NANYANG JUNIOR COLLEGE
JC 2 PRELIMINARY EXAMINATION
Higher 1

CANDIDATE NAME: **SOLUTION**

CLASS:

TUTOR'S NAME:

PHYSICS — 8866/02

Paper 2 Structured Questions

17 September 2015

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

The use of an approved scientific calculator is expected , where appropriate

Section A
Answer **all** questions.

Section B
Answer any **two** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
Section A	
1	
2	
3	
4	
5	
Section B	
6	
7	
8	
Total	

This document consists of **23** printed pages.

[Turn over

Data

speed of light in free space,	c	= 3.00×10^{8} m s^{-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
acceleration of free fall,	g	= 9.81 m s^{-2}

Formulae

uniformly accelerated motion,	s	= $ut + ½at^2$
	v^2	= $u^2 + 2as$
work done on/by a gas,	W	= $p\Delta V$
hydrostatic pressure,	p	= ρgh
resistors in series,	R	= $R_1 + R_2 + …$
resistors in parallel,	$1/R$	= $1/R_1 + 1/R_2 + …$

For Examiner's Use

Section A

Answer **all** questions in this section.

1 A speed-time graph for an MRT train travelling between two stations is shown in Fig. 1.1.

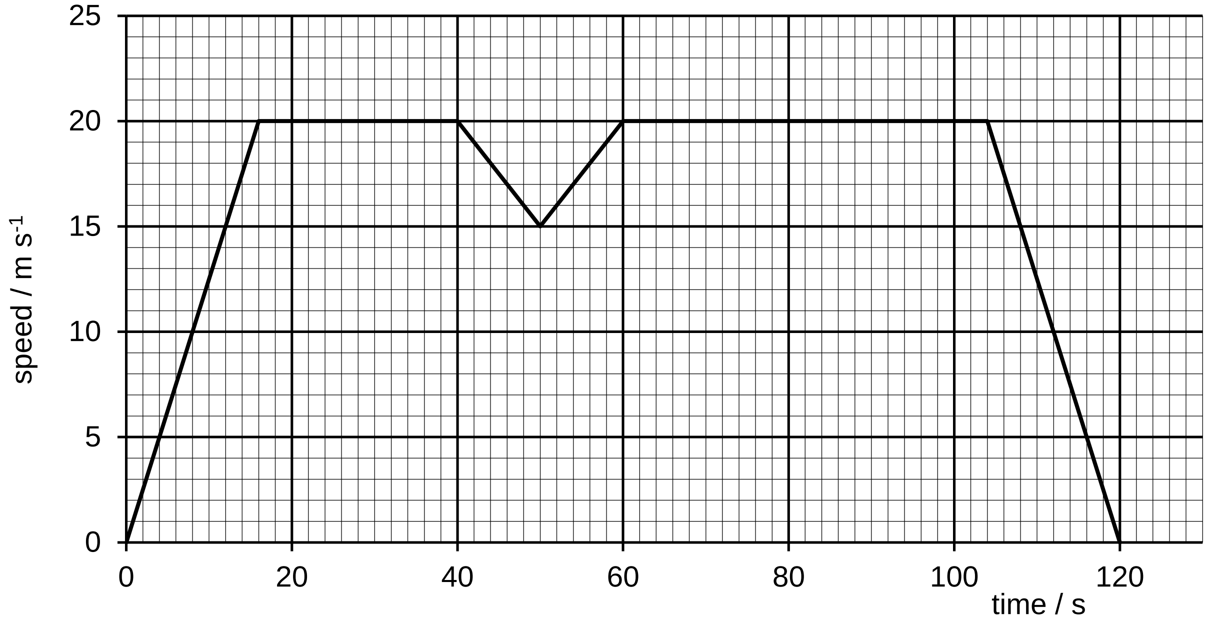

Fig 1.1

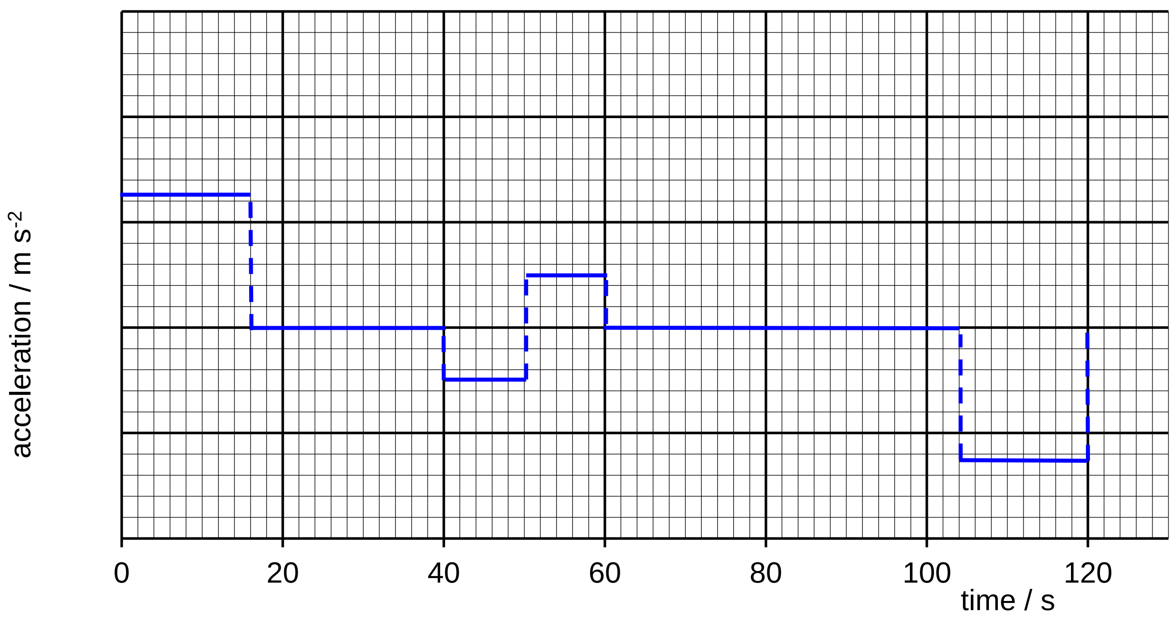

Fig 1.2

(a) On Fig. 1.2, draw the corresponding acceleration-time graph. Put numerical values on the acceleration axis. [2]

(b) Calculate the distance travelled between the two stations.

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distance travelled = area under speed-time graph from 0 – 120s
= ½ (20.0)(120+88) – 1/2 (20)(5.0)
= 2030
= 2.0×10^3 m

(c) On Fig.1.3, sketch a labelled distance-time graph of the train between the two stations.

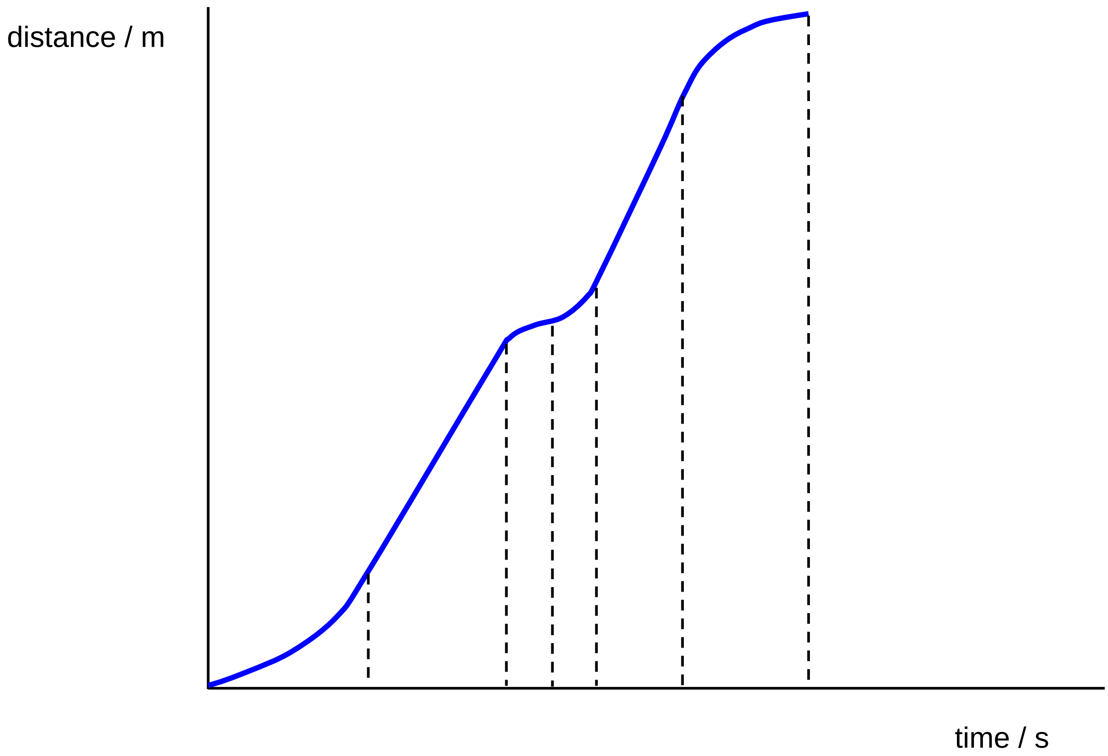

Fig 1.3

[2]

2 Sail systems are being developed to reduce the running costs of cargo ships. The sail and ship's engines work together to power the ship. One of these sails is shown in Fig. 2.1, pulling the ship at an angle of 40^o to the horizontal.

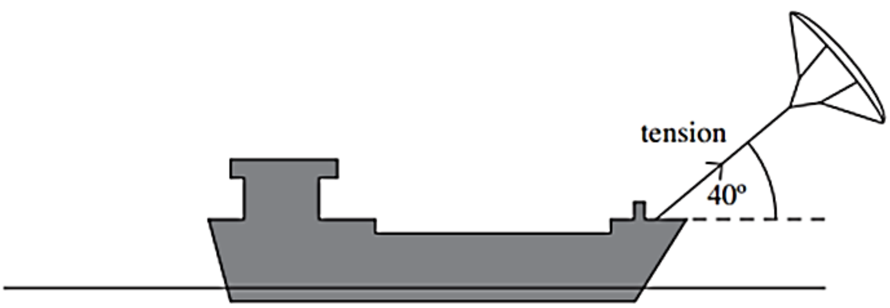

Fig. 2.1

With the sail and the engines operating, the ship is travelling at a steady speed of 7.0 m s^{-1}.

(a) The average tension in the cable is 170 kN. Show that, when the ship travels 1.0 km, the work done by the sail on the ship is 1.3×10^8 J. [2]

$W = F\, d \cos\theta = 170 \times 10^3 \times 1000 \times \cos 40 = 1.302 \times 10^8$ J

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(b) **(i)** Calculate the power developed by the sail.

P = Fv = $1.3 \times 10^5 \times 7.0 = 9.1(1) \times 10^5$
ecf wrong force from part a
or correct alternative approach using t=s/v and P= E/t

(ii) Calculate the percentage of the ship's power requirement that is provided by the wind when the ship is travelling at this speed.

The power output of the engines is 2.1 MW.

total power = $9.1 \text{ X } 10^5 + 21 \times 10^5$
ecf from b(i)
(percentage = 9.1/(9.1 + 21) × 100 = 30 (%))

(c) The angle of the cable to the horizontal is one of the factors that affects the horizontal force exerted by the sail on the ship. State one other factor that would affect this force.

any one

- (surface) area (of the sail)
- wind speed/strength/power/KE/force (not air resistance)
- acceleration or speed of the ship

3 Fig. 3.1 below shows the I-V graphs for conductors X and Y.

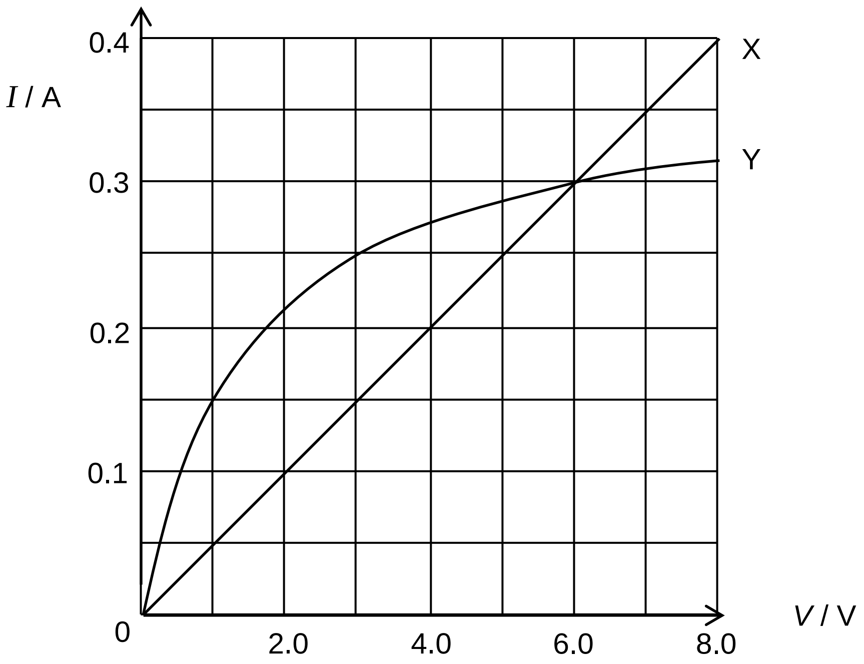

Fig. 3.1

(a) Deduce the type of conductors X and Y are.

X : metallic conductor at constant temperature Y : filament lamp

(b) Conductors X and Y are arranged in parallel and connected to a cell in a closed circuit. Draw a circuit diagram in the space below to show the arrangement.

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[1]

(c) The current in X is 0.15 A. Using the graphs given, determine the current in the cell.

From graph: $I_X = 0.15$ A → $V_X = 3.0$ V

→ $V_Y = 3.0$ V (parallel connection) → $I_Y = 0.25$ A

Current in cell = total current = 0.15 + 0.25 = 0.40 A

(d) The e.m.f. of the cell is 3.3 V. Calculate the internal resistance of the cell.

P.d. across internal resistance = 3.3 – 3.0 = 0.3 V

$r = V / I = 0.3 / 0.40 = 0.75\ \Omega$

4 **(a)** Fig. 4.1 shows two wires, X and Y, carrying currents of equal magnitude but in opposite direction.

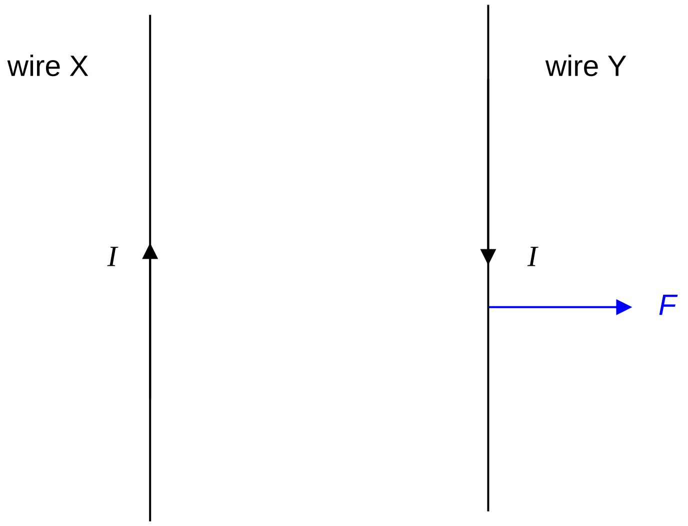

Fig. 4.1

Fig. 4.2 shows the top view of the wires.

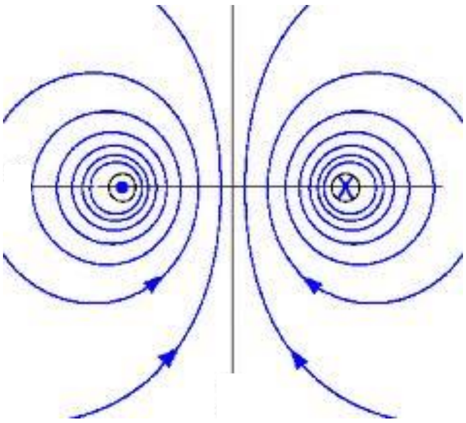

Fig. 4.2

(i) On Fig. 4.2, sketch the magnetic field pattern around the two wires. [2]

(ii) On Fig. 4.1, draw the direction of the force acting on wire Y. Label the force *F*.[1]

(b) Fig. 4.3 shows a wire of weight 0.100 N and length 1.00 m carrying a current of 5.0 A, suspended by two identical springs of spring constant 2.50 N m^{-1}.

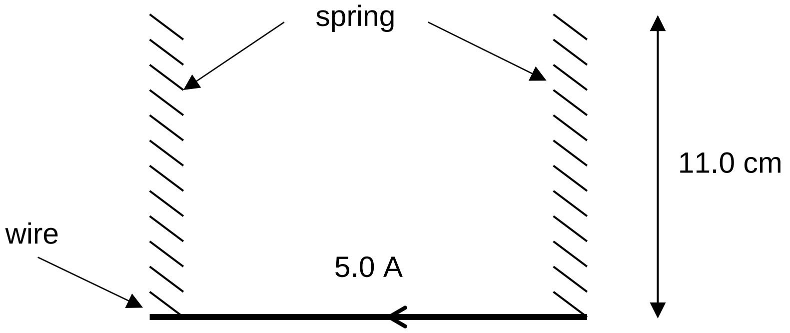

Fig. 4.3

The whole wire is in a region of constant magnetic field and the field is perpendicular to the wire.

The natural length of the spring is 10.0 cm. The system is in equilibrium and the wire is horizontal.

(i) Using the weight of the wire and the spring constant, explain quantitatively why the direction of the magnetic field is out of the page.

$$F = kx$$
$$0.100 = 2.50x + 2.50x$$
$$x = 0.0200 \text{ m}$$

If there is no magnetic field, the weight of the wire should extend the spring by 0.0200 m. But the figure indicates that the extension is only 1.0 cm. Therefore, the magnetic force should be upwards to reduce the extension of the springs and by Fleming's Left Hand Rule, the direction of the magnetic field is out of the page.

(ii) Calculate the magnetic flux density of the field.

Taking downwards as positive,

$$\sum F = ma$$

$$W - kx - kx - F_B = ma$$

$$0.100 - 2.50 \times 1.0 \times 10^{-2} - 2.50 \times 1.0 \times 10^{-2} - B \times 5.0 \times 1.00 \sin 90^0 = 0$$

$$B = 0.010 \text{ T}$$

5 Bats emit high frequency sound waves and receive reflected echoes. They use the echoes to locate their position. This process is called echolocation.

Fig. 5.1 illustrates this process.

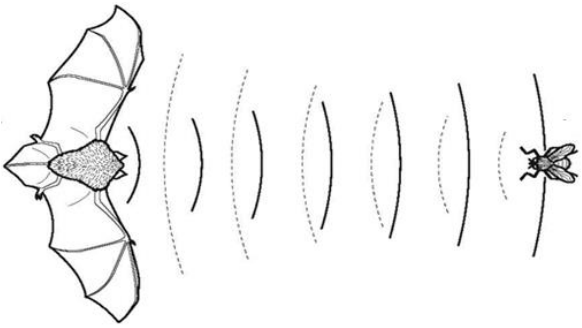

Fig. 5.1

(a) Sound waves emitted by the bat travel at 340 m s^{-1}. Their typical frequency range is 20 kHz to 80 kHz.

Calculate the range of wavelengths for this frequency range.

(b) Bats emit two waveforms, wave B and wave P, which superpose to form wave E.

- Wave B (shown in Fig. 5.2) gives information about the surrounding background.
- Wave P (not shown in Fig. 5.2) enables the bat to detect insect prey.
- Wave E (shown in Fig. 5.2) is the superposition of wave B and wave P.

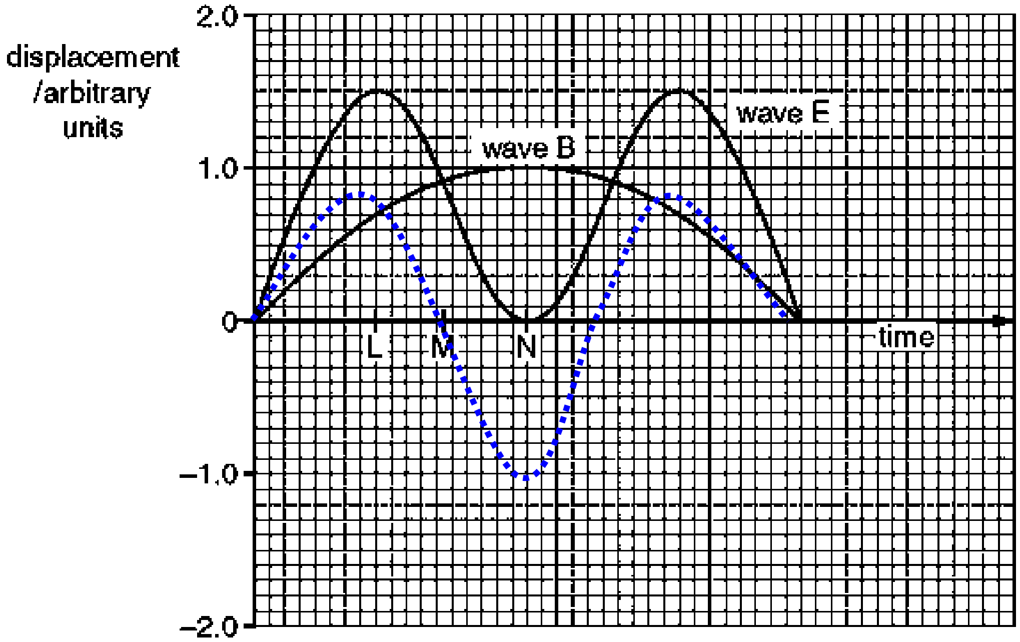

Fig. 5.2

(i) Use the principle of superposition to determine the displacement of wave P at times corresponding to points L, M and N on the time axis.

Write the displacement values in the spaces provided.

Displacement at L =1.5 - 0.7= 0.8 (units)
Displacement at M = 0.92 -0.92 = 0.0 (units)
Displacement at N =0 – 1.0 = –1.0 (units)

(ii) Hence draw the waveform for wave P on Fig. 5.2. [2]

(c) An effect known as the Doppler effect uses changes in frequency to determine speeds. The change in frequency, Δf, shown by wave P when it is reflected by an insect travelling with speed v, is given approximately by the formula

$$\frac{\Delta f}{f} = \frac{2v}{c}$$

where c represents the speed, 340 m s^{-1}, of sound waves emitted by the bat.

(i) Wave P has a frequency of 50.80 kHz. Its apparent frequency after reflection is 51.25 kHz

Calculate the speed of the insect.

Value of Δf = 51.25 - 50.80 = 0.45 kHz
and f = 50.80 kHz

$$\frac{\Delta f}{f} = \frac{2v}{c}$$

0.45/50.80 = 2v/340
Insect's speed, v = 1.51 m s^{-1}

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(ii) The bat best discriminates small insect prey when the wavelength of the reflected wave P is similar in size to the insect.

State the wave property that is being demonstrated in this situation

Diffraction

(d) The bat's high frequency waves are strongly attenuated in air. Fig. 5.3 is a graph of intensity I against range in air x for the high frequency waves.

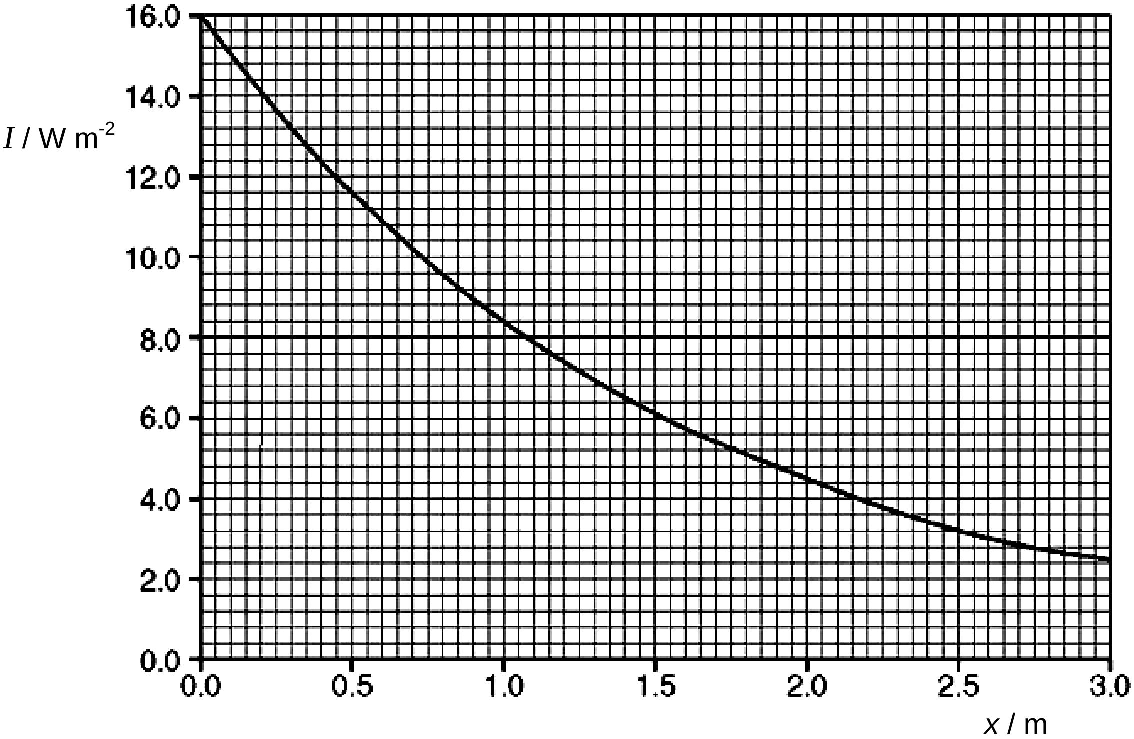


Fig. 5.3

The shape of the curve in Fig. 5.3 suggests that the decrease of the intensity I with range in air x could be exponential. In order to test this suggestion, a graph of ln (I) against x is plotted. This is shown in Fig. 5.4.

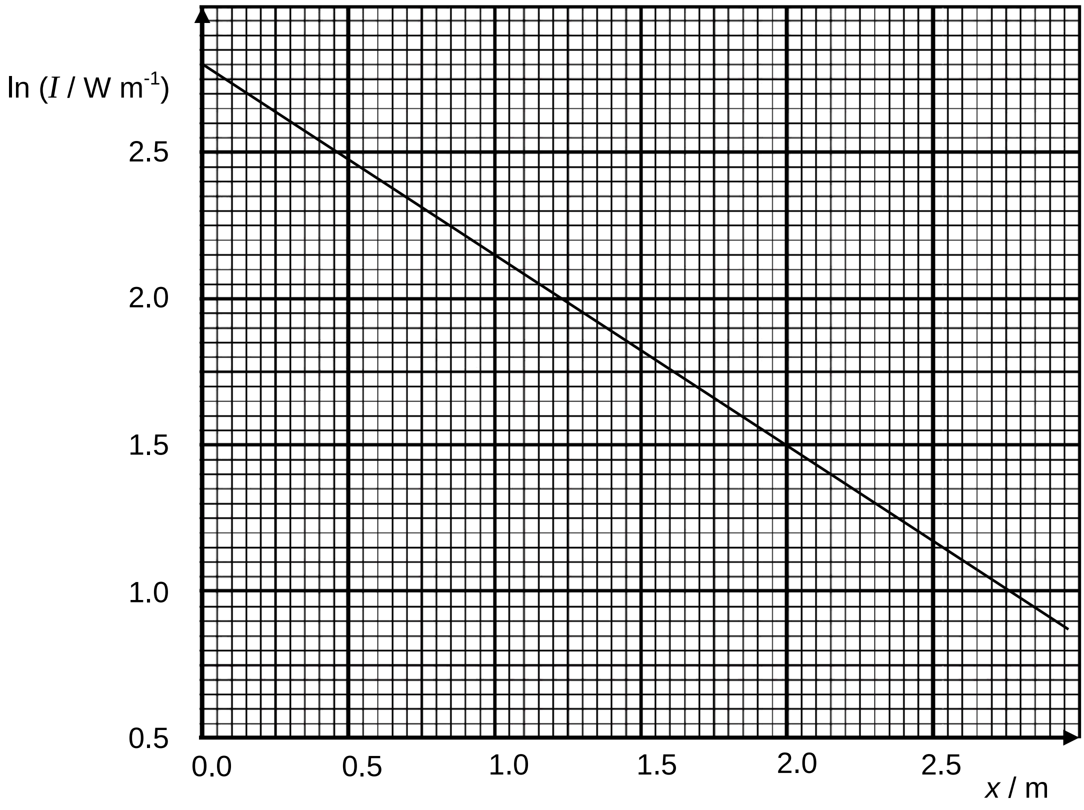


Fig. 5.4

Show that Fig. 5.4 indicates a relationship of the form

$$I = I_0 e^{-\alpha x}$$

where α is a constant.

Graph of ln(I) against x is a straight line with negative gradient,
equation of the straight line is : ln I = mx + ln I_o
where m is the gradient and ln I_o is the y-intercept

$$\ln\left(\frac{I}{I_o}\right) = mx$$

$$\therefore \frac{I}{I_o} = e^{mx} \text{ or } I = I_o e^{mx}$$

This equation is of the form of $I = I_o e^{-\alpha x}$ where m = -α

Section B

Answer **two** of the questions in this section.

6 **(a)** State Newton's second law and show how it leads to the relationship:

force = mass × acceleration

for a body of constant mass. [3]

Newton's second law of motion states that the rate of change of momentum of a body is directly proportional to the net external force acting on it and it takes place in the direction of the net external force.

$$\frac{d\vec{p}}{dt} \propto \vec{F}_{net} \Rightarrow \vec{F}_{net} = k\frac{d\vec{p}}{dt}$$

When SI units are used, the proportionality constant k is 1.
Hence

$$\vec{F}_{net} = \frac{d\vec{p}}{dt}$$

$$= \frac{d(m\vec{v})}{dt}$$

$$= m\frac{d\vec{v}}{dt} \text{ (for an object with a constant mass)}$$

$$\therefore \vec{F}_{net} = m\vec{a}$$

Thus force = mass × acceleration (shown)

(b) Fig. 6.1 below shows the top view of a train consisting of an engine pulling a cargo carriage and 2 passenger carriages. The mass of the engine, cargo carriage and each of the passenger carriages are 3500 kg, 7500 kg and 4500 kg respectively. The frictional force of the track acting on the engine, cargo carriage and each of the passenger carriages are 2.0 kN, 4.0 kN and 3.0 kN respectively.

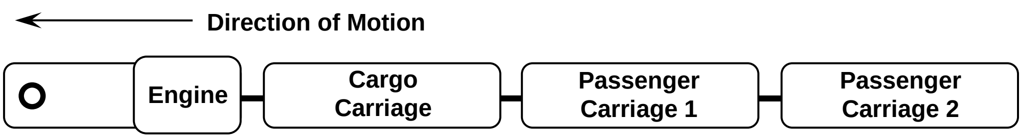


Fig. 6.1

(i) The train accelerates from rest to its operating speed of 30 m s^{-1} in 40 s.

1. Determine the driving force provided by the engine, assuming that acceleration during this period is constant and air resistance on the train is negligible.

acceleration of the train, $a = \frac{v-u}{t} = \frac{30-0}{40} = 0.75 \text{ m s}^{-2}$

Mass of Train = 3500 + 7500 + 2(4500) = 20000 kg

Total resistive force on train = 2.0 + 4.0 + 2(3.0) = 12.0 kN

By Newton's second law: (taking ← as positive)

$\vec{F}_{net} = m\vec{a}$

$D - 12\times10^{3} = 20000(0.75)$ where D is the driving force

$\therefore D = 27\ 000 \text{ N}$

2. Calculate the distance travelled by the train during this period. Hence or otherwise, determine the average power of the engine during this period.

Displacement of train in 40 s:

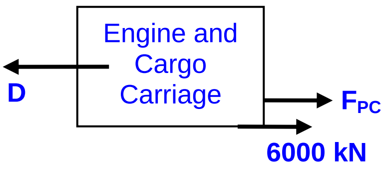
$s = \left(\frac{u+v}{2}\right)t = \left(\frac{0+30}{2}\right)40 = 600 \text{ m}$

$\text{Power} = \frac{\text{Work Done}}{\text{Time}} = \frac{27000(600)}{40} = 405000 \text{ W}$

3. By considering the forces acting on an appropriate body, determine the force in the connection between the cargo carriage and passenger carriage 1.

Method 1:

Considering only the horizontal forces acting on the free body of the engine and cargo carriage:



By Newton's 2nd Law:

← +ve:

$D - F_{PC} - 6000 = ma$

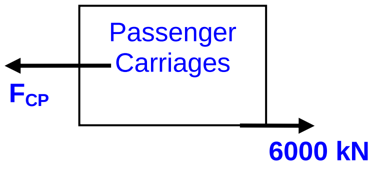
$27000 - F_{PC} - 6000 = 11000(0.75)$

$F_{PC} = 12750 \text{ N}$

$= 12.8 \text{ kN}$

Method 2:

Considering only the horizontal forces acting on the free body of the 2 passenger carriages:



By Newton's 2nd Law:
← +ve:

$F_{CP} - 6000 = ma$
$F_{CP} - 6000 = 9000(0.75)$
$F_{CP} = 12750$ N
= 12.8 kN

(ii) The train operator is studying the feasibility of making an additional stop at a certain town. Based on their current schedule, the maximum allowable delay is 5 minutes. The train has a deceleration of 2 m s^{-2}.

1. Calculate the time taken for the train to decelerate from its operating speed to rest, as well as the distance travelled during its deceleration.

$v = u + at$
$0 = 30 + (-2.0)t$
$t = 15$ s = time taken for train to come to rest from operating speed.
$v^2 = u^2 + 2as$
$0^2 = 30^2 + 2(-2.0)s$
$s = 225$ m = distance travelled by train when slowing down.

2. Determine the time delay due to the train accelerating and decelerating, and hence calculate the maximum time which the train may stop at the station.

Total distance travelled by train accelerating and decelerating whilst making a stop is 225 + 600 = 825 m

Time taken for train traveling at operating speed to cover 825 m

$= \frac{825}{30} = 27.5$ s

Delay in accelerating and decelerating the train when making and additional stop = 40 + 15 - 27.5 = 27.5 s
Hence, the maximum time at which the train may stand at the additional stop = 5(60) - 27.5 = 272.5 s

(iii) At the train depot, the passenger carriages are sometimes hoisted off the tracks using a light, frictionless pulley system as shown in Fig. 6.2.

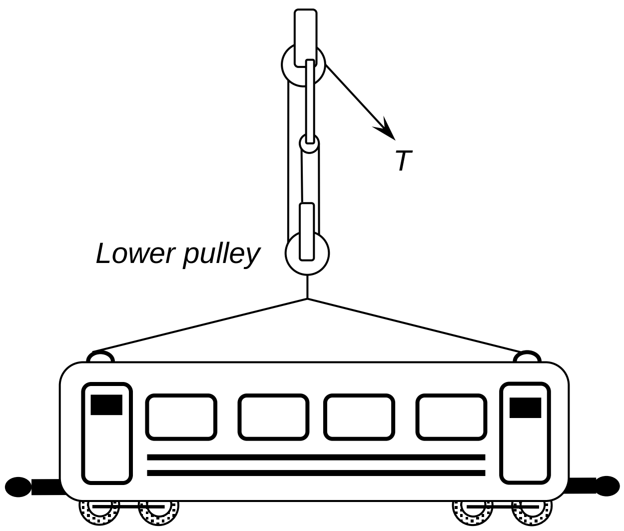


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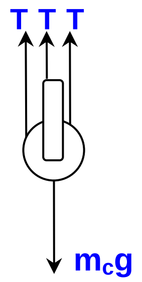
Fig. 6.2

By considering the forces acting on the lower pulley, determine the force *T* required to suspend the carriage in mid-air.

Considering a free body of the lower pulley:



Since the entire system is in equilibrium:
By Newton's 1st Law:
$3T = m_cg = 4500(9.81)$
$T = 14715 \text{ N} \approx 14.7 \text{ kN}$

7 **(a)** Explain what is meant by the superposition of waves.

When two or more waves meet at a point, the resultant displacement at that point is the vector sum of the respective displacements due to each of the waves.

(b) Two loudspeakers connected to the same voltage signal generator, are placed 5.0 m apart at P and Q. An observer A is 12.0 m from P and another observer B is at the perpendicular bisector of PQ, as shown in Fig. 7.1.

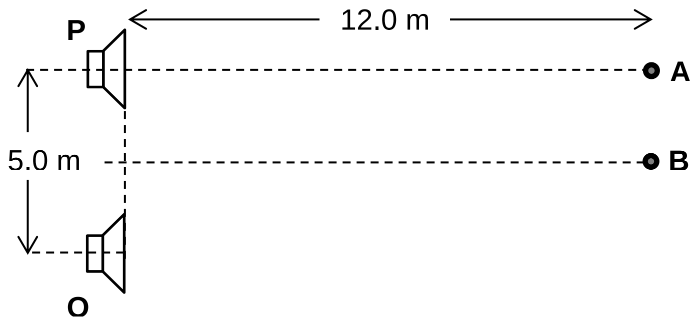


Fig. 7.1

When the loudspeakers are first switched on, producing 340 Hz tones, both observers can barely detect any sound.

(i) State the phase difference between the sound waves produced by the two loudspeakers.

π

(ii) Describe and explain what the two observers will hear when the frequency of the signal generator is gradually increased from 340 Hz.

Observer A:

A series of maxima and minima in intensity of sound. As frequency increases, wavelength decreases and the number of wavelengths in the path difference (PB–PA) increases. Phase difference between waves will gradually increase. When phase difference is 2π, 4π, etc, intensity of sound is maximum, and when phase difference is π, 3π, etc, intensity is minimum.

Observer B:

No change in intensity. Path difference at B is 0. Waves will meet exactly out of phase regardless of wavelength.

(iii) Calculate the frequency of the signal generator at which observer A detects sound of maximum intensity for the first time as the sound frequency is gradually increased from 340 Hz. (speed of sound in air = 340 m s^{-1})

Initially, path difference = 1.0 m = 1 λ

At first maximum, path difference = 1.5 λ' = 1.0 m

λ' = 0.67 m → f = v / λ' = 340 / 0.67 = 510 Hz

(c) One of the loudspeakers is now placed near one of the ends of a narrow open telescopic tube, as shown in Fig. 7.2. The signal generator is set at 520 Hz.

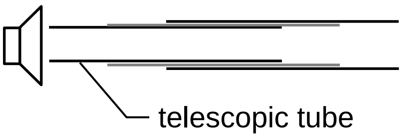


Fig. 7.2

(i) Describe and explain what is observed as the tube is gradually extended.

A series of alternating loud and soft sounds. Stationary waves will be formed in the tube when the tube is of certain lengths (multiples of half-wavelengths), causing the tube to resonate and produce a loud sound

(ii) Calculate the minimum length of the tube at which a loud sound is observed.

(iii) The loud sound in **(ii)** has a fundamental frequency of 540 Hz, as well as other secondary frequencies known as harmonics. Calculate one of these frequencies. Explain your working clearly.

(iv) Fig. 7.3 shows a double bass and a violin.

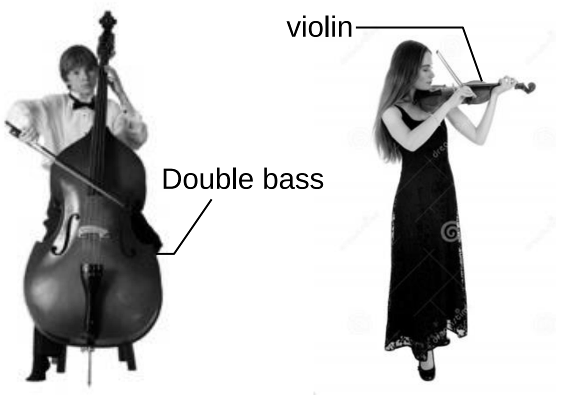


Fig. 7.3

The two musical instruments are very different in size, even though they are similar in shape. Suggest why this is so.

Musical instruments such as the double bass that produce low frequency sounds have to be large in size to accommodate stationary waves of long wavelengths.

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8 **(a)** For a particular metal surface, it is observed that there is a minimum frequency of light below which photoelectric emission does not occur. This observation provides evidence for a particulate nature of electromagnetic radiation.

State three further observations from photoelectric emission that provide evidence for a particulate nature of electromagnetic radiation.

Any 3 of the following:

1) There is no time lag between the illumination of the metal surface and the emission of photoelectrons.
2) The maximum kinetic energy of the photoelectron is independent of the intensity of light.
3) The maximum kinetic energy of the photoelectron is dependent on the frequency of light.
4) The rate of emission of photoelectrons is proportional to the intensity of light.

(b) Some data for the variation with frequency f of the maximum kinetic energy E_{MAX} of electrons emitted from a metal surface are shown in Fig. 8.1.

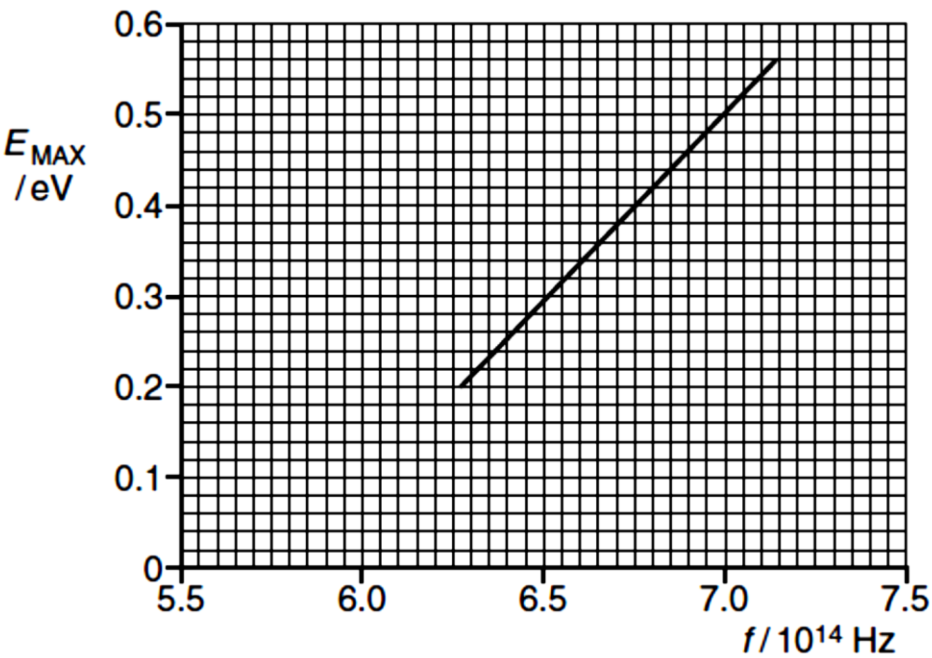

Fig. 8.1

(i) Explain why emitted electrons may have kinetic energy less than the maximum value at any particular frequency.

The emitted electron may come from below the surface of the metal, so additional energy is required to bring it to the surface.

(ii) Use Fig. 8.1 to determine

1. the threshold frequency,

5.8×10^{14} Hz

2. the work function energy, in eV, of the metal surface.

$\phi = hf_o$
$= (6.63 \times 10^{-34})(5.8 \times 10^{14})$
$= 3.85 \times 10^{-19}$ J $= 2.4$ eV

(c) White light is incident on a cloud of cool hydrogen gas, as illustrated in Fig. 8.2.

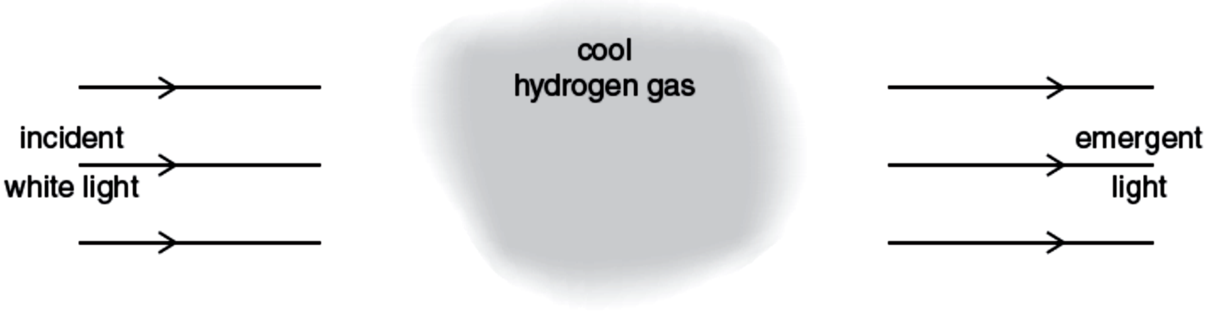

Fig. 8.2

The spectrum of the light emerging from the gas cloud is found to contain a number of dark lines.

(i) Explain why these dark lines occur.

- Photons with energies equal to the difference in energy between any higher energy level and the ground state will be absorbed by electrons at the ground state.
- These electron then transits to the higher energy levels.
- Subsequently these electrons de-excite, and emit photons, some of the same energies as what have been absorbed but these photons can be emitted in any direction.
- These result in the formation of the dark lines in the spectrum.

(ii) Some electron energy levels in a hydrogen atom are illustrated in Fig. 8.3.

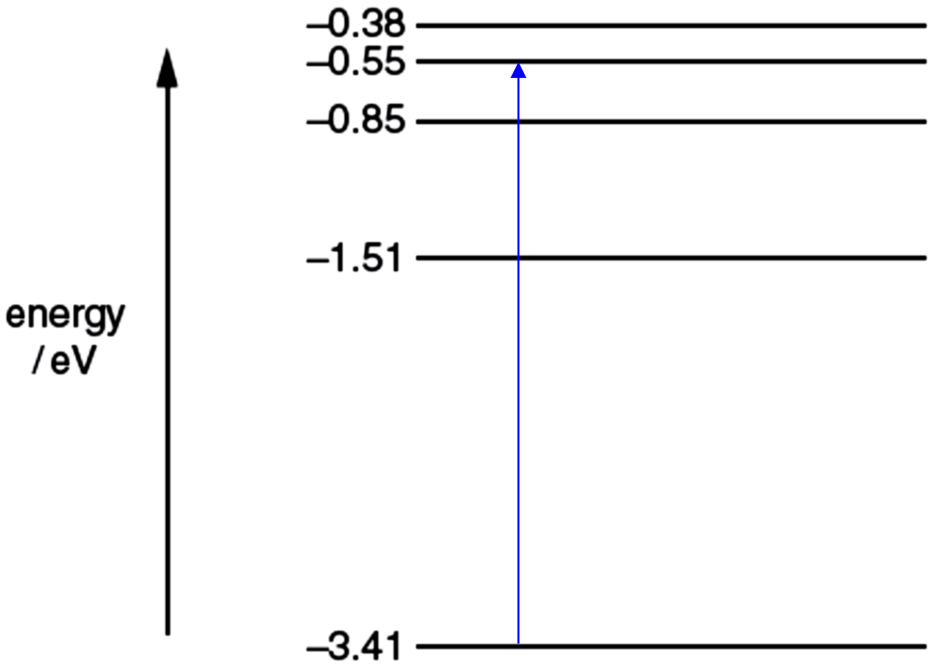

Fig. 8.3

One dark line is observed at a wavelength of 435 nm.

On Fig. 8.3, draw an arrow to indicate the energy change that gives rise to this dark line. [1]

$$\frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3.0\times10^{8})}{435\times10^{-9}} = 4.57\times10^{-19} = 2.86 \text{ eV}$$

(d) A beam of light is incident normally on a metal surface, as illustrated in Fig. 8.4.

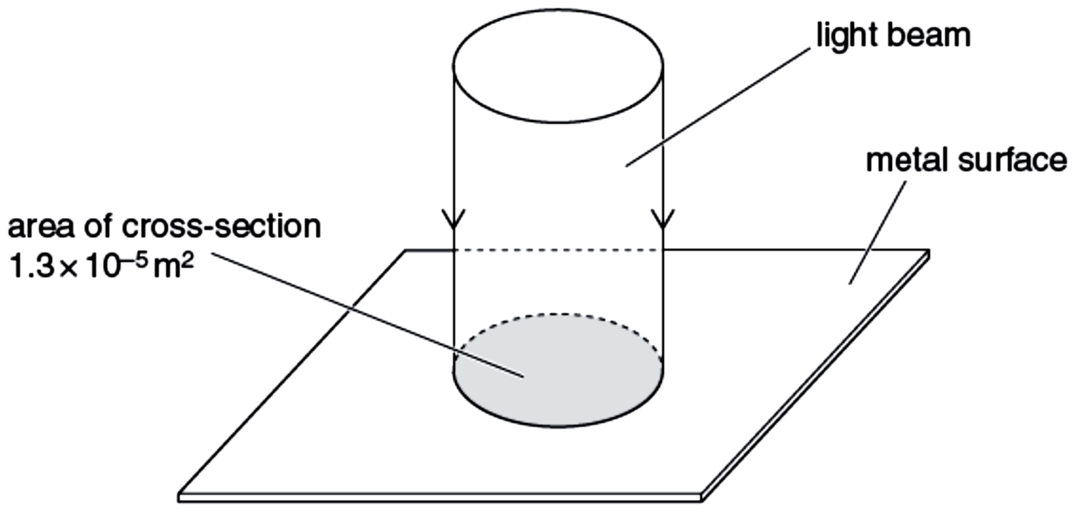

Fig. 8.4

The beam of light has cross-sectional area 1.3×10^{-5} m^2 and power 2.7×10^{-3} W. The light has wavelength 570 nm.

The light energy is absorbed by the metal and no light is reflected.

For Examiner's Use

(i) Show that a photon of this light has energy of 3.5 × 10^-19^ J. [1]

$$E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3.0\times10^{8})}{570\times10^{-9}} = 3.49\times10^{-19}\ \text{J}$$

(ii) Calculate, for a time of 1.0 s,

1. the number of photons incident on the surface,

$$\text{Power} = \frac{N_p(E)}{t}$$

$$\frac{N_p}{t} = \frac{P}{E} = \frac{2.7\times10^{-3}}{3.49\times10^{-19}} = 7.74\times10^{15}\ \text{photons per second}$$

Hence number of photons incident in 1.0 s = 7.74 x 10^{15}

2. the change in momentum of each photon.

Change in momentum

$$= \left(\frac{h}{\lambda}\right) = \left(\frac{6.63\times10^{-34}}{570\times10^{-9}}\right) = 1.16\times10^{-27}\ \text{kg m s}^{-1}$$

(iii) Use your answer in **(d)(ii)** to calculate the pressure that the light exerts on the metal surface.

$$\text{Pressure} = \frac{F}{A} = \frac{\frac{N_p}{t}(\Delta p)}{A} = \frac{(7.74\times10^{15})(1.16\times10^{-27})}{1.3\times10^{-5}} = 6.93\times10^{-7}\ \text{Pa}$$