direction of the magnetic induction required to balance the electrostatic force on the electrons in part (*b*), so that zero deflection would be produced. **4**

(12)

8. (*a*) A student investigating the force on a current-carrying conductor placed perpendicularly to a uniform magnetic field obtains the following readings.

Length of conductor	= (0·050 ± 0·001) m				
Current	= (2·50 ± 0·01) A				
Force readings	3·8 mN	3·4 mN	3·3 mN	3·7 mN	3·3 mN

(i) Calculate the magnetic induction B, in Tesla, using the equation $F = BIl$.

(ii) Calculate the **absolute** uncertainty in this value.

(iii) Suggest **one** improvement that would reduce the uncertainty in the value obtained for the magnetic induction. **Justify your answer.** **7**

(*b*) The rectangular coil, PQRS, of a model motor consists of 20 turns of wire. PQ = 50 mm and QR = 40 mm.

The coil is placed horizontally between two magnets as shown in Figure 6.

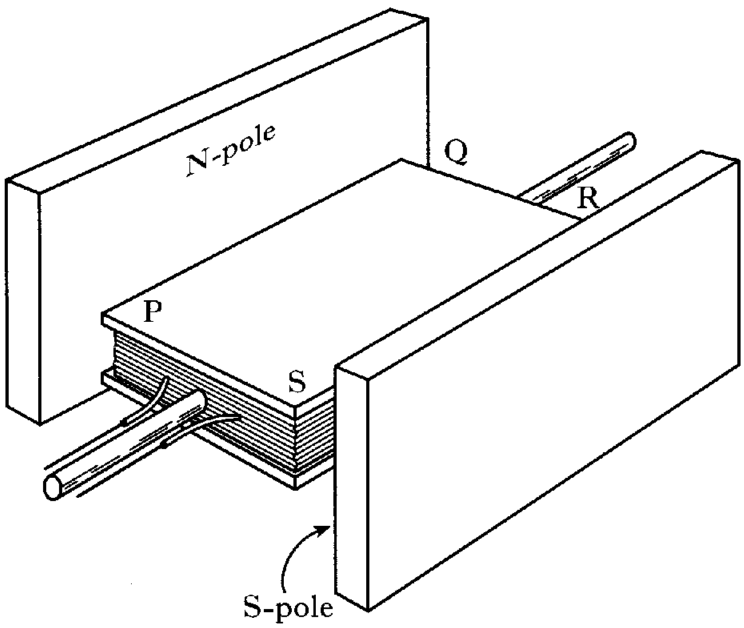

Figure 6

The magnets produce a uniform horizontal field of magnetic induction 0·1 T. The current in the coil is 2·2 A.

(i) Explain why the force on the wire on side QR is zero.

(ii) Calculate the torque on the coil.

(iii) The coil starts to rotate. What happens to the torque? Give a reason for your answer. **6**

(13)

Marks

9. In the circuit shown in Figure 7 the battery has e.m.f. 12 V and negligible internal resistance. The resistance of the inductor can be ignored.

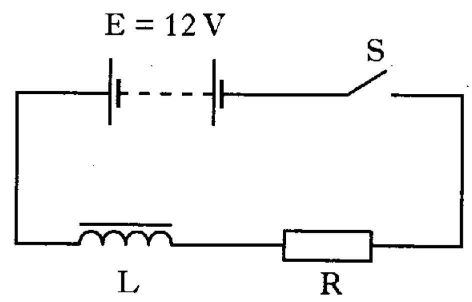

Figure 7

The graph in Figure 8 shows the growth of current in the circuit after switch S is closed.

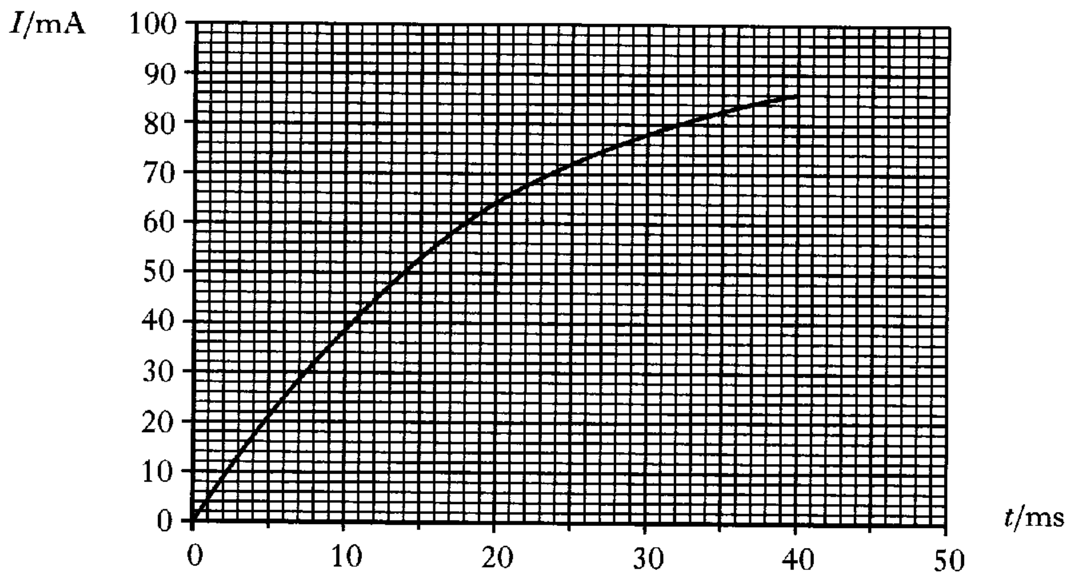

Figure 8

(*a*) State the magnitude of the back e.m.f. at the instant the switch is closed. **1**

(*b*) Use the graph to determine the initial rate of change of current. **1**

(*c*) Calculate the self-inductance of the coil. **2**

(*d*) The final steady current is 96 mA. Calculate the resistance of resistor R. **2**

(*e*) Calculate the maximum energy stored in the inductor. **2**

(8)

[Turn over

Marks

10. (*a*) A water wave travelling in the negative x direction has frequency 3·0 Hz, velocity $0{\cdot}050\,m\,s^{-1}$ and initial amplitude 0·040 m.

(i) Write down an expression for the displacement y of a point on the water surface in terms of x and time t.

(ii) After some time the amplitude of the wave has fallen to 0·020 m.

By what factor has the intensity of the wave changed compared to its initial value? **4**

(*b*) When a continuous sound wave of constant frequency is reflected from a wall, a stationary wave is produced.

Explain in terms of the incident and reflected waves how nodes **and** anti-nodes are formed. **2**

(*c*) (i) A car horn produces a note of frequency 200 Hz.

The horn is sounded as the car is moving at $30\,m\,s^{-1}$ away from a stationary observer.

Calculate the frequency heard by the observer.

(ii) An observer on Earth notes that the frequency of light from a distant galaxy is Doppler shifted towards the red end of the spectrum.

State whether the galaxy is moving towards or away from Earth. **You must justify your answer**. **4**

(10)

Marks

11. (*a*) (i) Explain, **with the aid of a diagram**, how a thin coating on the surface of a camera lens can make it non-reflecting for monochromatic light at near normal incidence.

(ii) Calculate the thickness of a layer of magnesium fluoride required to make the surface of a lens non-reflecting for light of wavelength 500 nm.

(iii) When white light is incident upon a lens with this coating, a purple hue is observed in the reflected light. Explain how this colour effect is produced. **6**

(*b*) Light from a red laser is incident upon a double slit which has a slit separation of $5{\cdot}0 \times 10^{-5}$ m. A screen is placed 2·0 m beyond the double slit as shown in Figure 9.

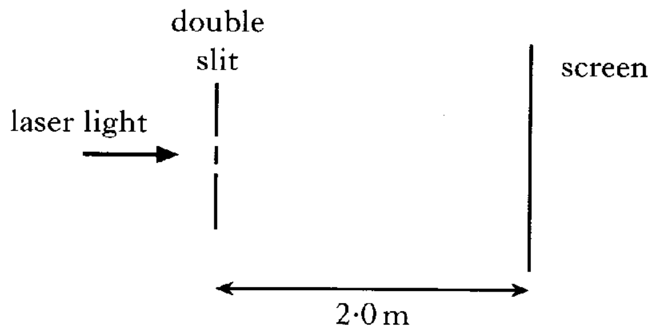

Figure 9

A pattern of light and dark fringes, as shown in Figure 10, is observed on the screen.

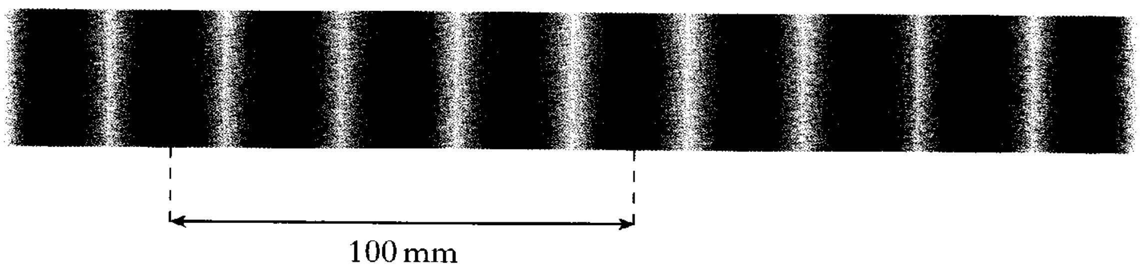

Figure 10

Calculate the wavelength of the laser light. **3**

(9)

[*END OF QUESTION PAPER*]