NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 2

CANDIDATE NAME

CLASS

TUTOR'S NAME

CENTRE NUMBER S

INDEX NUMBER

PHYSICS 9749/02

Paper 2 Structured Questions **13 September 2022**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and tutor's name in the spaces at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use a HB pencil for any diagrams, 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	**/ 8**
5	**/ 9**
6	**/ 11**
7	**/ 8**
8	**/ 20**
Total	**/ 80**

This document consists of **22** printed pages.

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

1 **(a)** A ball leaves the edge of a table with a horizontal velocity v, as shown in Fig. 1.1.

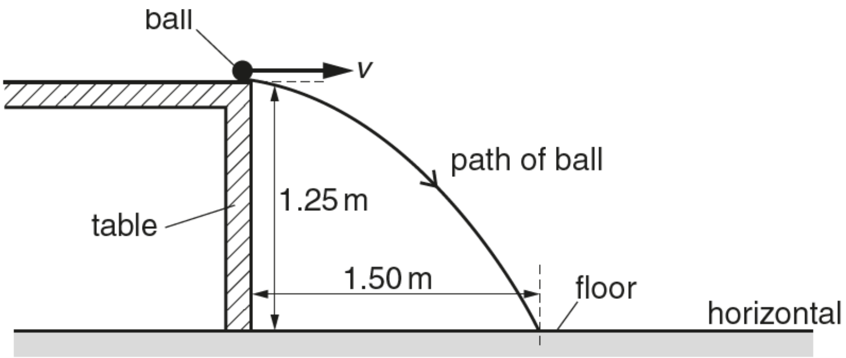

Fig. 1.1

The height of the table is 1.25 m. The ball travels a distance of 1.50 m horizontally before hitting the floor.

Air resistance is negligible.

Calculate, for the ball,

(i) the horizontal velocity v as it leaves the table,

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

(ii) the velocity just before it hits the floor.

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

(b) A second ball leaves the edge of the table with a horizontal velocity 2*v*.

(i) State and explain whether the time taken to hit the floor is the same or different compared to the first ball.

....

....[2]

(ii) Describe the variation of the vertical component of velocity if air resistance is not negligible.

....

....[2]

[Total: 8]

2 **(a)** State Newton's Second Law of motion.

....

....[1]

(b) A jet of water hits a vertical wall at right angles, as shown in Fig. 2.1. The jet of water has density ρ, cross-sectional area A, and hits the vertical wall with impact velocity u. The water then runs down the wall after impact with the wall.

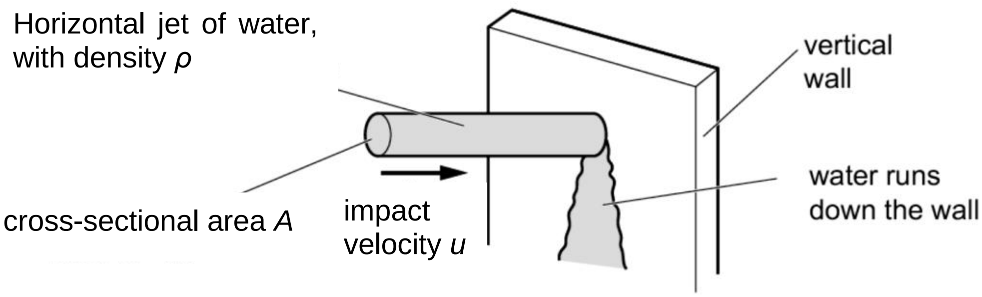

Fig. 2.1

(i) Using Newton's Law of motion, show that the magnitude of the average force exerted on the water by the wall is

$$F = \rho A u^2 .$$

[3]

(ii) The density of water ρ is 1000 kg m^{-3}. Given that the jet of water in **(b)** has cross-sectional area A of 1.5 cm^2 and impact velocity u of 5.0 m s^{-1},

1. Calculate the magnitude of the average force exerted on the wall by the water. Explain your answer.

magnitude of average force = ... N [2]

2. On Fig. 2.2, sketch a graph to show the variation of pressure p on the wall with impact velocity u. [1]

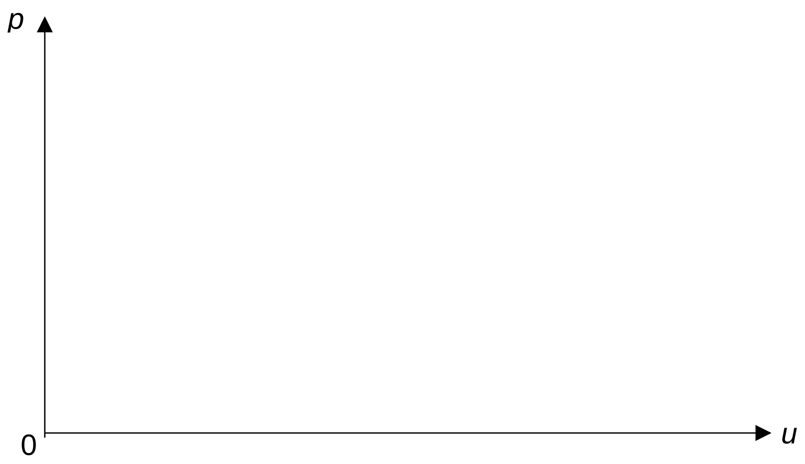

Fig. 2.2

3. Suggest the change, if any, to pressure p if the cross-sectional area A of the water jet is doubled.

....

....[1]

[Total: 8]

3 A ball of mass M of 750 g is held on a smooth horizontal surface between two identical springs at their natural lengths as shown in Fig. 3.1.

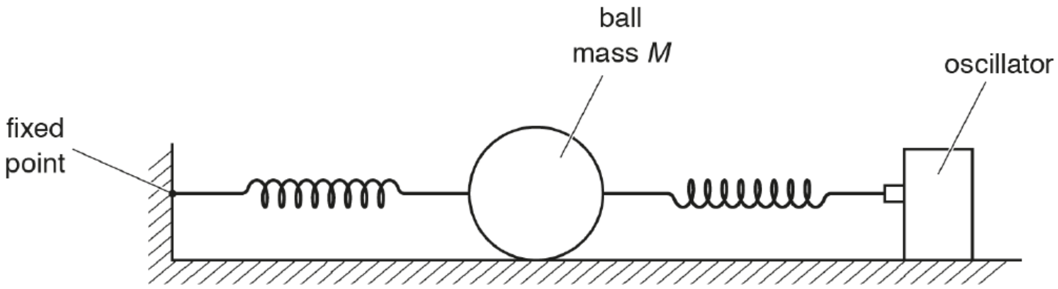

Fig. 3.1

One spring is attached to a fixed point while the other spring is attached to a mechanical oscillator. At t = 0 the ball is displaced to its amplitude position. The variation with time t of the displacement L of the ball is shown in Fig. 3.2.

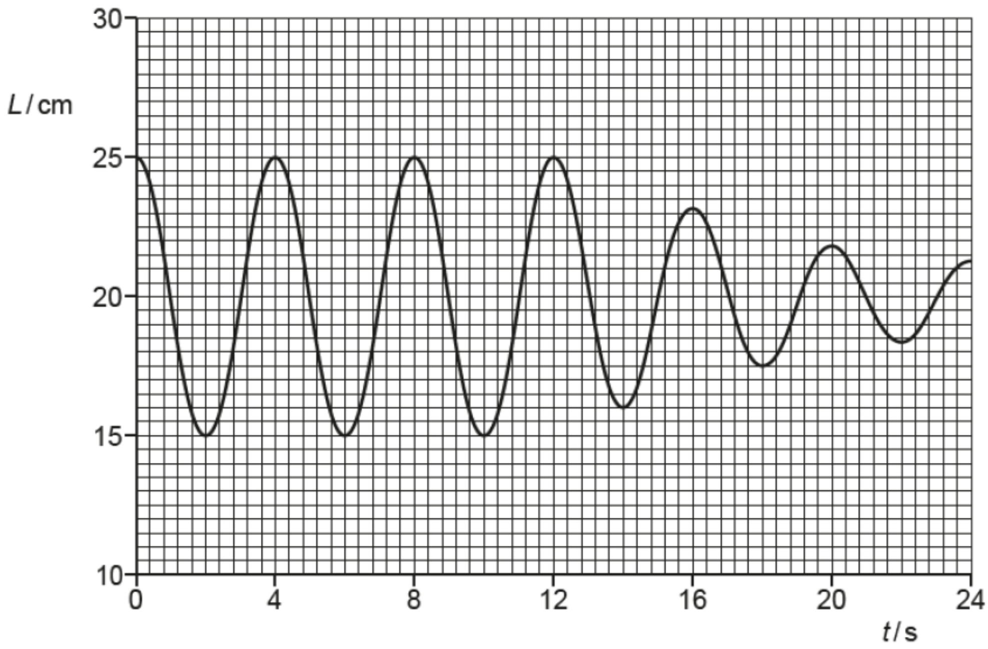

Fig. 3.2

(a) For the first 12 s of the oscillations,

(i) state one time at which the ball is moving with maximum speed,

time = ... s [1]

(ii) state one time at which the springs have maximum elastic potential energy,

time = ... s [1]

(iii) calculate the angular frequency ω of the ball,

ω = ... rad s^{-1} [1]

(iv) calculate the maximum acceleration of the ball.

maximum acceleration = ... m s^{-2} [2]

(b) Some salt is sprinkled on the horizontal surface at t = 12.0 s.

Calculate the loss in total energy of the oscillations during the first 24 s of the oscillations.

Show your working clearly.

[3]

[Total: 8]

4 Microwaves of the same wavelength and amplitude are emitted in phase from two point sources X and Y, as shown in Fig. 4.1.

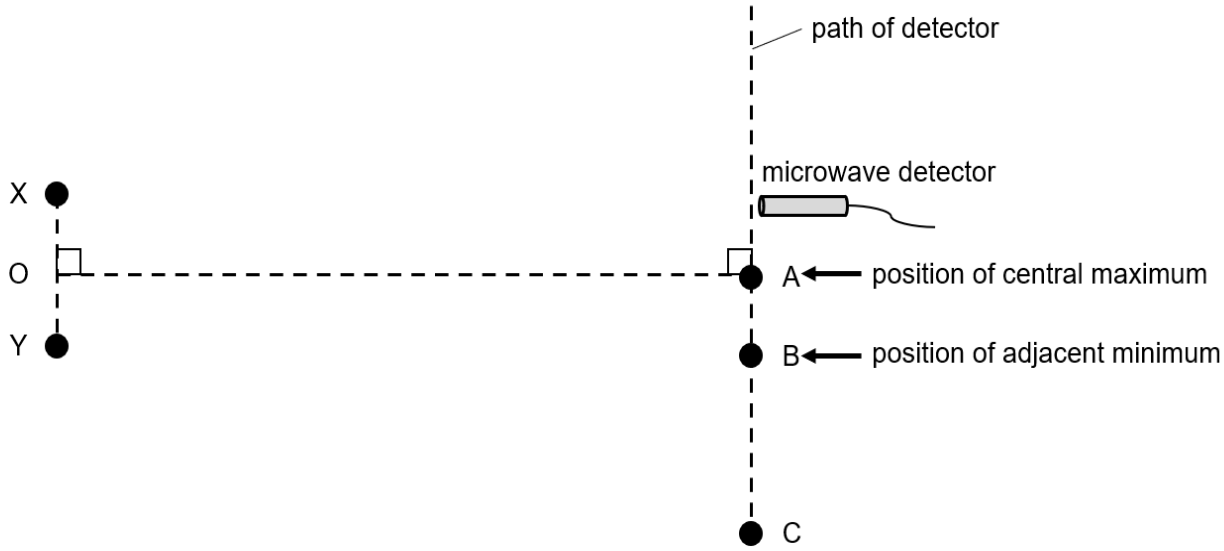

Fig. 4.1 (not to scale)

(a) State and explain along which of the lines XY and OA do the microwaves superpose to produce a stationary wave.

....

....[2]

(b) A microwave detector is moved along a line from A to C. The microwave detector gives a maximum intensity reading at A and the first minimum reading at B. The microwaves have a wavelength of 4.0 cm.

For the waves arriving at B, determine the path difference.

path difference = ... m [1]

(c) Describe the effect, if any, on the intensity of the microwave detected at A and B when the following changes are made, separately to the sources X and Y:

(i) when the amplitude of both source X and Y is doubled.

....

....

....[2]

(ii) when the amplitude of one of the sources is halved.

....

....

....[2]

(iii) when the sources are now anti-phase.

....

....[1]

[Total: 8]

5 Fig. 5.1 shows the electric field in the region between two points P and Q. The electric potential at P and at Q are +400 V and –400 V respectively.

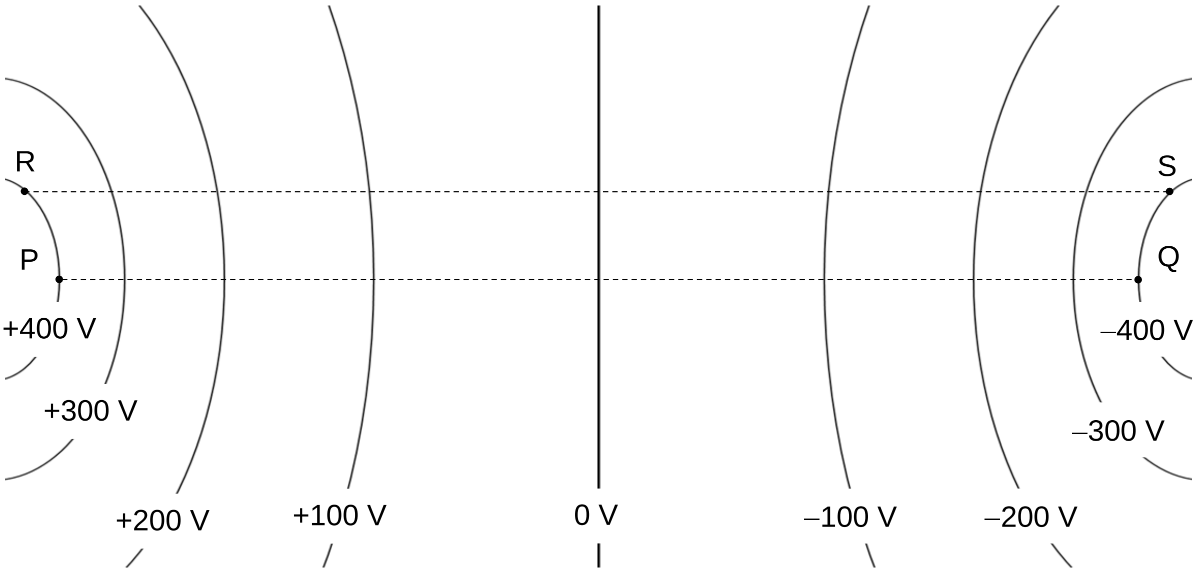

Fig. 5.1

(a) Define *electric potential* at a point.

....

....

....[2]

(b) Describe how the direction and magnitude of the electric field strength varies along the line PQ.

....

....

....[2]

(c) An electron is projected from P towards Q with a speed of 2.2×10^{7} m s^{-1}. Calculate its speed when it reaches Q.

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

(d) Another electron is projected from R towards S. Explain why this electron will not move in the path RS.

....

....[1]

(e) Sketch a possible path taken by the electron in **(d)**. [1]

[Total: 9]

6 **(a)** A cell of e.m.f. 1.5V and internal resistance 0.25 Ω is connected in series with a resistor R, as shown in Fig. 6.1.

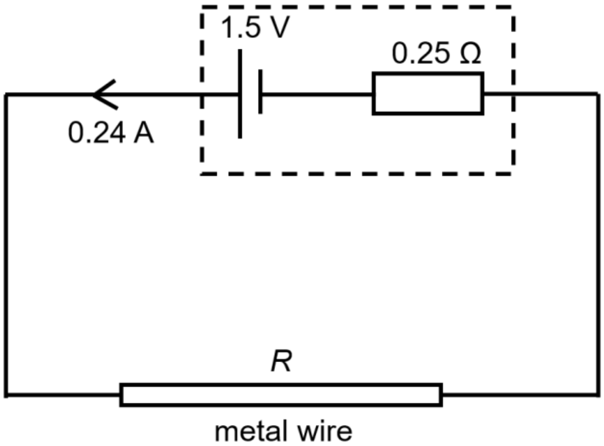

Fig. 6.1

The resistor R is made of metal wire.

A current of 0.24 A passes through R for a time of 5.0 minutes.

Calculate

(i) the charge that passes through the cell,

charge = ... C [1]

(ii) the total energy transferred by the cell,

energy = ... J [2]

(iii) the energy transferred in the resistor R,

energy = ... J [2]

(iv) the resistance of R.

resistance = ... Ω [2]

(b) Two cells identical to the one in **(a)** are now connected in series with a fixed resistor of resistance 2000 Ω and a thermistor, as shown in Fig. 6.2.

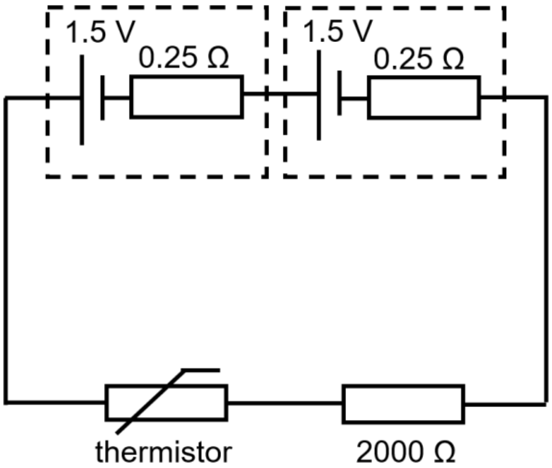

Fig. 6.2

The thermistor has resistance 4000 Ω at 0 °C and 1800 Ω at 20 °C.

(i) Explain why, in this circuit, the internal resistance of the cells may be considered to be negligible.

....

....

.... [1]

(ii) In one particular application of the circuit of Fig. 6.2, it is desired that the potential difference across the **fixed** resistor should range from 1.2 V at 0 °C to 2.4 V at 20 °C.

Determine whether it is possible to achieve this range of potential differences.

....

....

....[3]

[Total: 11]

7 **(a)** Distinguish between the appearance of emission and absorption line spectra.

....

....[2]

(b) The lowest six discrete energy levels for a hydrogen atom are shown in Fig. 7.1, where the ground state is –13.6 eV.

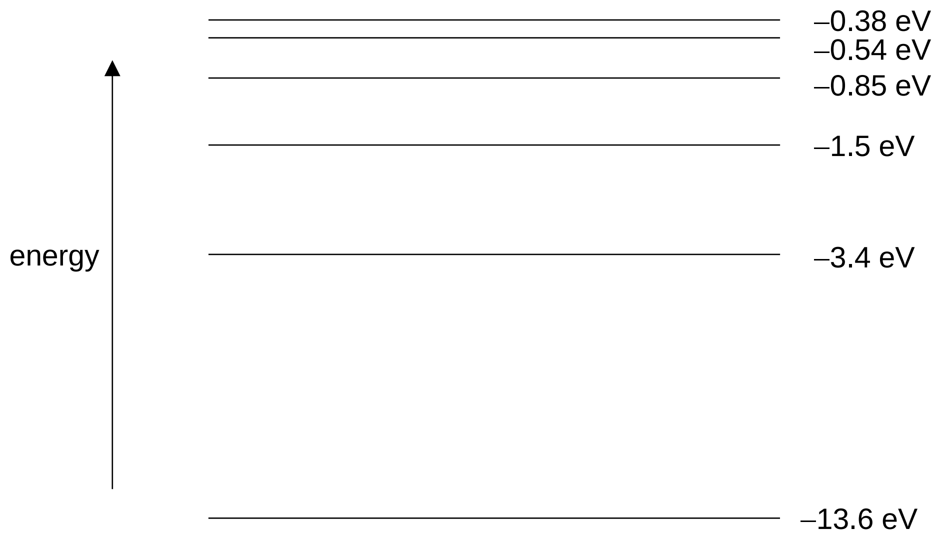

Fig. 7.1 (not to scale)

(i) The spectrum produced by hydrogen is a line spectrum. Use Fig. 7.1 to explain why the spectrum is a line spectrum rather than a continuous spectrum.

....

....

....

....[2]

(ii) Describe one way by which an electron in gaseous hydrogen can be raised from a ground state to the –0.54 eV energy level.

....

....

....[1]

(iii) State the total number of different wavelengths that may be emitted as the electron de-excites from the –0.54 eV energy level.

number = ...[1]

(iv) Electromagnetic radiation is emitted when an electron falls to the ground state from from the –0.54 eV energy level.

Calculate the wavelength of this radiation. Suggest the type of radiation emitted.

wavelength = ... m

type of radiation = ...

[2]

[Total: 8]

8 Read the passage below and answer the questions that follow.

Optical Tweezers

In early 1970s, Arthur Ashkin first reported the observation of micron-sized particles being accelerated and trapped in stable optical potential wells by utilising only the radiation pressure caused by continuous laser. This led to the development of a single-beam, gradient force optical trap, commonly known as Optical Tweezers.

Optical tweezers have since been used in fields ranging from fundamental physical sciences to biology, performing single molecule force and motion measurements, and non-invasively manipulating objects such as DNA and live single cells.

Optical tweezers have the ability of applying pico-newton forces to micron-sized particles. In such systems, transparent dielectric particles made of glass or polystyrene are commonly used as they have higher index of refraction than their surrounding medium (typically liquid), thus attracting them toward the region of maximum laser intensity.

An optical trap uses forces exerted by a highly focused monochromatic laser beam in order to trap and manipulate microscopic dielectric objects. The beam is focused through a microscope objective lens in order to produce a narrow beam waist as shown in Fig. 8.1. Dielectric particles suspended in the surrounding liquid medium will be attracted to the centre of the beam waist and towards the optical axis as shown in Fig. 8.2, where it is the region of maximum laser intensity. The laser intensity decreases with distance from the optical axis.

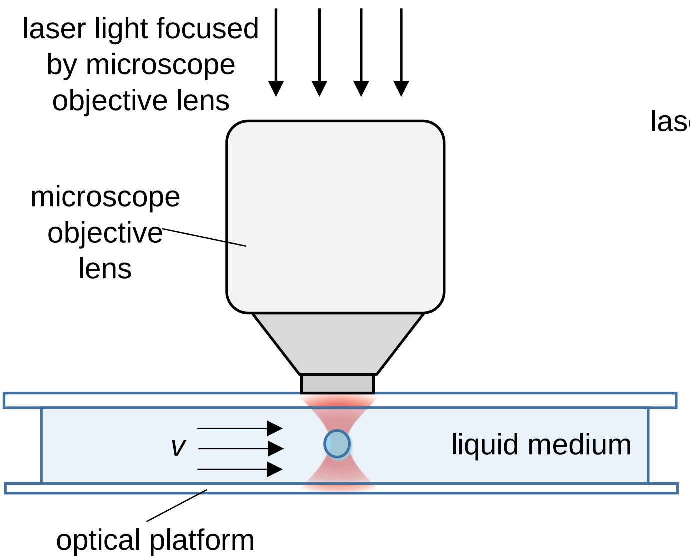

Fig. 8.1

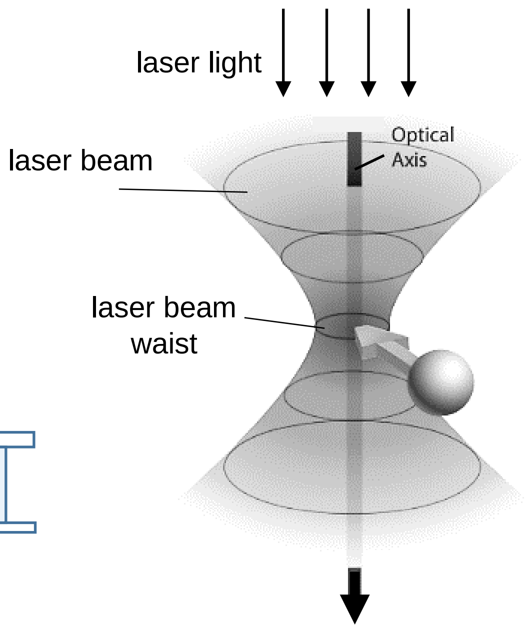

Fig. 8.2

For particles of radius much larger than the wavelength λ of the laser, the Mie scattering approach is utilised. The laser beam is made up of a stream of photons. Some incident photons are reflected by the dielectric sphere, while the rest are refracted through the dielectric sphere. The reflected and refracted processes lead to a change in the momentum of the photons, producing a resultant force on the sphere, which is proportional to the light intensity of the incident laser. With a dielectric sphere of refractive index larger than that of the liquid medium, the refracted light will induce a force in the direction of the intensity gradient, causing the sphere to move towards the centre of the beam waist.

Using the Mie approach, geometric optics is used for the calculation of optical forces. A simplified ray diagram of the refracted laser beam is shown in Fig. 8.3, where two beams G and H pass from a liquid medium through a polystyrene sphere. The sphere experiences a net force towards the centre of the laser waist beam due to both refracted and reflected beams of beams G and H. The sphere will then be stably trapped, with the centre of the sphere aligned with the optical axis.

The force due to the reflected beam may be taken to be negligible, compared to that due to the refracted beam.

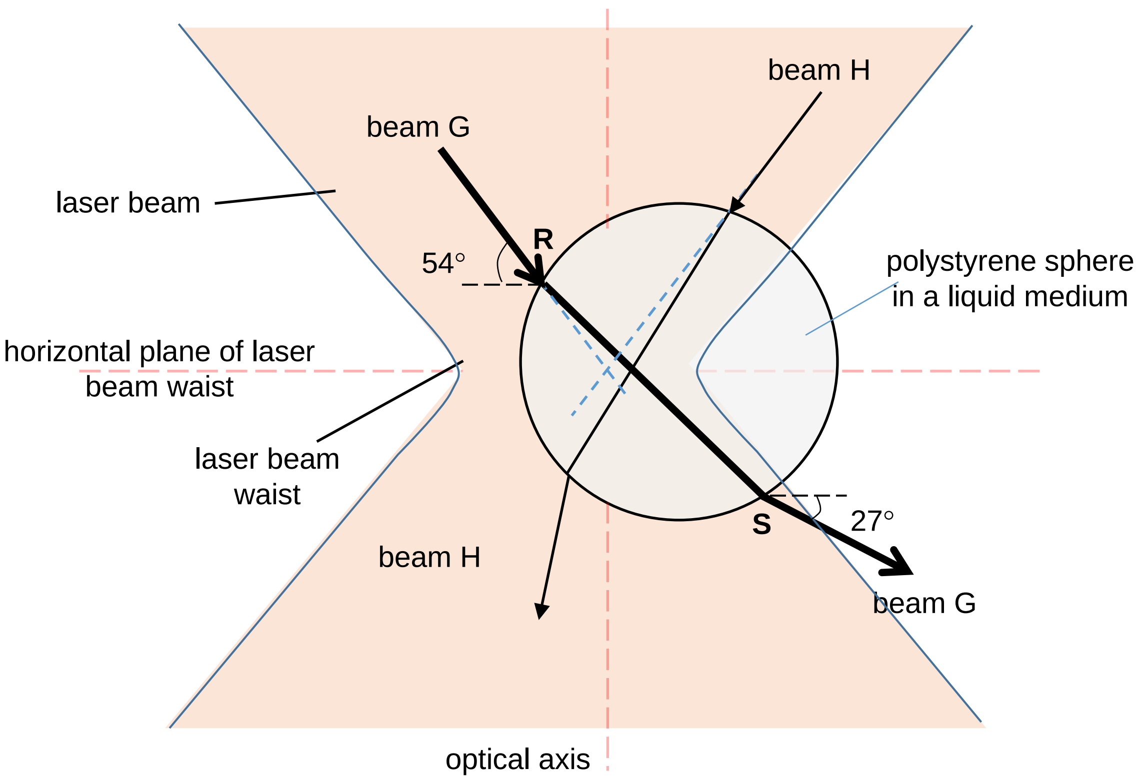

Fig. 8.3 (Reflected beams not drawn)

When the centre of a trapped sphere is displaced by a small displacement Δx from the equilibrium position, there is a restoring force F which obeys Hooke's law where

$$F = k\Delta x$$

and k is the trap stiffness.

The restoring force F can be determined using the Stoke's method, by allowing a fluid of known velocity v to flow past the sphere and measuring the corresponding displacement Δx as shown in Fig. 8.4. The viscous drag F_{drag} acting on the sphere is given by the relationship

$$F_{drag} = 6\pi r\eta v$$

where r is the radius of the sphere, η is the fluid viscosity and v is the velocity of fluid flow.

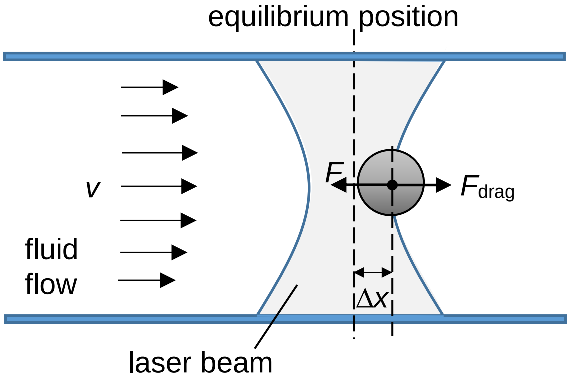

Fig. 8.4

The optical trap can then be calibrated to obtain the trap stiffness k for molecular force measurements.

(a) Suggest why opaque particles are not used for optical tweezer manipulation.

....

....

....[1]

(b) A laser of wavelength 603 nm is used for trapping polystyrene spheres.

With reference to Fig. 8.3, laser beam G with photons of total momentum p_i in unit time is incident on the sphere at R at an angle of 54° to the horizontal, and exits at S with total momentum p_f in unit time at an angle 27° to the horizontal.

(i) For laser beam G, sketch a vector diagram to show the total initial momentum p_i, total final momentum p_f, and total change in momentum Δp of the photons in unit time. Label the vectors clearly.

[2]

(ii) With reference to your answer in **(b)(i)** and using Newton's laws of motion, explain how the refracted laser beam G gives rise to a force acting on the sphere.

....

....

....

....[2]

(iii) Calculate the momentum of a single photon.

momentum = ... N s [2]

(iv) Using your answer in **(b)(i)**, show that the change in momentum of one photon is 5.14×10^{-28} N s.

[1]

(v) The force on the sphere due to laser beam G is 16 pN.

Hence calculate the number of photons in laser beam G passing through the sphere in unit time.

number of photons = ... [2]

(vi) Due to laser beams G and H, the sphere experiences a net force of 19 pN towards the centre of the beam waist.

Calculate the magnitude of the force due to beam H.

magnitude of force = ... N [3]

(vii) Suggest why laser beam G produces a larger force on the sphere as compared to laser beam H.

....

....

....[1]

(c) An optical tweezer system is calibrated using the Stoke's method by trapping a polystyrene sphere of diameter 4.0 μm in liquid as shown in Fig. 8.4. Values for v and Δx are obtained from the experiment and the values are plotted on the graph of Fig. 8.5.

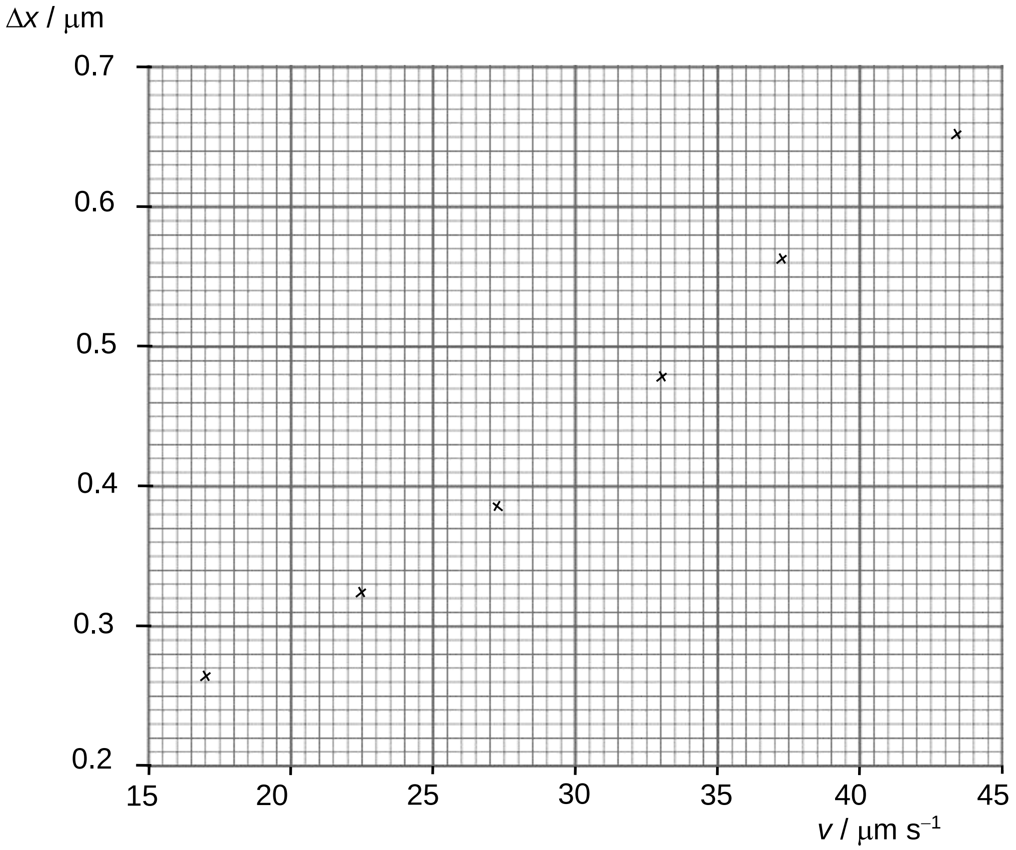

Fig. 8.5

(i) Determine the base units of viscosity η.

SI base units = ... [1]

(ii) On Fig. 8.5, draw the line of best fit for all the points. [1]

(iii) Determine the gradient of the line drawn in **(c)(ii)**.

gradient = ... [2]

(iv) Hence, determine the trap stiffness k of this optical tweezer system, given that the value of η is 0.890×10^{-3}.

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

[Total: 20]

End of Paper