H

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.

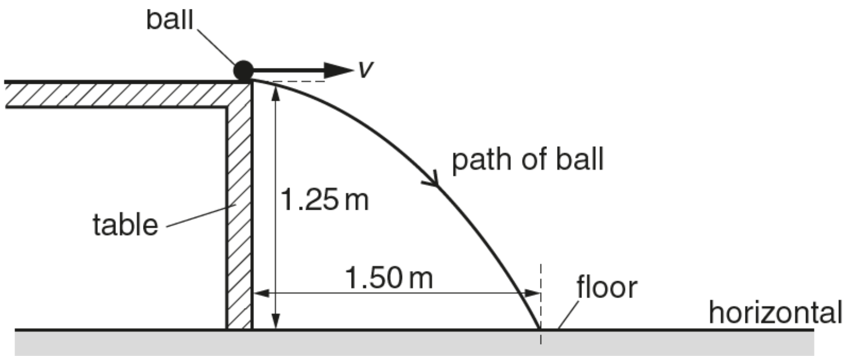


Fig. 1.1

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,

$u_x = v$, $u_y = 0$

$s_x = u_x t$ **= vt** **[1]**

$s_y = 0 + \frac{1}{2}at^2 \Rightarrow 1.25 = 0 + \frac{1}{2}(9.81)t^2$ **[1]**

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

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

$v = \sqrt{(v_y)^2 + (v_x)^2}$ [1]

$v_y = u_y + at = 0 + (9.81)(0.505)$ = 4.95 m s^{-1}[1]

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.

Since both ball initial velocity for the vertical component is zero, the height is the same and same acceleration of free fall, the time taken is the same.

.......[2]

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

The vertical component of velocity is increasing at a decreasing rate.

.....[2]

[Total: 8]

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

The rate of change in the momentum of a body is proportional to the resultant external force that acts on it, and the change in momentum is in the direction of the force.

[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.

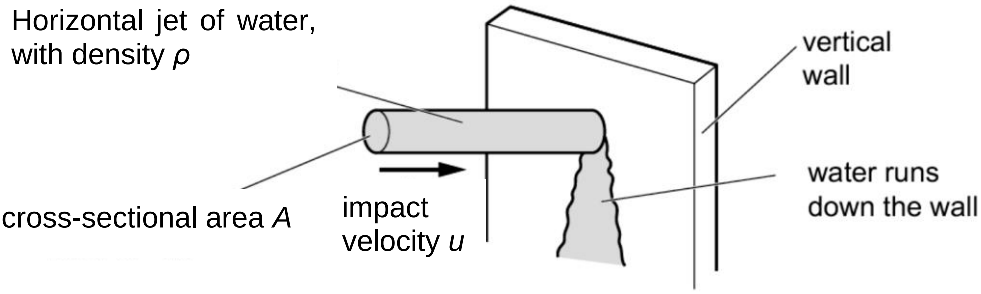


Fig. 2.1

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

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

From Newton's Second Law,

Force on water, F = rate of change of momentum of water

$$\text{Average } F = \frac{\Delta p}{\Delta t}$$

$$= \frac{M(0-u)}{\Delta t}$$

$$= -\left(\rho \times \frac{V}{\Delta t}\right)u = -\left(\rho \times \frac{Al}{\Delta t}\right)u = -\rho(Au)u$$

$$= -\rho A u^2$$

Hence, magnitude of F = $\rho A u^2$

Equation for N2L [1]

Sub in final velocity = 0 [1]

Sub in (M/t) = ρAu [1]

[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.

Force by wall on water = $\rho A u^2$ = (1000)(1.5 x 10^{-4})(5.0^2) = 3.75 = 3.8 N [1]

By Newton's 3rd Law, magnitude of force by water on wall is equal to that by wall on water [1]

Hence magnitude of average force by water on wall = 3.8 N

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]

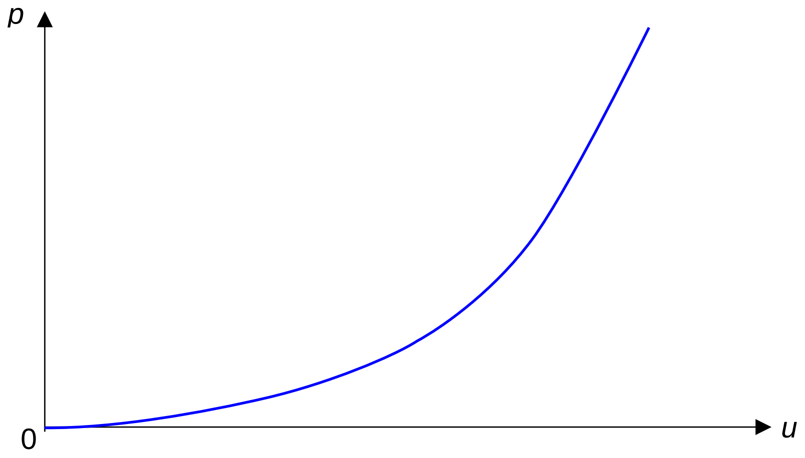


Fig. 2.2

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

No change.
(Since Pressure = Force/Area = F/A = $(\rho A u^2)/A$ = ρu^2, pressure is independent of A)

[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.

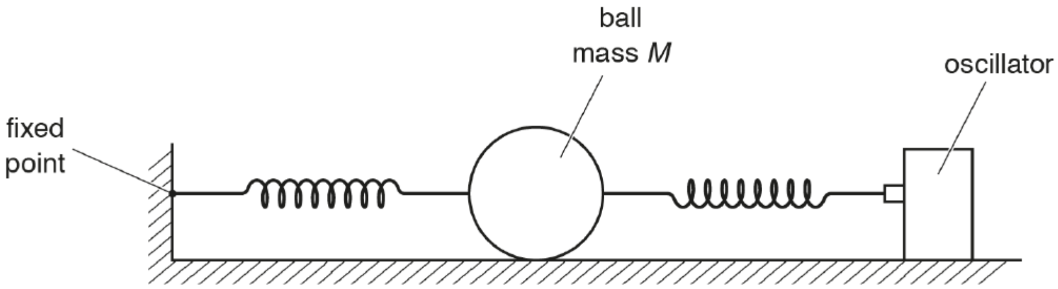


Fig. 3.1

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.

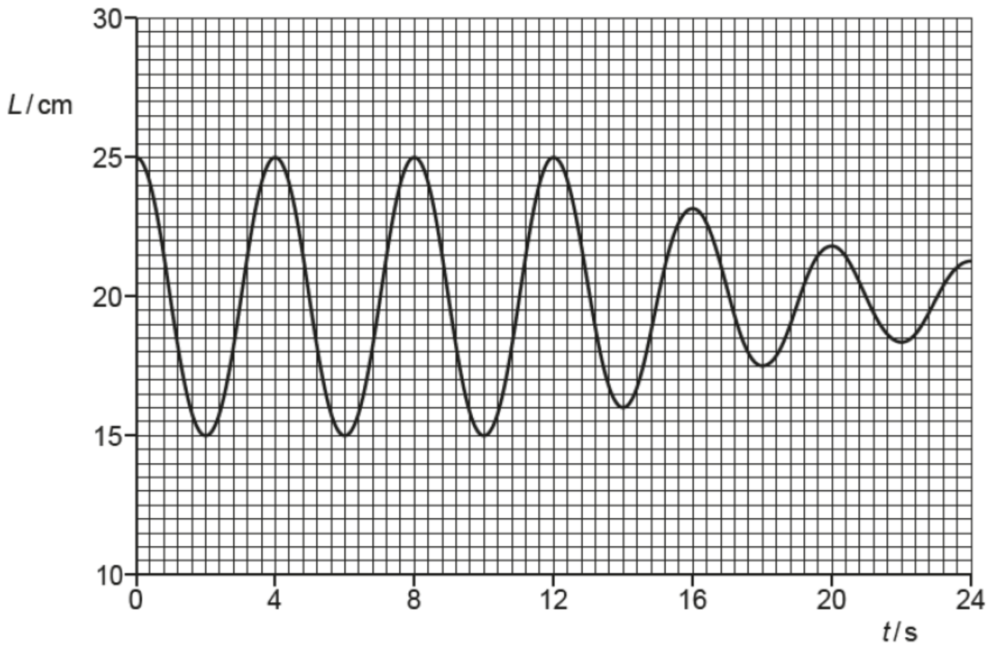


Fig. 3.2

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

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

Equilibrium: 1.0 s, 3.0 s, 5.0 s, 7.0 s, 9.0 s, 11.0 s.

time = ... s [1]

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

Max displacement: 0.0 s, 2.0 s, 4.0 s, 6.0 s, 8.0 s, 12.0 s.

ne = ... s [1]

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

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{4.0}$$
$$= 1.57 \text{ rad s}^{-1}$$

ω = ... rad s^{-1} [1]

(iv) calculate the maximum acceleration of the ball.

$$a_{max} = \omega^2 x_o$$
$$= (1.57)^2 (0.05)$$
$$= 0.123 \text{ m s}^{-2}$$

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.

At t = 0 s, x_o = 0.05 m

$$\text{Total } E = \frac{1}{2} m v_{max}^{2} = \frac{1}{2} m \omega^2 x_o^{2}$$
$$= \frac{1}{2}(0.750)(1.5708)^2 (0.05)^2$$
$$= 2.3132 \times 10^{-3} \text{ J}$$

At t = 24 s, x_o = 0.0125 m

$$\text{Total } E = \frac{1}{2} m v_{max}^{2} = \frac{1}{2} m \omega^2 x_o^{2}$$
$$= \frac{1}{2}(0.750)(1.5708)^2 (0.0125)^2$$
$$= 1.4457 \times 10^{-4} \text{ J}$$

Loss in Total E = 2.17×10^{-3} J

[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.

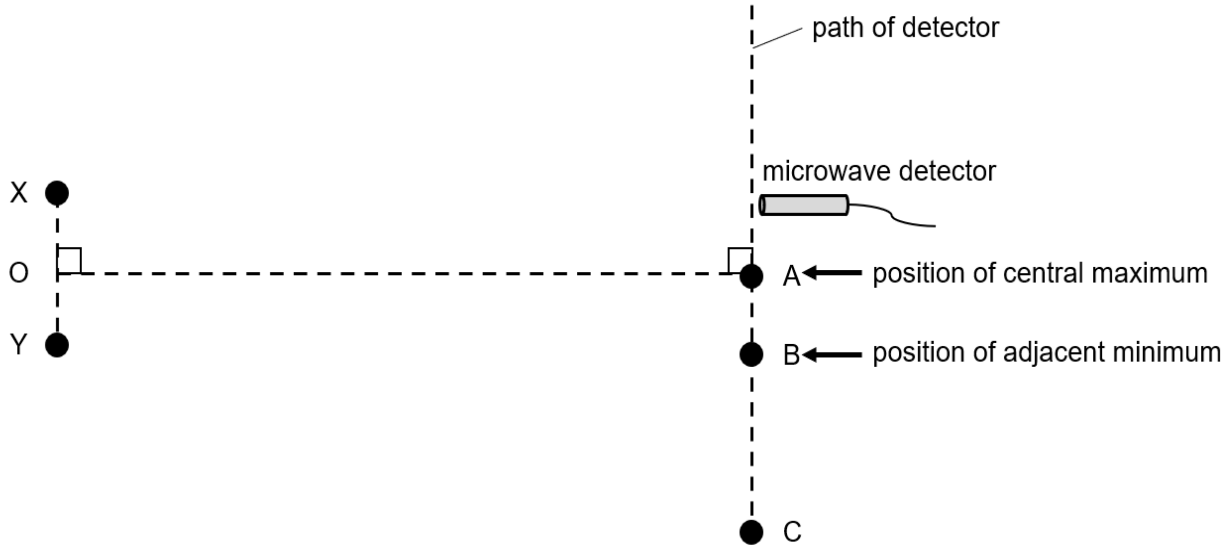


Fig. 4.1 (not to scale)

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

XY. [A1]

Only along XY the microwaves travel in a direction **opposite** to one another. [M1]

Do not accept: "Different direction"

(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.

B is at position of 1st minima. Hence path difference is 0.5λ.

Path difference = 0.020 m [A1]

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.

Resultant amplitude is doubled. Intensity is proportional to $(\text{amplitude})^2$. [B1]

Maximum intensity increased by a factor of 4 [B1]

....[2]

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

Resultant amplitude at maxima is 1.5 x_0 and minima at 0.5 x_0. [B1]

Maximum intensity at A becomes 0.5625 or (9/16) times of initial intensity and minimum intensity at B becomes 0.0625 or (1/16) of the initial intensity at A. [B1]

....

....[2]

(iii) the sources are now anti-phase.

the maximum becomes a minimum **and** the minimum becomes a maximum [B1]

the intensity at A and B will swap (B1)

[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.

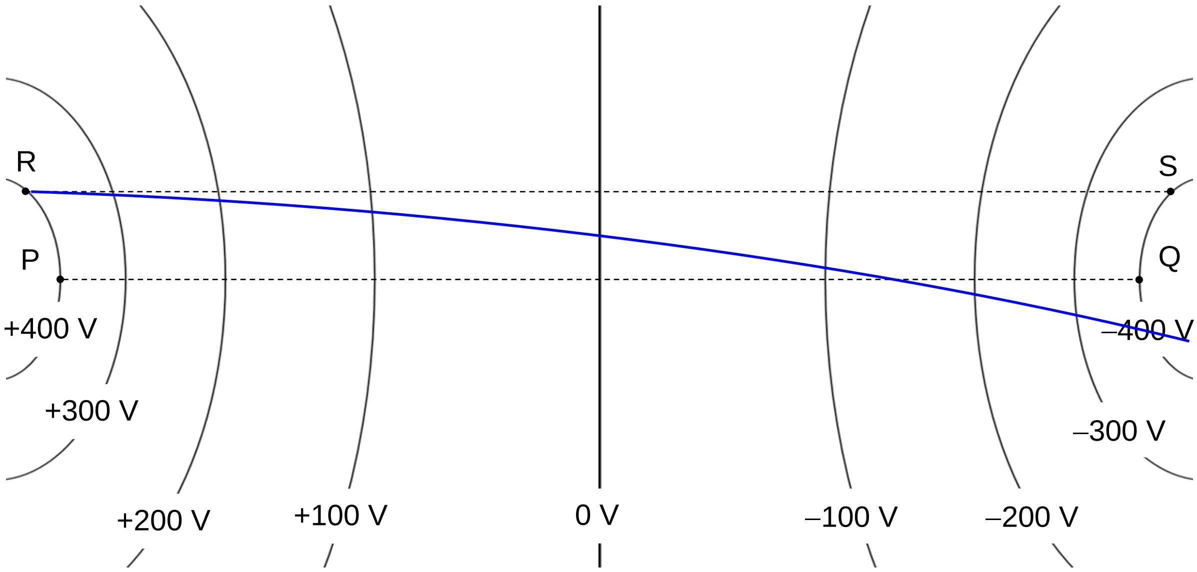


Fig. 5.1

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

Electric potential at a point is the work done by external agent per unit positive charge on a small test charge to bring it from infinity to that point, (without change in its kinetic energy.) [2]

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

From P to Q, the direction of the field is always towards Q, and the magnitude will decrease to a minimum and then increase. [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.

Loss in KE = Gain in EPE

$\frac{1}{2} m_e (u^2 - v^2) = q\,\Delta V \rightarrow \frac{1}{2} \times 9.1\times10^{-31} \times ((2.2\times10^7)^2 - v^2) = 1.6\times10^{-19} \times 800$

$v = 1.4\times10^7$ m s^{-1}

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.

The direction of the electric field is not along the line RS, thus the electron will accelerate in a direction different from its velocity and move in a curved path. [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.

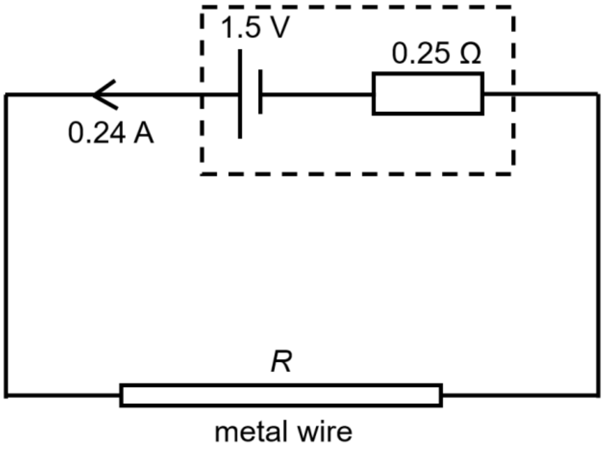


Fig. 6.1

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,

$Q = I\,t = 0.24 \times 5.0 \times 60 = 72$ C

charge = ... C [1]

(ii) the total energy transferred by the cell,

$W = Q\,V = 72\,(1.5) = 108$ J

Or

$W = I\,E\,t = (0.24)(1.5)\,(5\times60) = 108$ J

energy = ... J [2]

(iii) the energy transferred in the resistor R,

By conservation of energy,

Energy transferred in R = Total energy – Energy dissipated in 0.25 Ω

$= 108 - I^2\,r\,t$

$= 108 - (0.24)^2\,(0.25)(5.0\times60)$

$= 104$ J

[2]

(iv) the resistance of R.

$E = I^2 R t$ $104 = (0.24)^2 (R)(5.0\times60)$ $R = 6.0\ \Omega$	$E = I (R+r)$ $1.5 = 0.24 (R + 0.25)$ $R = 6.0\ \Omega$

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.

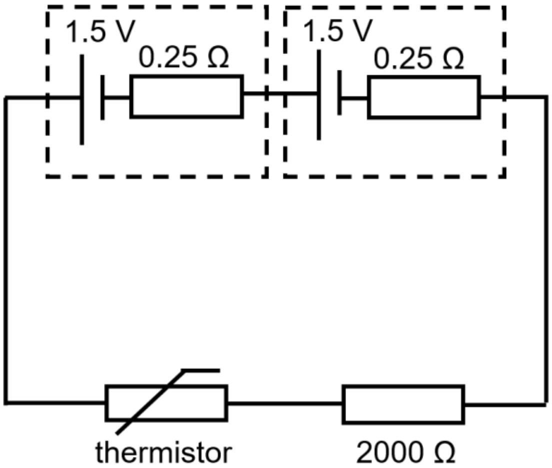


Fig. 6.2

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

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

The combined resistance of the fixed resistor and thermistor at 20 °C is between 3800Ω and 6000Ω,

while the combined resistance of the internal resistance of the cells is 0.50Ω×2.

Since the external resistance (5800Ω) is much greater than the internal resistance of the cells (0.50Ω), the internal resistance of the cells can be neglected, whereas the external resistance in fig 7.1 is 6.0Ω.

..... [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.

In order to get that range R would need to be changed to another resistor.

Let the resistor of the fixed resistor be R.

At 0°C, R needs to be 1.2 V

$$\frac{V_R}{E} = \frac{R}{R + 4000}$$

$$\frac{1.2}{3.0} = \frac{R}{R + 4000}$$

$$R = 2700\ \Omega$$

Checking whether 2700 Ω will give 2.4 V at 20°C,

$$\frac{V_R}{E} = \frac{R}{R + 4000}$$

$$\frac{V_R}{3.0} = \frac{2700}{2700 + 1800}$$

$$V_R = 1.8\ \text{V}$$

Since the same fixed resistor does not give the required range, it is not possible to achieve this range of potential differences.

[3]

11]

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

Emission spectrum consists of coloured lines on a dark background while absorption spectrum consists of dark lines on a coloured spectrum.

.......[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.

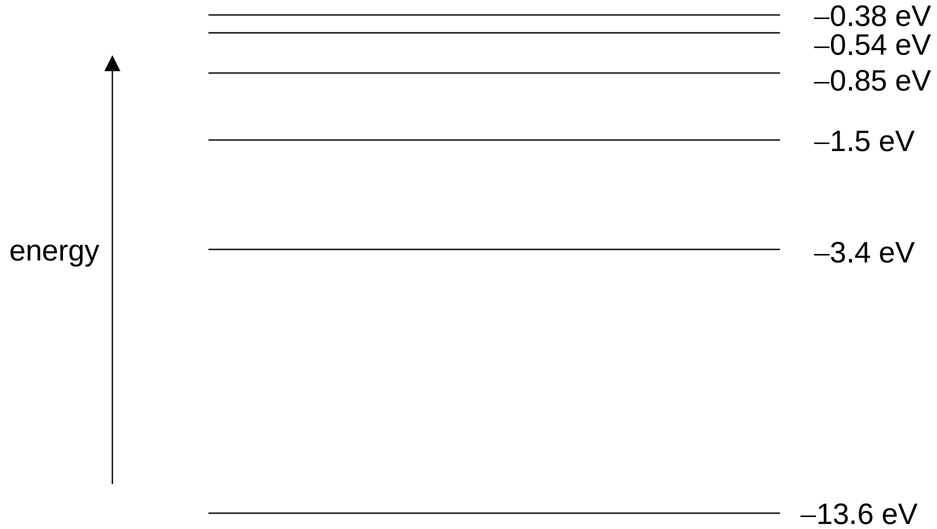


Fig. 7.1 (not to scale)

(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.

Fig. 7.1 shows that the energy levels of electrons within the atom are discrete. Hence the energies of the photons emitted when the electrons de-excite from higher to lower energy levels are discrete as well. Light of a single wavelength and frequency is produced, corresponding to each line on the line 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.

Electrons can be excited through collision with other particles that possess at least 13.06 eV of energy. OR

Electrons can be excited through absorption of photons with exactly 13.06 eV of energy.

.......[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.

5C2 = 10

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.

$$\left|E_f - E_i\right| = \frac{hc}{\lambda}$$

$$\left|(-13.6 + 0.54) \times 1.60 \times 10^{-19}\right| = \frac{\left(6.63 \times 10^{-34}\right)\left(3.00 \times 10^{8}\right)}{\lambda}$$

$$\lambda = 9.52 \times 10^{-8}\,\text{m}$$

ultraviolet

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.

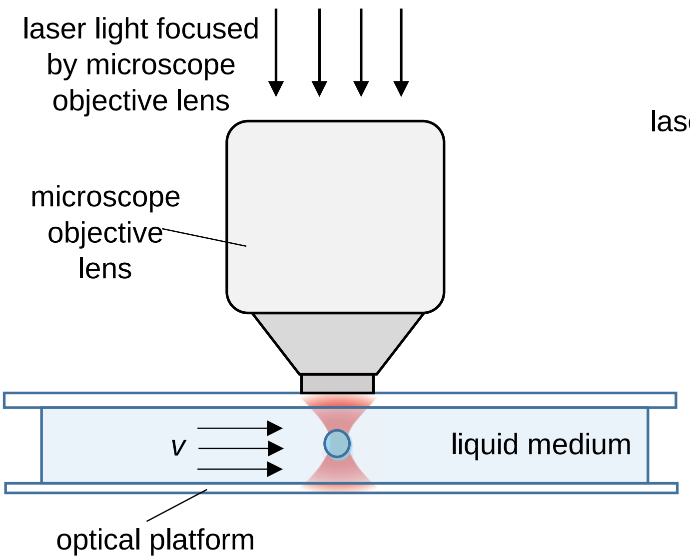


Fig. 8.1

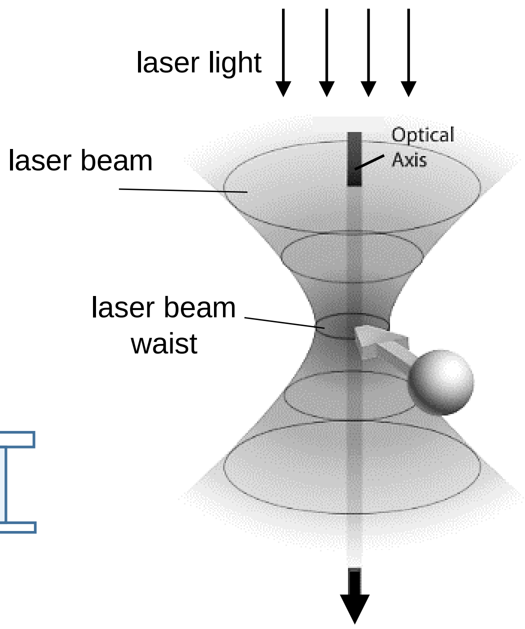


Fig. 8.2

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.

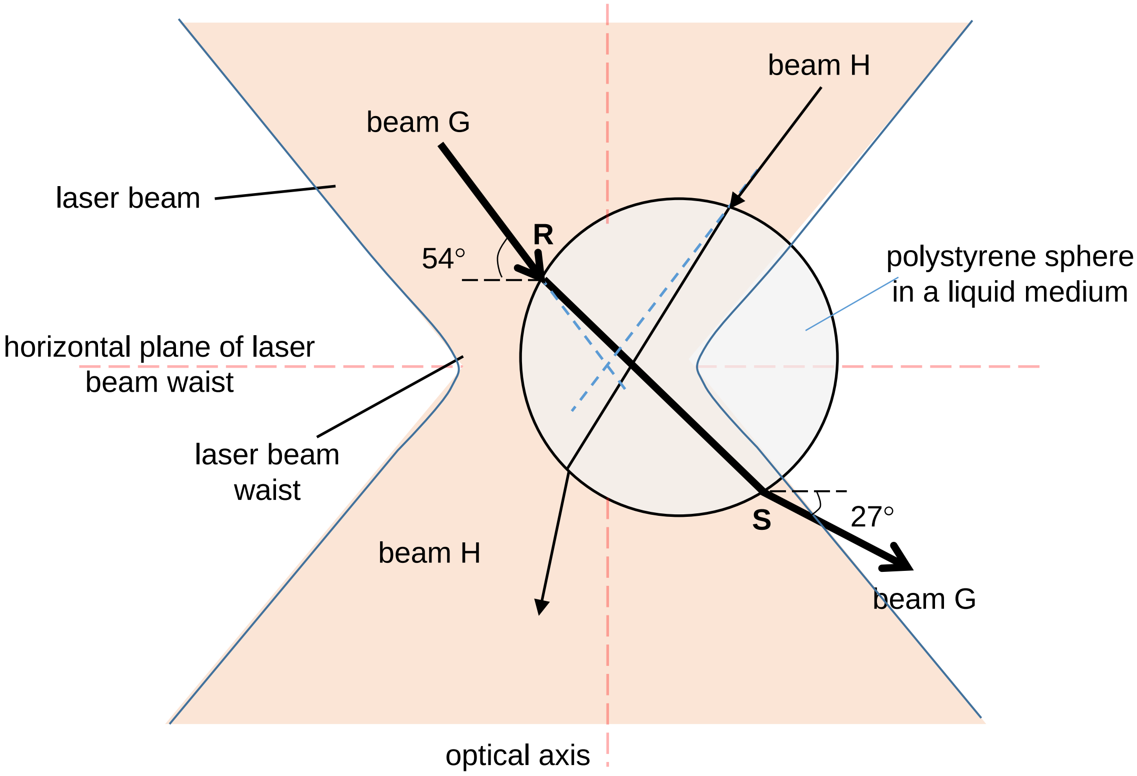


Fig. 8.3 (Reflected beams not drawn)

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.

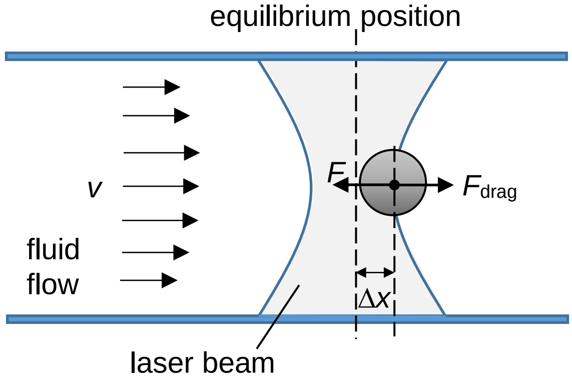


Fig. 8.4

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.

It is because incident light particles will hit the sphere and get reflected, causing a scattering force in the direction of the laser light. Hence no trapping will occur/ no light can be transmitted through the particle and hence no restoring force can be produced.

[1]

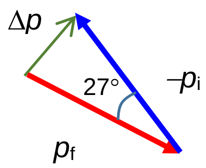
(b) A laser of wavelength 603 nm is used for trapping polystyrene spheres.

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.

Correct triangle [B1]

Correct angle [B1]



[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.

There is a change in momentum in unit time of beam G in direction shown in (b)(i). By Newton's second law, there is a force on the laser beam in this same direction as there is a rate of change of momentum. [B1]

By Newton's third law, there is a force equal in magnitude and opposite in direction acting on the sphere. [B1]

[2]

(iii) Calculate the momentum of a single photon.

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{603 \times 10^{-9}} = 1.1 \times 10^{-27} \text{ N s}$$

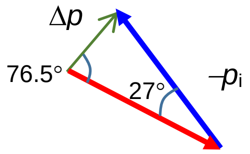
momentum = ... N s [2]

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

$$\frac{1.1 \times 10^{-27}}{\sin 76.5°} = \frac{\Delta p}{\sin 27°}$$

$$\Delta p = 5.1358 \times 10^{-28} \text{ N s} \quad \text{[C1]}$$

$$= 5.14 \text{ N s}$$



[1]

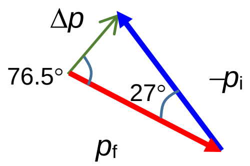
(v) The force on the sphere due to laser beam G is 16 pN.

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

$$F = \frac{N \Delta p}{t}$$

$$N = \frac{Ft}{\Delta p} = \frac{(16 \times 10^{-12})(1)}{5.3158 \times 10^{-28}} \quad \text{[M1]}$$

$$= 3.01 \times 10^{16} \quad \text{[A1]}$$



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.

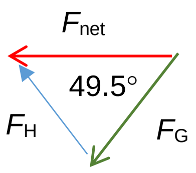
Calculate the magnitude of the force due to beam H.

Calculate angle [C1]

$$F_H = \sqrt{F_{net}^2 + F_G^2 - 2(F_{net})(F_G)\cos 49.5°}$$

$$= \sqrt{19^2 + 16^2 - 2(19)(16)\cos 49.5°} \quad \text{[M1]}$$

$$= 14.9 \text{ pN} \quad \text{[A1]}$$



magnitude of force = ... N [3]

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

Beam G originates from a region of higher intensity nearer the optical axis, hence there are more photons incident on the sphere as compared to beam H, and hence a larger rate of change of momentum.

....[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.

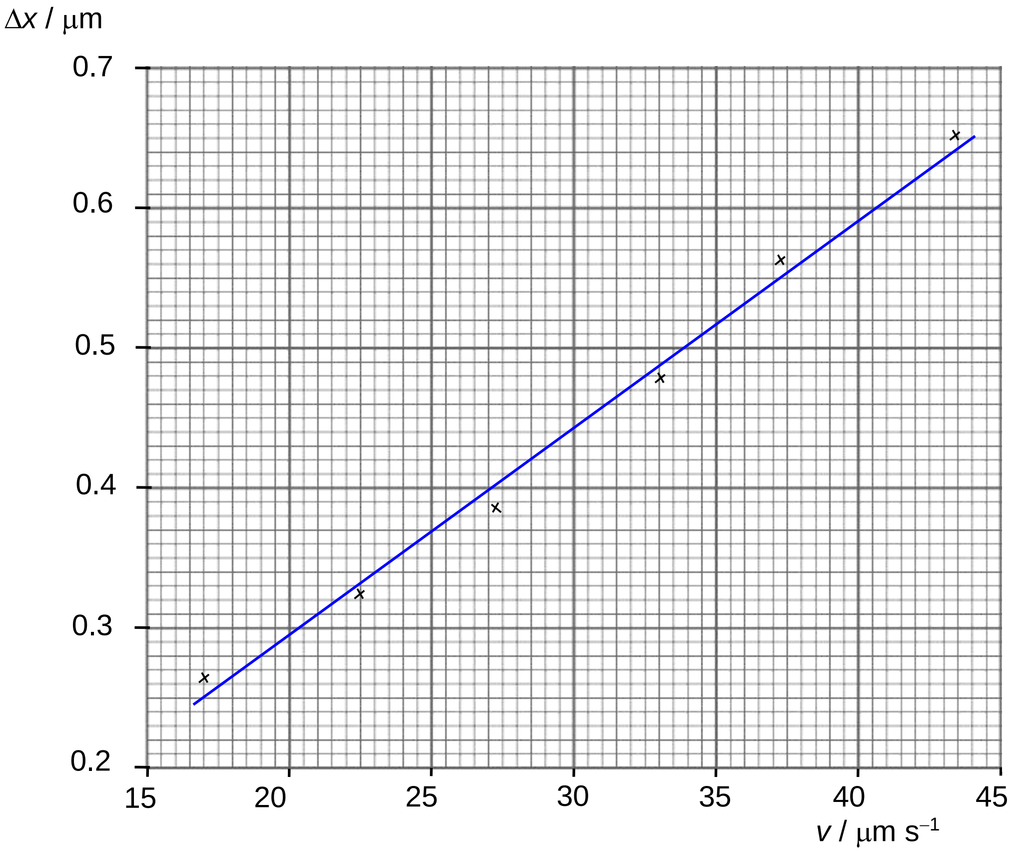


Fig. 8.5

(i) Determine the base units of viscosity η.

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

Units of η = units of $\frac{F}{r\,v} = \frac{\text{kg m s}^{-2}}{\text{m m s}^{-1}} = \text{kg m}^{-1}\text{ s}^{-1}$

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)**.

Reading off coordinates from the graph, we have

(17.0, 0.250), (42.0, 0.620)

$$\text{Gradient} = \frac{(0.620 - 0.250) \times 10^{-6}}{(42.0 - 17.0) \times 10^{-6}} \quad \text{[M1]}$$

$$= \frac{0.370}{25.0} = 0.0148 \quad \text{[A1]}$$

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}.

$$\text{Gradient} = \frac{6\pi r\eta}{k}$$

$$0.0148 = \frac{6\pi(2 \times 10^{-6})(0.890 \times 10^{-3})}{k} \quad \text{[M1]}$$

$$k = 2.27 \times 10^{-6} \text{ N m}^{-1} \quad \text{[A1]}$$

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

[Total: 20]

End of Paper