Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2020 Preliminary Examination

PHYSICS **9749/02**
Higher 2

16 September 2020
Paper 2 Structured Questions **2 hours**

Candidates answer on the Question Paper.
No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces at the top of this page.
Write in dark blue or black pen in the spaces provided in this booklet.
You may use pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions. The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	/ 8
2	/ 8
3	/ 8
4	/ 12
5	/ 12
6	/ 8
7	/ 24
Deduction	
Total	/ 80

This document consists of **24** printed pages.

Data

speed of light in free space	c	=	3.00×10^{8} m s^{-1}
permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space	ε_0	=	8.85×10^{-12} F m^{-1}
		=	$(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge	e	=	1.60×10^{-19} C
the Planck constant	h	=	6.63×10^{-34} J s
unified atomic mass constant	u	=	1.66×10^{-27} kg
rest mass of electron	m_e	=	9.11×10^{-31} kg
rest mass of proton	m_p	=	1.67×10^{-27} kg
molar gas constant	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant	k	=	1.38×10^{-23} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on/by a gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	ϕ	=	$-Gm/r$
temperature	T/K	=	T / °C + 273.15
pressure of an ideal gas	p	=	$\frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\frac{3}{2}kT$
displacement of particle in s.h.m.	x	=	$x_0 \sin\omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos\omega t = \pm\omega\sqrt{x_0^2 - x^2}$
electric current	I	=	$Anvq$
resistors in series	R	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential	V	=	$\frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	x	=	$x_0 \sin\omega t$
magnetic flux density due to a long straight wire	B	=	$\frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$
radioactive decay	x	=	$x_0 \exp(-\lambda t)$
decay constant	λ	=	$\frac{\ln 2}{t_{\frac{1}{2}}}$

Answer **all** the questions in the spaces provided.

1 **(a)** A projectile, at ground level, is launched with an initial velocity u at an angle θ to the horizontal as shown in Fig. 1.1.

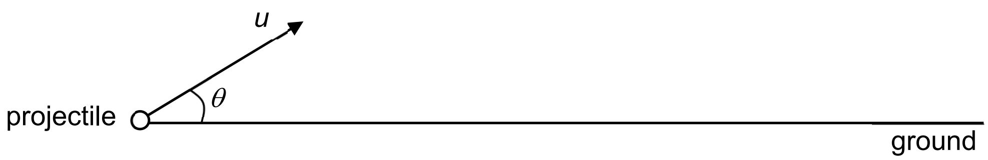

Fig. 1.1

Ignoring the effects of air resistance, show that the time t_0 taken by the projectile to land on the ground is given by

$$t_0 = \frac{2u\sin\theta}{g}.$$

Explain your working.

[2]

(b) Fig. 1.2 shows a cart moving with constant velocity v in front of the projectile launcher.

A projectile is launched with velocity $u = 35$ m s^{-1} at an angle $\theta = 23°$. At this instant, the back of the cart is 45 m from the position of launch.

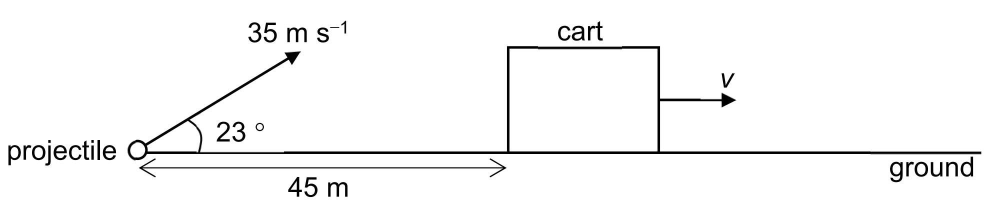

Fig. 1.2

(i) Ignoring the effects of air resistance,

1. Determine the velocity v of the cart such that the projectile will land just behind it.

v = ... m s^{-1} [3]

2. On Fig. 1.3, sketch the variation with time t of the kinetic energy E_K of the projectile from the time it was launched to the time it just lands behind the cart. Include all relevant numerical values on the horizontal axis.

Fig. 1.3

[2]

(ii) Suggest how the projectile should be launched such that it will still land just behind the cart, if the effects of air resistance on the projectile are not negligible.

....

.... [1]

2 Fig. 2.1 shows a crane being used to lift and lower a load of mass 300 kg. The load at point B is attached to point A of the jib using a cable.

Another supporting cable attached at point C supports the far end of the jib at point A. The supporting cable makes an angle of 25° with the jib at point A.

The nearer end of the jib is connected to the cab at point D.

The mass of the jib is 2400 kg and the mass of the cab is 16000 kg. Their centres of mass are at their mid-points E and F respectively. The masses of the hook at point B and the cables are negligible.

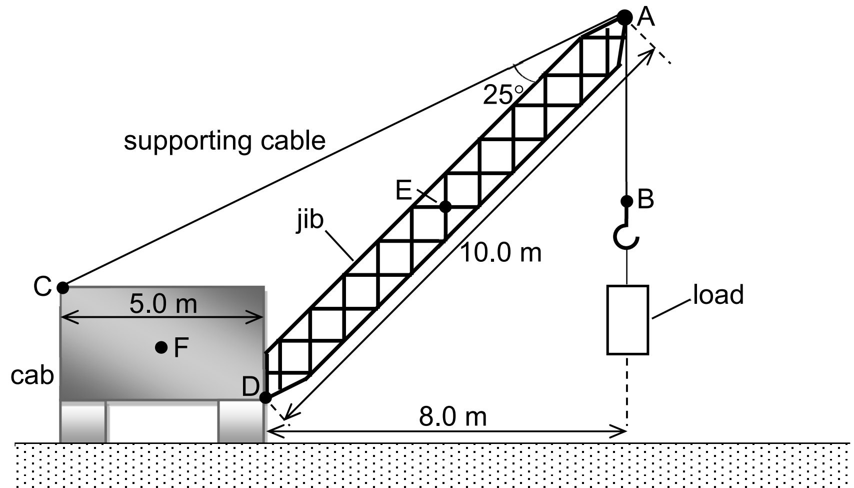

Fig. 2.1

(a) When the load is lowered with a deceleration of 1.0 m s^{-2},

(i) show that the tension in the cable AB is 3240 N,

[1]

(ii) calculate the corresponding tension in the supporting cable AC.

tension in AC = ... N [2]

(b) For the jib in the position shown in Fig. 2.1, there is a maximum load which will just topple the crane.

(i) On Fig. 2.1, label **G**, the point about which the crane will topple.

[1]

(ii) Determine the maximum load which will just topple the crane.

maximum load = ... N [2]

(c) The load is a rectangular slab of concrete. Fig. 2.2 shows how the slab of concrete is hooked to cable AB of the jib.

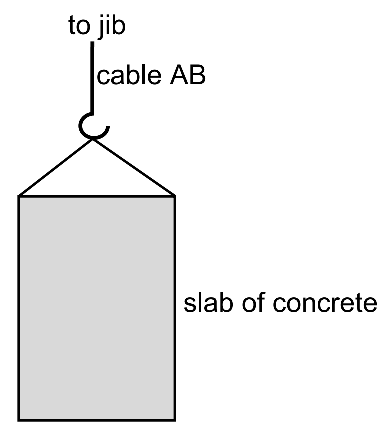

Fig. 2.2

Explain why the crane is more likely to topple on a windy day when carrying this slab of concrete.

....

....

.... [2]

3 A small ball of mass 0.30 kg is attached to one end of a light inelastic string. The other end C of the string is fixed. The ball is made to rotate about C in a vertical circle of radius 65 cm as shown in Fig. 3.1.

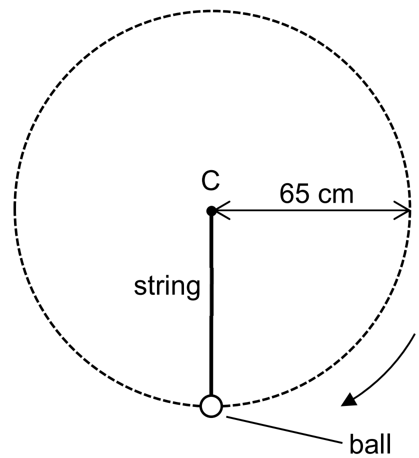

Fig. 3.1

The angular speed of the ball is gradually increased from zero until the string snaps. This happens when the tension in the string is 16 N.

(a) The string is observed to snap when the ball is vertically below C.

(i) On Fig. 3.1, sketch the path of the ball after the string snaps. [1]

(ii) Calculate the angular speed ω_1 of the ball at the instant the string snaps.

ω_1 = ... rad s^{-1} [2]

(b) Another experiment is carried out with another set of identical string and ball. The ball is rotated in a horizontal circle, with the string inclined at an angle θ to the vertical, as shown in Fig. 3.2.

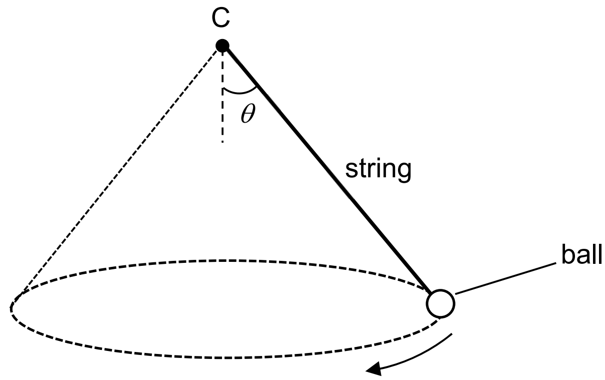

Fig. 3.2

The angular speed of the ball is gradually increased from zero and the ball is observed to rise to a higher horizontal plane. The string snaps when the angular speed is increased to ω_2.

(i) In terms of the forces acting on the ball, explain the observation that the ball rises to a higher horizontal plane when the angular speed is increased.

....

....

....

....

....

....

.... [3]

(ii) Explain, using relevant equations or otherwise, whether ω_2 is larger or smaller than ω_1 in **(a)(ii)** when the string snaps.

....

....

....

....

.... [2]

4 **(a)** **(i)** State what is meant by the wavelength λ and frequency f of a wave.

wavelength: ....

....

frequency: ....

.... [2]

(ii) Deduce a relation between the two quantities in **(a)(i)** and the speed v of propagation of a wave.

[1]

(b) Coherent light of wavelength 633 nm is incident normally on a double slit arrangement, as shown in Fig 4.1.

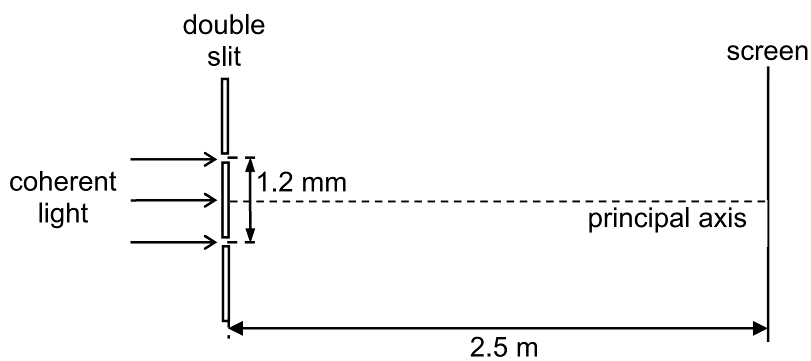

Fig. 4.1 (not to scale)

The separation of the slits is 1.2 mm.

Interference fringes are observed on a screen placed parallel to and 2.5 m from the plane of the double slit. The variation with angular position θ from the principal axis of the intensity of the fringes is shown in Fig. 4.2.

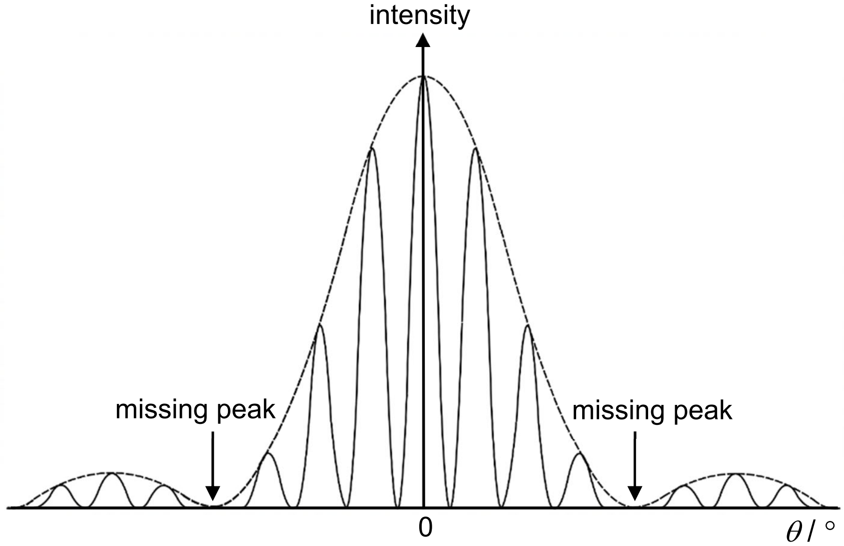

Fig. 4.2

(i) State two conditions necessary for the superposition of two waves to give rise to a well-defined interference pattern.

1. ....

....

2. ....

.... [2]

(ii) **1.** Explain why missing peaks are observed in the double slit interference intensity pattern.

....

....

.... [1]

2. Calculate the width *b* of each slit.

b = ... mm [2]

3. Determine the distance of the missing peak from the centre of the central bright fringe.

distance = ... m [2]

(iii) State and explain the changes to the interference pattern in Fig. 4.2 when the slit widths of the double slits are increased.

....

....

....

.... [2]

5 A cloud chamber consists of a rectangular box saturated with alcohol vapour. When a charged particle enters the cloud chamber, it interacts with the vapour and leaves a trail, indicating its path in the chamber.

A student designed a cloud chamber with a detector for the charged particles placed at one side of the chamber. A sample which emits identical charged particles is placed at a small opening through one side of the chamber. The charged particles are all emitted with the same speed. A uniform vertical magnetic field of flux density *B* is directed perpendicularly through the entire chamber.

Fig. 5.1 shows the top view of the chamber and the dotted line represents the path of a charged particle entering the chamber and moving on a horizontal plane in the chamber.

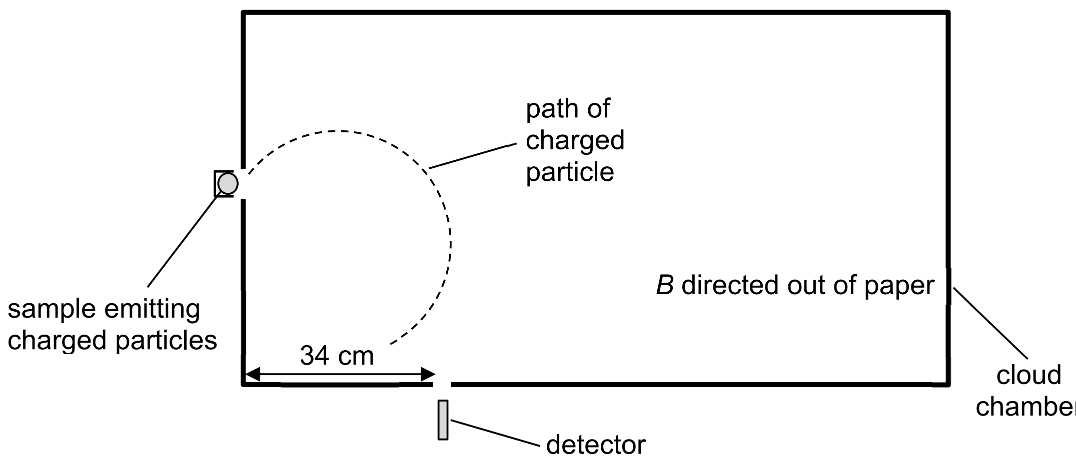

Fig. 5.1 (top view)

(a) **(i)** Define magnetic flux density.

....

....

.... [2]

(ii) State if the charged particle is positively or negatively charged.

.... [1]

(b) The design of the cloud chamber is refined so that particles only enter perpendicularly, as shown in Fig. 5.2.

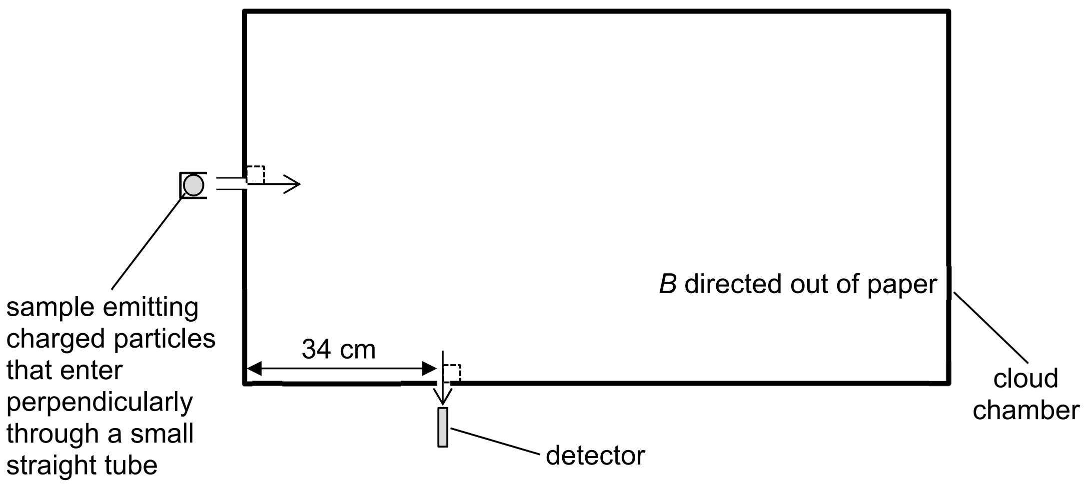

Fig. 5.2 (top view)

The magnitude of B is adjusted so that the particles with the same speed as in Fig. 5.1 will exit perpendicularly through a small opening on another side where the detector is placed. The detector is placed 34 cm from the corner of the chamber.

(i) Derive an expression for B in terms of mass m, speed v and charge q of a charged particle and the radius r of its circular path in the chamber.

[2]

(ii) Deduce whether the magnitude of B has increased or decreased.

....

.... [1]

(iii) Given the magnitude of B is 7.6×10^{-3} T, and each particle has a charge of magnitude 3.2×10^{-19} C and mass 6.6×10^{-27} kg, determine the speed of the charged particle that reaches the detector.

speed = ... m s^{-1} [2]

(c) The design of the cloud chamber is further amended so that particles which enter perpendicularly will move though the chamber undeflected. This is achieved by simultaneously applying a uniform electric field across the chamber.

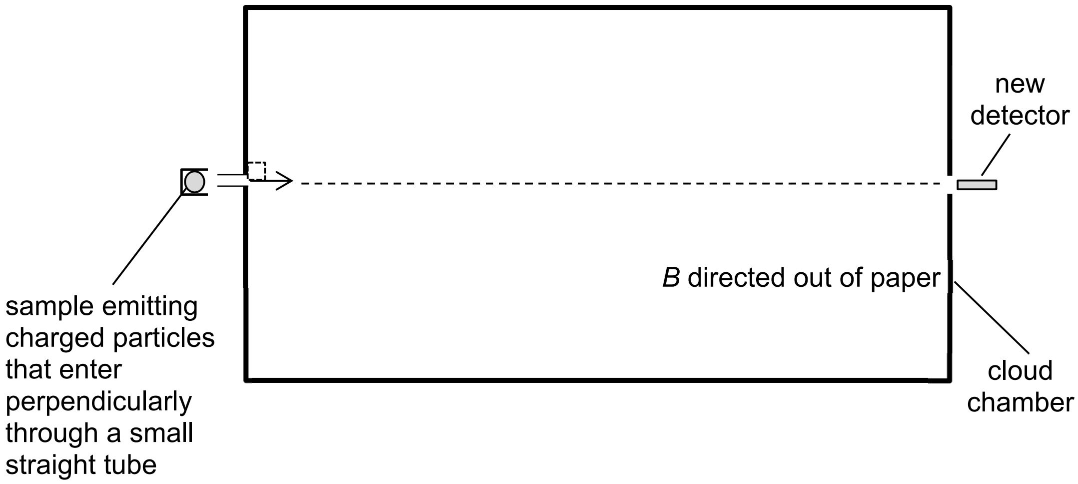

Fig. 5.3 (top view)

(i) State and explain the direction of the electric field.

....

....

.... [2]

(ii) The sample is now placed in the centre of the cloud chamber. Fig. 5.4 shows the direction of speed v of one of the emitted charged particles.

With the electric and magnetic fields still applied in the same directions in the cloud chamber as in **(c)(i)**, draw arrows to represent the electric force and the magnetic force acting on the particle at this instant. Label the forces.

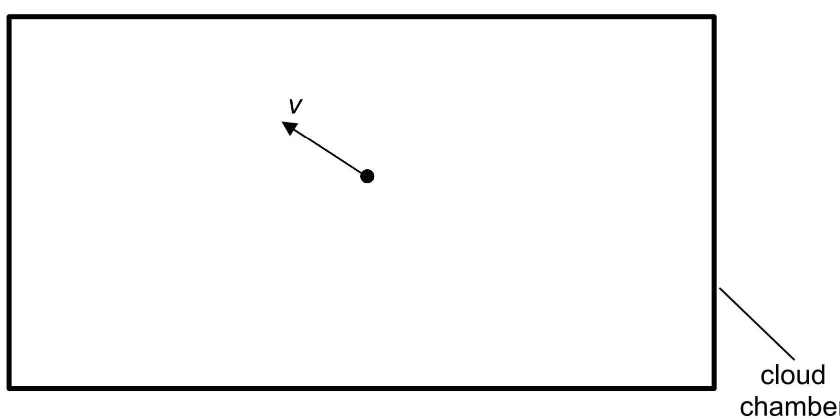

Fig. 5.4 (top view)

[2]

6 A student uses a 240 V, 50 Hz sinusoidal alternating supply, a transformer and a diode to design a circuit. The circuit produces a direct voltage of peak value 6.0 V across a load of resistance 4.0 Ω. Both the transformer and diode can be assumed to be ideal.

The partially completed circuit diagram is shown in Fig. 6.1.

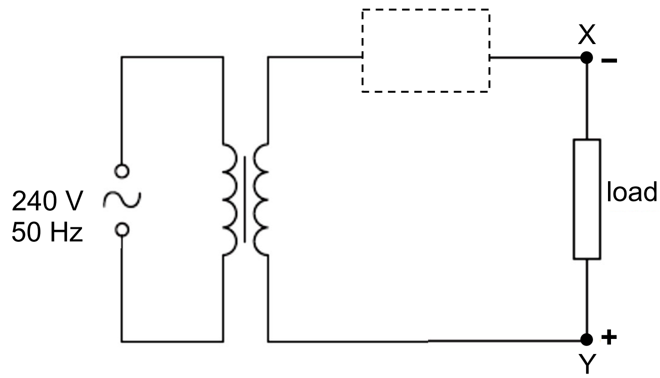

Fig. 6.1

(a) In the dotted box of Fig. 6.1, draw the symbol representing the diode that needs to be connected such that Y has a higher potential than X across the load.

[1]

(b) The root-mean-square (r.m.s.) voltage of the alternating supply is 240 V.

Explain what is meant by root-mean-square voltage.

....

....

.... [1]

(c) Calculate the ratio

$$\frac{\text{number of turns on the secondary coil}}{\text{number of turns on the primary coil}}.$$

ratio = ... [2]

(d) On Fig. 6.2, sketch a graph to show for the load, the variation with time t of the potential of X with respect to Y (V_{XY}) for up to $t = 0.060$ s.

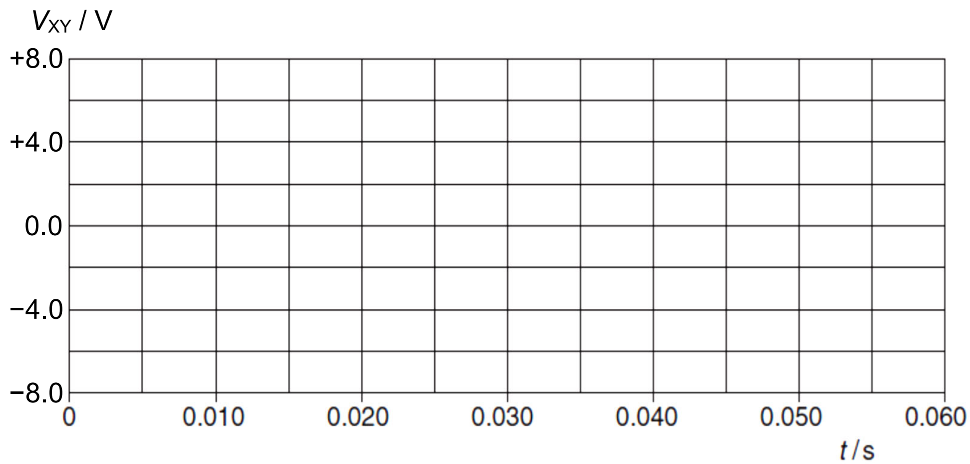

Fig. 6.2

[2]

(e) Calculate, for the load,

(i) the r.m.s. voltage,

r.m.s. voltage = ... V [1]

(ii) the mean power dissipated.

mean power = ... W [1]

7 Read the following article and answer the questions that follow.

Optical Tweezers

If you had to hold on to a grain of rice or a strand of hair, you might use a pair of tweezers. However, what would you use if you had to hold on to a particle just a few nanometers in size?

In 1970, Arthur Ashkin discovered that by using light from a tightly focused laser beam, you can effectively trap and even move microscopic particles. This led to the development of "optical tweezers", which allow scientists to study microscopic and even nanoscopic materials, including particles the size of just a few atoms.

In recent years, optical tweezers have been successfully used to study a variety of biological systems, including trapping single viruses and characterising biological motors within cells. Hence, in 2018, Arthur Ashkin was awarded the Nobel Prize in Physics for his groundbreaking work on optical trapping.

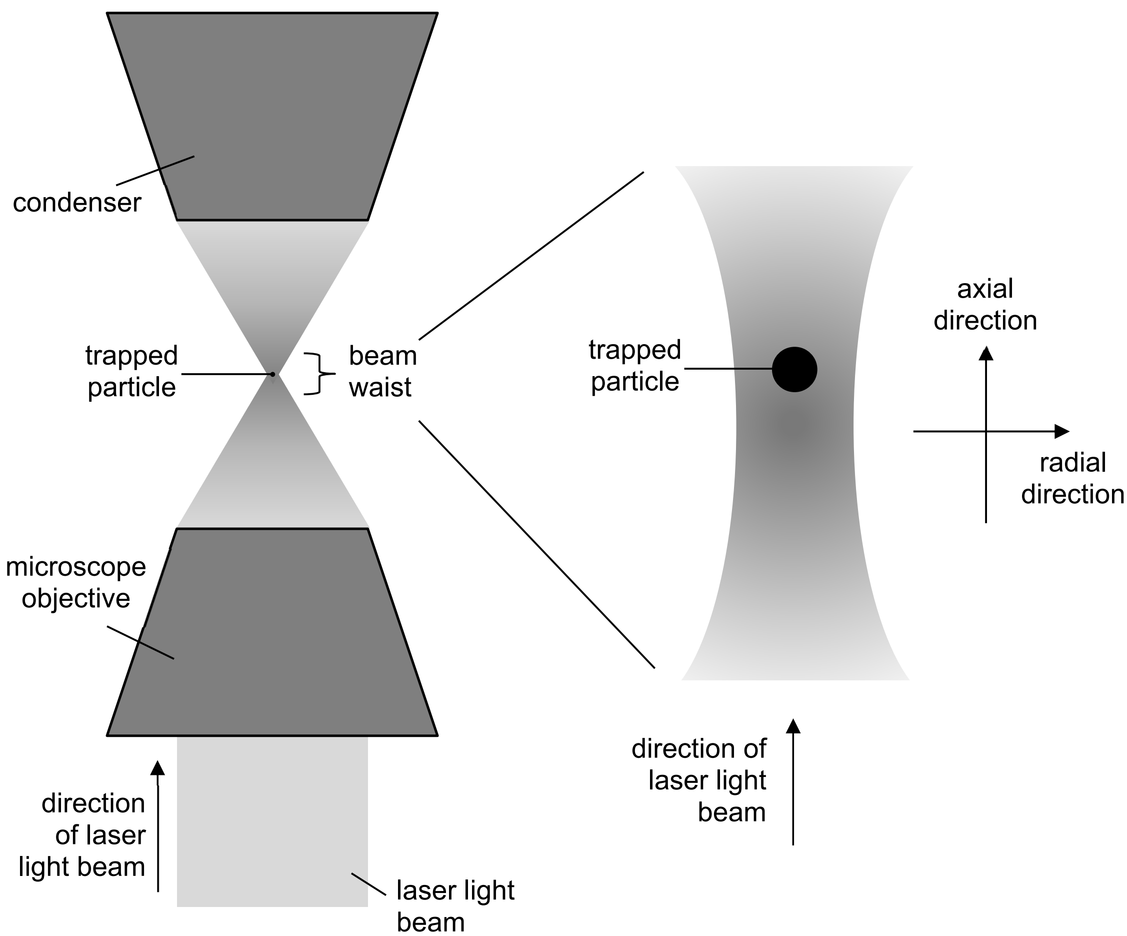

Fig. 7.1 **Fig. 7.2**

In a general optical tweezer setup, as shown in Fig. 7.1, collimated laser light is passed through a microscope objective, which focuses the laser at its focal point. The beam then diverges and enters a condenser. This forms the "beam waist" (the narrowest part of the focused laser beam), which is where the particle will be trapped, as shown in Fig. 7.2.

When trapped, the particle experiences forces from the laser light in all directions due to reflection and refraction. These forces act as a form of restoring force so that if the particle is displaced slightly, these forces will return it back to its equilibrium position. Hence, the particle remains trapped within the beam.

The forces experienced by the trapped particle are generally categorised into two types: *gradient* forces and *scattering* forces. *Gradient* forces act in all directions on the particle and arise from the intensity profile of the beam waist – the particle feels an attractive force towards the most intense part of the beam, which is the centre of the beam. *Scattering* forces, on the other hand, act in the direction of travel of the laser light and arise from the scattering of light off the particle, which tends to push and displace the particle in the direction of the laser light.

Fig. 7.3 and Fig. 7.4 show the variation with displacement of the restoring forces acting on the particle along the radial direction (perpendicular to the direction of beam propagation) and the axial direction (parallel to the direction of beam propagation) respectively.

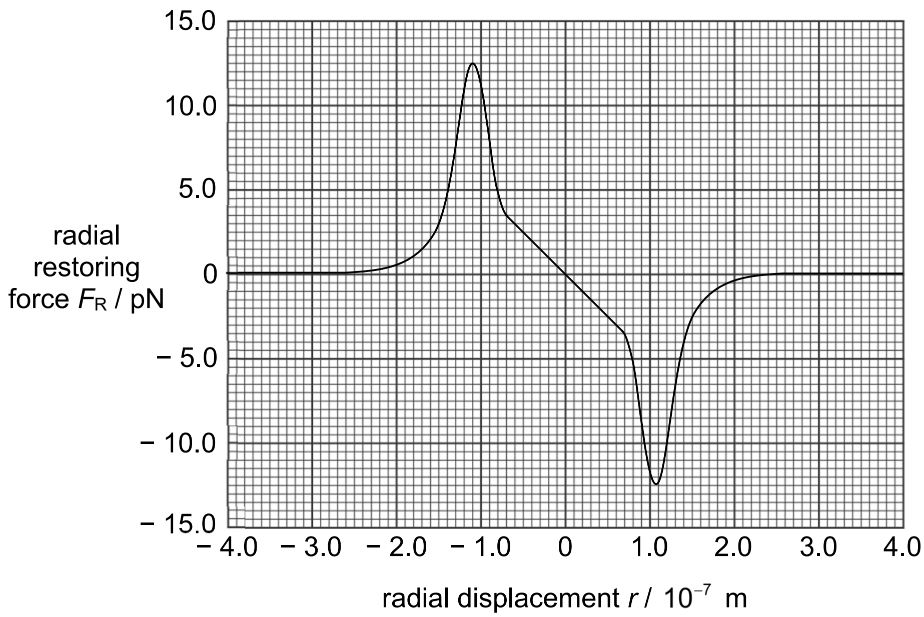

Fig. 7.3

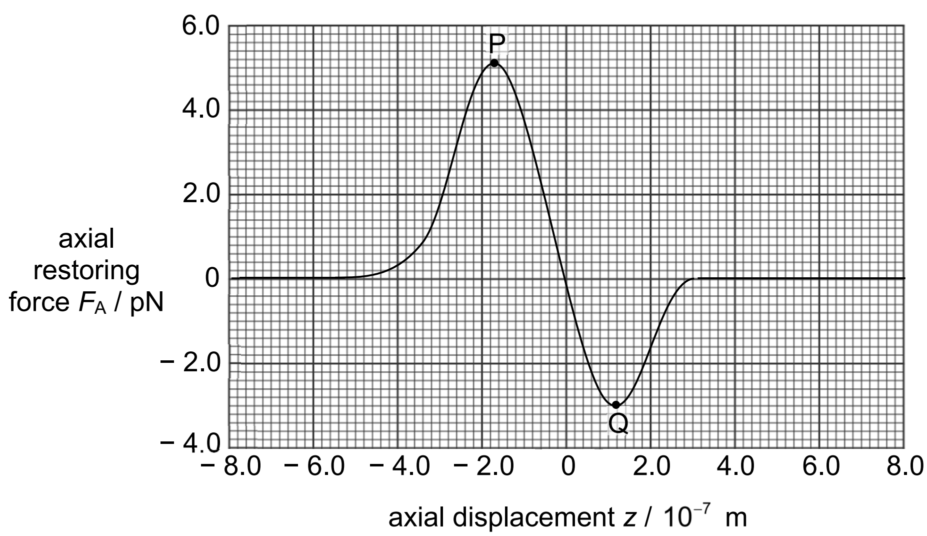

Fig. 7.4

(a) State and explain why *gradient* forces need to be larger in magnitude as compared to *scattering* forces in order for the particle to remain trapped in the beam.

....

....

....

.... [2]

(b) If the radial displacement r of a trapped particle from its equilibrium position is small, the radial restoring force F_R experienced by the particle can be modelled using Hooke's Law for a mass on a spring, which can be expressed as

$$F_R = -kr$$

where k is the radial spring constant.

(i) From Fig. 7.3, estimate the maximum displacement of the particle from its equilibrium position in which the restoring force can be approximated using Hooke's Law.

maximum displacement = ... m [1]

(ii) From Fig. 7.3, determine k.

k = ... N m^{-1} [2]

(iii) The particle is displaced from its equilibrium position along the radial direction such that the radial restoring force F_R can be described by Hooke's Law. It then begins to oscillate about its equilibrium position. The mass of the particle is 1.50×10^{-14} kg.

1. Explain why the oscillation of the particle can be described as simple harmonic.

....

....

....

....

....

.... [3]

2. Determine the frequency of oscillation of the particle.

frequency = ... Hz [2]

(c) By referring to Fig. 7.4, sketch on Fig. 7.5 the variation with axial displacement z of the particle's potential energy U along the axial direction from $z = -8.0 \times 10^{-7}$ m to $z = 8.0 \times 10^{-7}$ m as it oscillates in the axial direction.

On your sketch, label the points P and Q that correspond to the turning points P and Q in Fig 7.4.

Let U at the equilibrium position ($z = 0$) be zero.

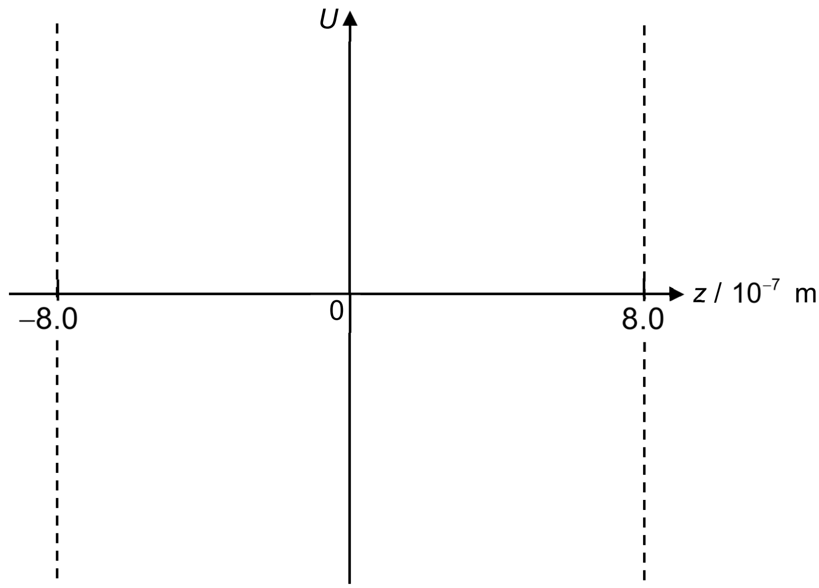

Fig. 7.5

[3]

(d) When the properties of a biological molecule like DNA are being studied, it is usually first attached to a microscopic glass bead. The bead is then immersed in a medium with a refractive index that is smaller than the refractive index of the glass bead. Following which, the bead is trapped and manipulated by optical tweezers in order to study the molecule's properties.

The restoring forces experienced by the trapped glass bead can be explained using the refraction of light through the glass bead. Fig. 7.6 shows a light ray from the laser beam being refracted as it passes through the glass bead.

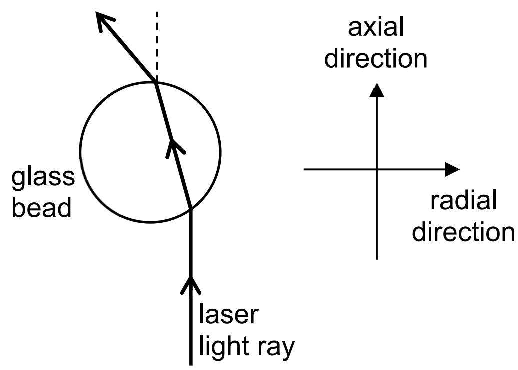

Fig. 7.6

(i) By considering the momentum of photons, explain how the refraction of the light ray exerts a force radially to the right on the glass bead.

....

....

....

....

....

.... [3]

(ii) A photon of wavelength 960 nm enters the glass bead and undergoes refraction, as shown in Fig. 7.7. It leaves the glass bead with the same wavelength but at an angle of 32° to its original direction.

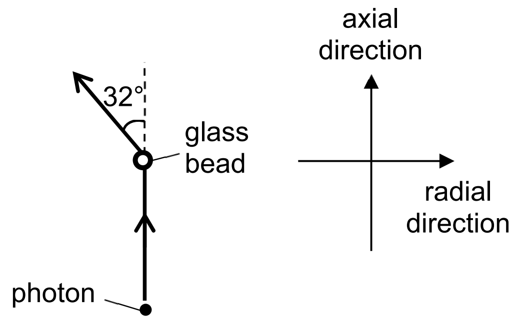

Fig. 7.7

Calculate

1. the momentum of the incident photon,

momentum = ... kg m s^{-1} [2]

2. the magnitude of the impulse of the photon in the radial direction,

impulse = ... kg m s^{-1} [2]

3. the magnitude of the impulse of the photon in the axial direction.

impulse = ... kg m s^{-1} [2]

(e) A major limitation of using optical tweezers to study biological samples is laser-induced heating arising from the high intensity of the tightly focused laser beam.

This results in an increase in temperature of the sample attached to the glass bead and the particles of the medium in which the glass bead is immersed in.

Suggest two reasons why the increase in temperature is not desirable to the study of the biological sample.

1. ....

....

....

2. ....

....

.... [2]

End of Paper 2