SECTION B

Instructions for Section B

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

Where an answer box is provided, write your final answer in the box.

If an answer box has a unit printed in it, give your answer in that unit.

In questions where more than one mark is available, appropriate working **must** be shown.

Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Take the value of g to be 9.8 m s^{-2}.

Question 1 (7 marks)

Some physics students are conducting an experiment investigating both electrostatic and gravitational forces. They suspend two equally charged balls, each of mass 4.0 g, from light, non-conducting strings suspended from a low ceiling.

The charged balls repel each other with the strings at an angle of 60°, as shown in Figure 1.

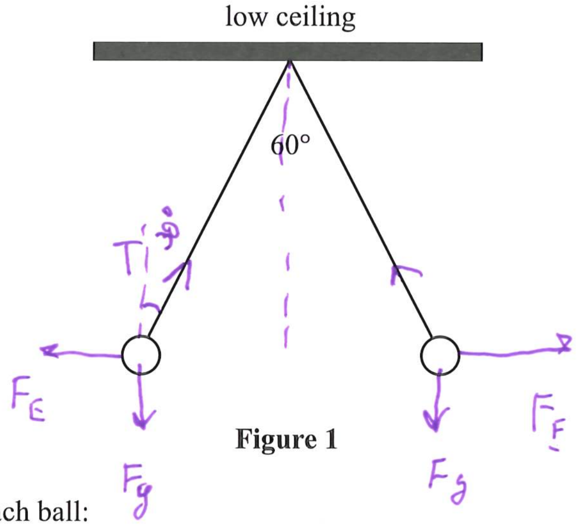

Figure 1

There are three forces acting on each ball:

- a tension force, T
- a gravitational force, F_g
- an electrostatic force, F_E.

a. On Figure 1, using the labels T, F_g and F_E, draw each of the three forces acting on each of the charged balls. 3 marks

b. Show that the tension force, T, in each string is 4.5×10^{-2} N. Use $g = 9.8$ N kg^{-1}. Show your working. 2 marks

$T\cos 30° = mg$

$T = \frac{0.004 \times 9.8}{\cos 30°} = 4.5 \times 10^{-2}$

c. Calculate the magnitude of the electrostatic force, F_E. Show your working. 2 marks

$F_e = T\sin 30° = 2.3 \times 10^{-2}$

2.3×10^{-2} N

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Question 2 (7 marks)

Phobos is a small moon in a circular orbit around Mars at an altitude of 6000 km above the surface of Mars. The gravitational field strength of Mars at its surface is 3.72 N kg^{-1}. The radius of Mars is 3390 km.

a. Show that the gravitational field strength 6000 km above the surface of Mars is 0.48 N kg^{-1}. 2 marks

$g_0 = \frac{GM}{r^2}$ $M = \frac{g_0 r^2}{G} = \frac{3.72 \times (3.39 \times 10^6)^2}{6.67 \times 10^{-11}} = 6.41 \times 10^{23}$ kg

$g_1 = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 6.41 \times 10^{23}}{(9.39 \times 10^6)^2} = 0.48$

or

$\frac{g_1}{g_0} = \left(\frac{r_0}{r_1}\right)^2 = \left(\frac{3390}{9390}\right)^2 = 0.13$

$3.72 \times 0.13 = 0.48$

b. Calculate the orbital period of Phobos. Give your answer in seconds. 3 marks

$T = 2\pi\sqrt{\frac{r^3}{GM}} = 2\pi\sqrt{\frac{(9.39 \times 10^6)^3}{6.67 \times 10^{-11} \times 6.41 \times 10^{23}}} = 27649$

or

$T = 2\pi\sqrt{\frac{r}{g}} = 2\pi\sqrt{\frac{9.39 \times 10^6}{0.48}} = 27790$

27790

| 27649 s |

2.8×10^4

c. Phobos is very slowly getting closer to Mars as it orbits.

Will the orbital period of Phobos become shorter, stay the same or become longer as it orbits closer to Mars? Explain your reasoning. 2 marks

| Shorter |

$\frac{r^3}{T^2}$ - const $r\downarrow$ $T\downarrow$

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Question 3 (5 marks)

Two long, straight current-carrying wires, P and Q, are parallel, as shown in Figure 2a. The current in the wires is the same in magnitude and opposite in direction.

Figure 2b shows the wires as viewed from above.

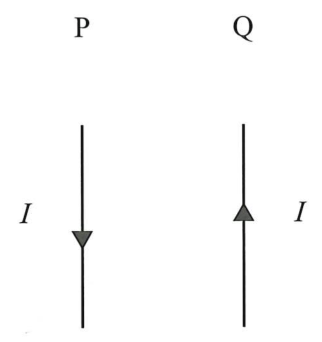

Figure 2a – Front view

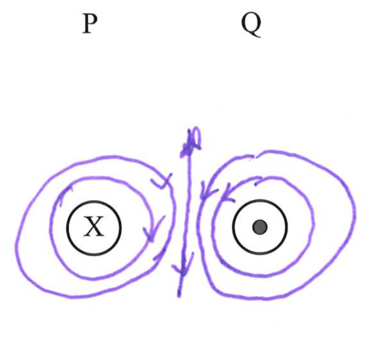

Figure 2b – Top view

a. On Figure 2b, sketch the magnetic field around the wires, showing the direction of the magnetic field. Use at least five field lines. 3 marks

b. Do the two wires, P and Q, attract or repel each other? Explain your reasoning. 2 marks

Repel

Using RHSR

Question 4 (5 marks)

A transformer is used to provide a low-voltage supply for six outdoor garden globes. The circuit is shown in Figure 3. Assume there is no power loss in the connecting wires. All voltage values are RMS values.

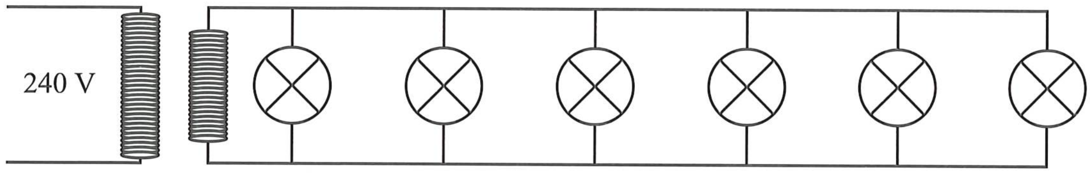

Figure 3

The input of the transformer is connected to a power supply that provides an AC voltage of 240 V. The globes in the circuit are designed to operate with an AC voltage of 12 V. Each globe is designed to operate with a power of 20 W.

a. Assuming that the transformer is ideal, calculate the ratio of primary turns to secondary turns of the transformer. 1 mark

240 : 12 = 20 : 1

20 : 1

The globes are turned on.

b. Calculate the current in the primary coil of the transformer. 2 marks

20 × 6 = 120 W

240 I = 120

I = 0.5

0.5 A

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SECTION B – Question 4 – continued

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c. Explain why the input current to the primary coil of the transformer must be AC rather than constant DC for the globes to shine. 2 marks

Changing magnetic flux required for transformer to work. AC creates changing flux, DC - constant

Question 5 (3 marks)

Figure 4a shows a single square loop of conducting wire placed just outside a constant uniform magnetic field, B. The length of each side of the loop is 0.040 m. The magnetic field has a magnitude of 0.30 T and is directed out of the page.

Over a time period of 0.50 s, the loop is moved at a constant speed, v, from completely outside the magnetic field, Figure 4a, to completely inside the magnetic field, Figure 4b.

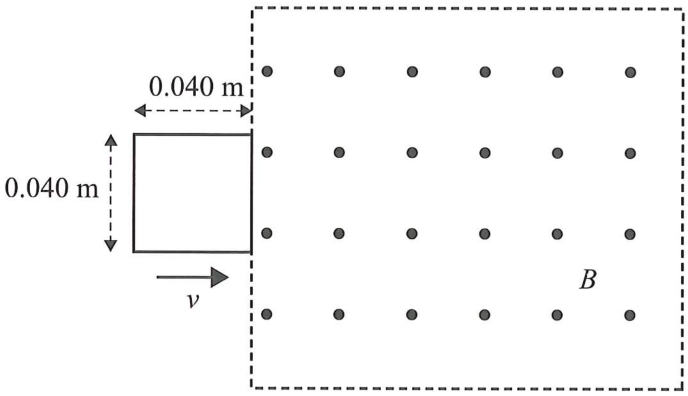

Figure 4a

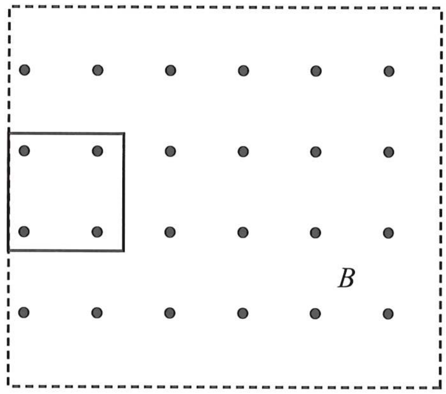

Figure 4b

a. Calculate the average EMF produced in the loop as it moves from the position just outside the region of the field, Figure 4a, to the position completely within the area of the magnetic field, Figure 4b. Show your working. 2 marks

$\mathcal{E} = \frac{BA}{t} = \frac{0.3 \times 0.04^2}{0.5} = 9.6 \times 10^{-4}$

9.6×10^{-4} V

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b. On the small square loop in Figure 5, show the direction of the induced current as the loop moves into the area of the magnetic field. 1 mark

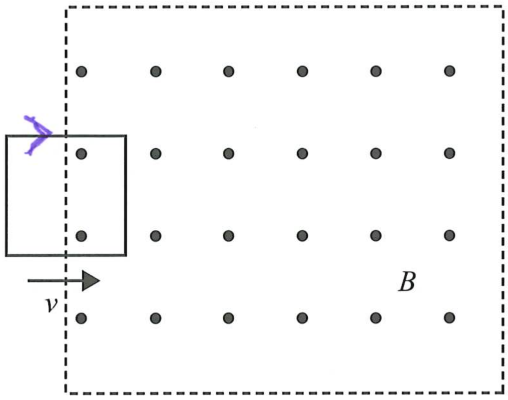

Figure 5

Question 6 (3 marks)

Kim and Charlie are attempting to create a DC generator and have arranged the magnets along the axis of rotation of the wire loop, J, K, L and M, as shown in Figure 6. They are having some trouble getting it to work. They rotate the loop in the direction of the arrow, as shown in Figure 6.

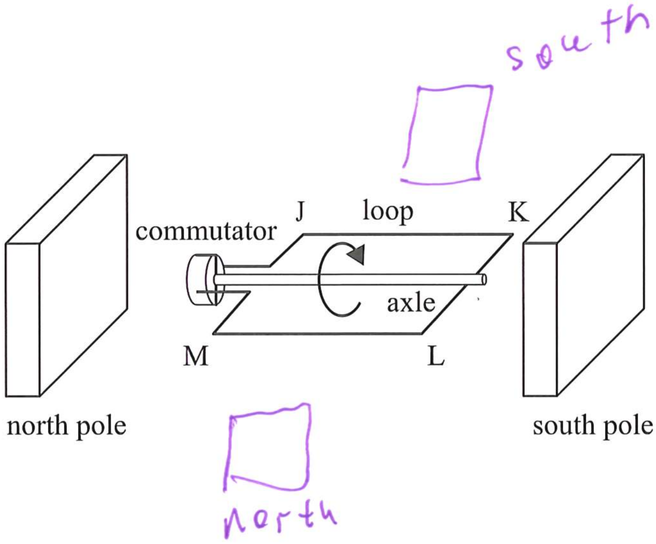

Figure 6

a. Using physics concepts, explain why this orientation of the magnets will not generate an EMF. 2 marks

$\Phi = 0$ $\Phi = BA\cos\theta$ $\theta = 90°$

No change in flux

b. Kim and Charlie decide to move the magnets so that an EMF is generated. On Figure 6, draw the positions of the magnets to ensure that an EMF is generated. 1 mark

Question 7 (7 marks)

Two high-voltage transmission lines span a distance of 260 km between Power Plant A and Town B, as shown in Figure 7. Power Plant A provides 350 MW of power. The potential difference at Power Plant A is 500 kV. The current in the transmission lines has an RMS value of 700 A and the power loss in the transmission lines is 20 MW.

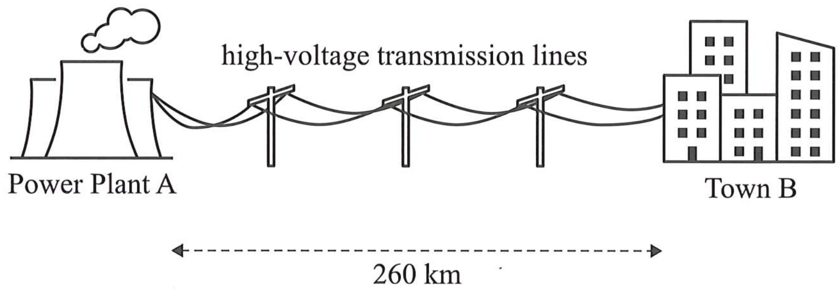

Figure 7

a. Show, using calculations, that the total resistance of the two transmission lines is 41 Ω. 2 marks

$R = \frac{P_{Loss}}{I^2} = \frac{20 \times 10^6}{700^2} = 40.82 = 41\,\Omega$

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b. Town B needs a minimum of 480 kV.

Determine whether 480 kV will be available to Town B. Show your working. 3 marks

$V_{line} = IR = 700 \times 41 = 28700$

$V_B = 500\,000 - 28\,700 = 471\,300$

No

c. Explain what would happen if the electricity between Power Plant A and Town B were to be transmitted at 50 kV instead of 500 kV. Assume that the resistance of the transmission lines is still 41 Ω. 2 marks

P const $P = IV$ V↓ I↑

I↑ P_{Loss} ↑ P_B and V_B ↓

Question 8 (7 marks)

Maia is at a skatepark. She stands on her skateboard as it rolls in a straight line down a gentle slope at a constant speed of 3.0 m s^{-1}, as shown in Figure 8. The slope is 5° to the horizontal.

The combined mass of Maia and the skateboard is 65 kg.

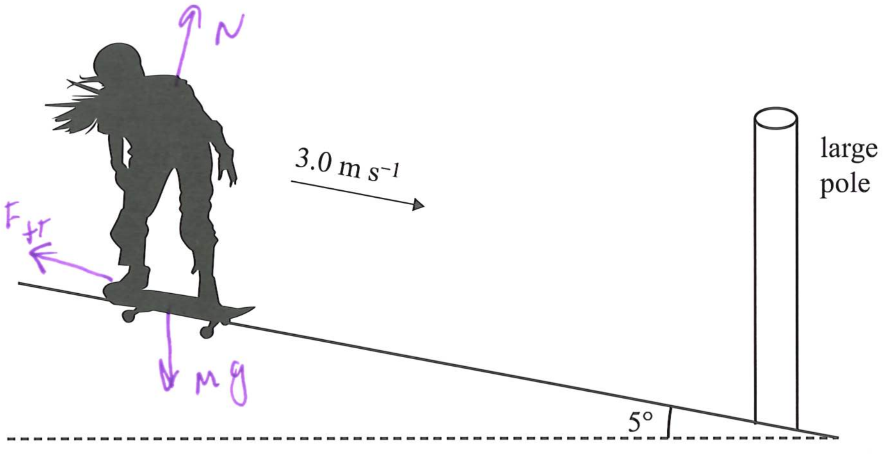

Figure 8

a. In Figure 9, the combined system of Maia and the skateboard is modelled as a small box with point M at the centre of mass.

Draw and label arrows to represent each of the forces acting on the system – that is, Maia and skateboard, as they roll down the slope. 3 marks

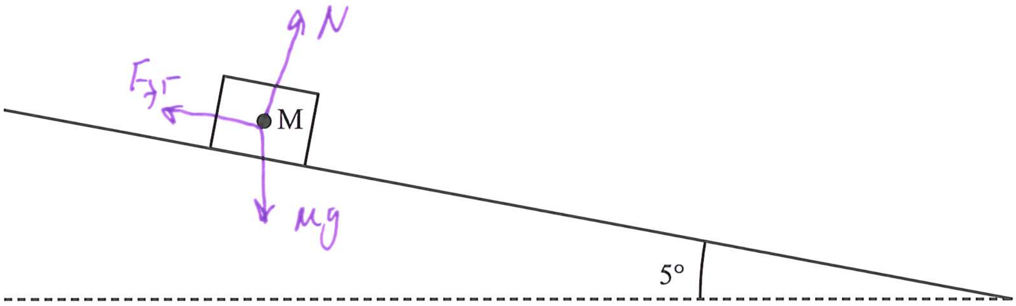

Figure 9

b. Calculate the magnitude of the total frictional forces acting on Maia and the skateboard. 2 marks

$F_{fr} = mg \sin\theta$

$= 65 \times 9.8 \sin 5°$

$= 55.5$ N

55.5 N

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Near the bottom of the ramp, Maia takes hold of a large pole and comes to a complete rest while still standing on the skateboard. Maia and the skateboard now have no momentum or kinetic energy.

c. Explain what happened to both the momentum and the kinetic energy of Maia and the skateboard. No calculations are required. 2 marks

Momentum to Earth

Energy into heat, sound etc.

Question 9 (7 marks)

Giorgos is practising his tennis serve using a tennis ball of mass 56 g.

a. Giorgos practises throwing the ball vertically upwards from point A to point B, as shown in Figure 10. His daughter Eka, a physics student, models the throw, assuming that the ball is at the level of Giorgos's shoulder, point A, both when it leaves his hand and also when he catches it again. Point A is 1.8 m from the ground. The ball reaches a maximum height, point B, 1.8 m above Giorgos's shoulder.

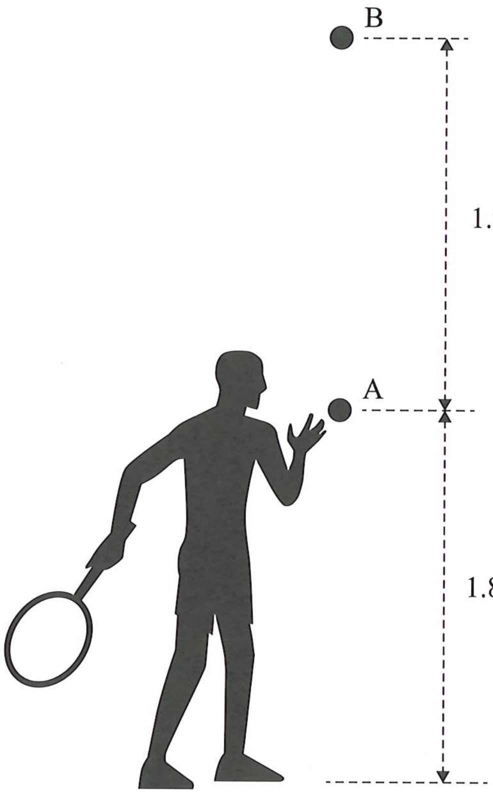

Figure 10

Show that the ball is in the air for 1.2 s from the time it leaves Giorgos's hand, which is level with his shoulder, until he catches it again at the same height. 2 marks

$s = \frac{at^2}{2}$ $t = \sqrt{\frac{2s}{g}} = \sqrt{\frac{2 \times 1.8}{9.8}} = 0.6$

$0.6 \times 2 = 1.2s$

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b. Giorgos swings his racquet from point D through point C, which is horizontally behind him at shoulder height, as shown in Figure 11, to point B. Eka models this swing as circular motion of the racquet head. The centre of the racquet head moves with constant speed in a circular arc of radius 1.8 m from point C to point B.

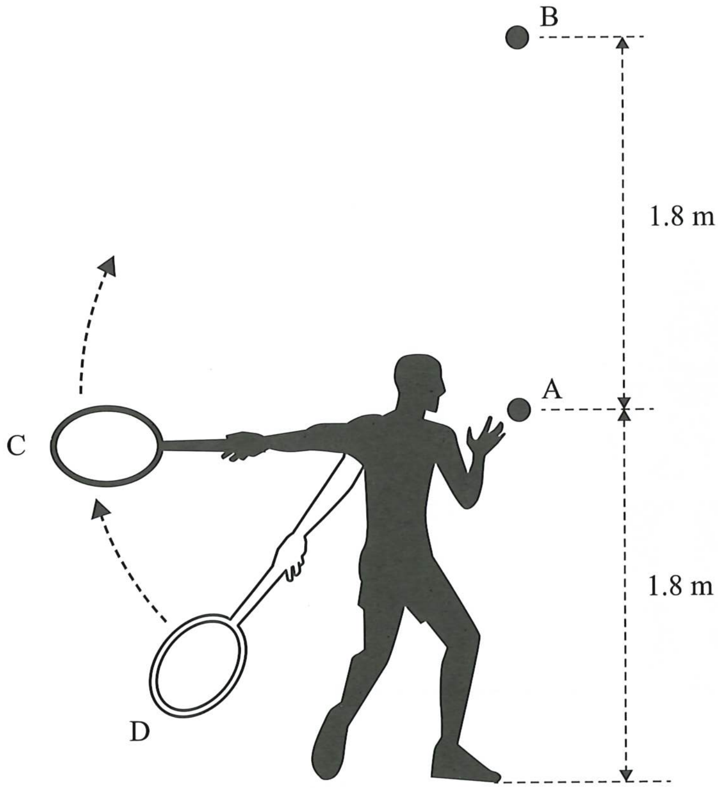

Figure 11

The racquet passes point C at the same time that the ball is released at point A and then the racquet hits the ball at point B.

Calculate the speed of the racquet at point C. 2 marks

$T = \frac{2\pi r}{4v}$ $v = \frac{2\pi r}{4T} = \frac{2\pi \times 1.8}{4 \times 0.6} =$ 4.7

4.7 m s^{-1}

c. The ball leaves Giorgos's racquet with an initial speed of 24 m s^{-1} in a horizontal direction, as shown in Figure 12. A tennis net is located 12 m in front of Giorgos and has a height of 0.90 m.

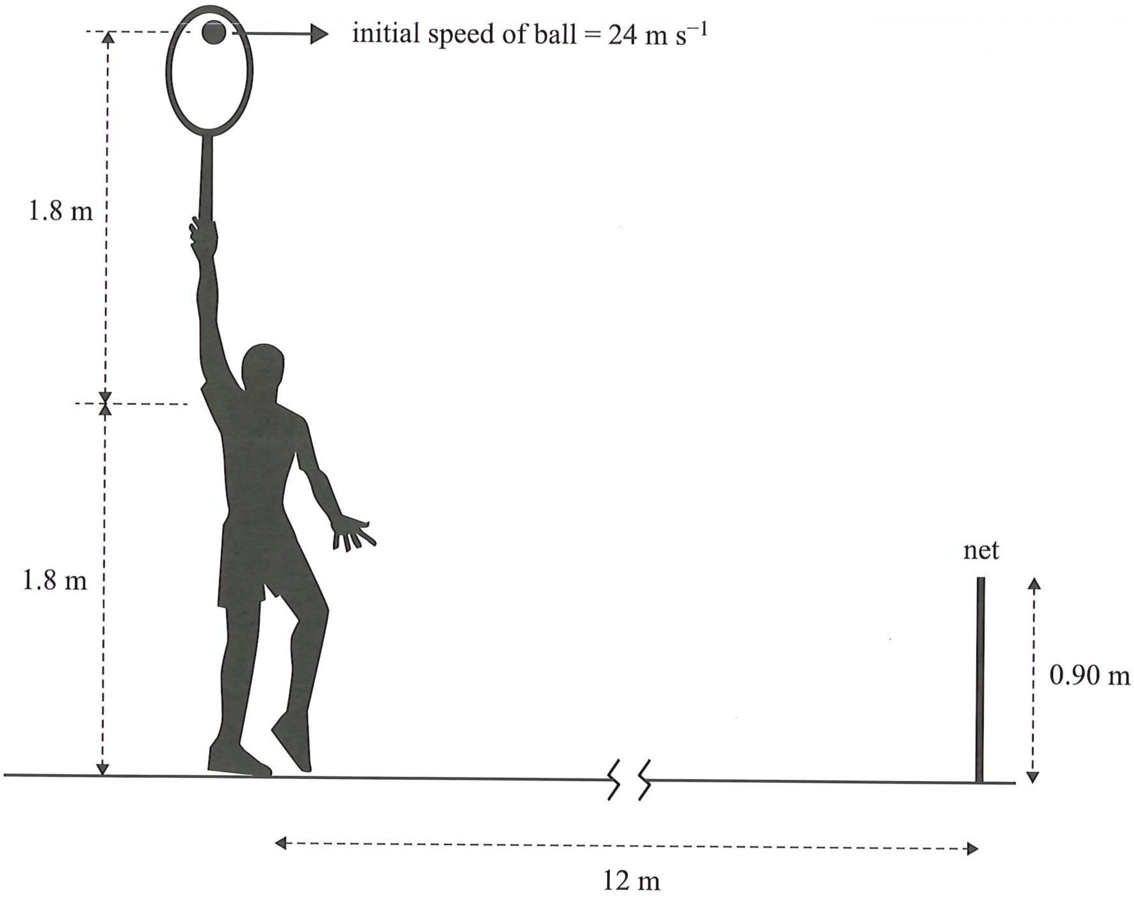

Figure 12

How far above the net will the ball be when it passes above the net? Assume that there is no air resistance. Show your working. 3 marks

$x = 24t$ $12 = 24t$ $t = 0.5$ s

$y = 3.6 - 4.9t^2 = 3.6 - 4.9 \times 0.5^2 = 2.4$ m

$2.4 - 0.9 = 1.5$ m

1.5 m m

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SECTION B – continued

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Question 10 (6 marks)

A proton in an accelerator beamline of proper length 4.80 km has a Lorentz factor, γ, of 2.00.

a. Calculate the speed of the proton relative to the beamline in terms of c, the speed of light in a vacuum. Give your answer to three significant figures. 3 marks

$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$ $\left(\frac{v}{c}\right)^2 = \frac{-1}{\gamma^2}+1$

$v = \sqrt{1-\frac{1}{\gamma^2}}\ c = \sqrt{1-\frac{1}{4}}c = \frac{\sqrt{3}}{2}c$

0.866 c

b. Calculate the length of the beamline in the reference frame of the proton. 1 mark

$\frac{4.8}{2} = 2.4$

2.4 km

c. Calculate the kinetic energy of the proton in joules. Show your working.

Mass of proton = 1.67×10^{-27} kg. 2 marks

$(\gamma-1)m_0c^2 = 1.67\times10^{-27} \times 9\times10^{16}$

$= 1.5 \times 10^{-10}$ J

1.5×10^{-10} J

Question 11 (3 marks)

A guitar string of length 0.75 m and fixed at both ends is plucked and a standing wave is produced.

The envelope of the standing wave is shown in Figure 13.

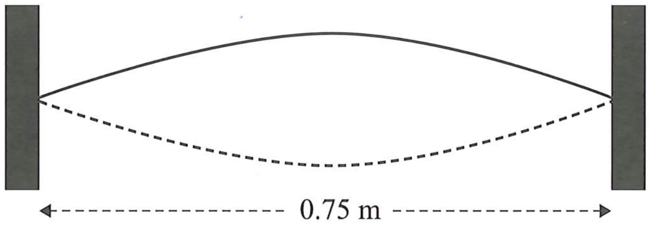

Figure 13

The speed of the wave along the string is 393 m s^{-1}.

a. What is the frequency of the wave? 1 mark

$f = \frac{v}{\lambda} = \frac{393}{1.5} = 262$

262 Hz

b. Describe how the standing wave is produced on the string fixed at both ends. 2 marks

Waves travelling in opposite directions and reflecting at the end. Superposition of the waves produce an interference pattern.

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Question 12 (4 marks)

A ray of monochromatic light is incident on a triangular glass prism with a refractive index of 1.52. The ray is perpendicular to the side AB of the glass prism, as shown in Figure 14.

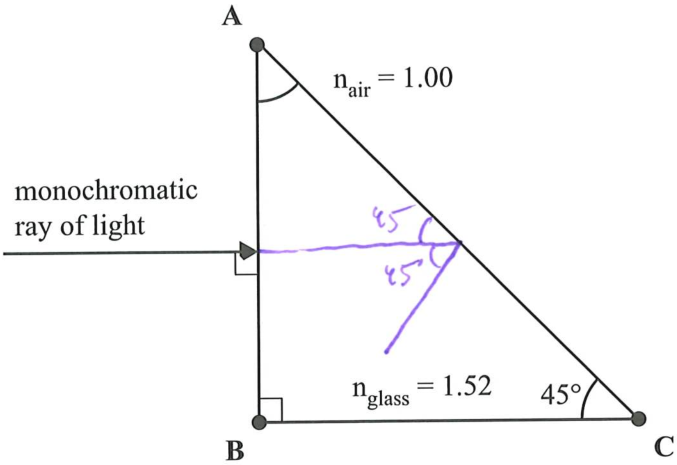

Figure 14

The ray of light travels through the glass prism before reaching side AC.

a. Calculate the critical angle for the glass prism at the glass–air interface. 2 marks

$\theta_c = \sin^{-1}\left(\frac{1}{1.52}\right) = 41°$

°

b. Will the ray of light undergo total internal reflection at side AC of the glass prism? Justify your answer. 2 marks

41 < 45 Yes

Question 13 (6 marks)

A group of physics students undertake a Young's double-slit experiment using the apparatus shown in Figure 15. They use a green laser that produces light with a wavelength of 510 nm. The light is incident on two narrow slits, S_1 and S_2. The distance between the two slits is 100 μm.

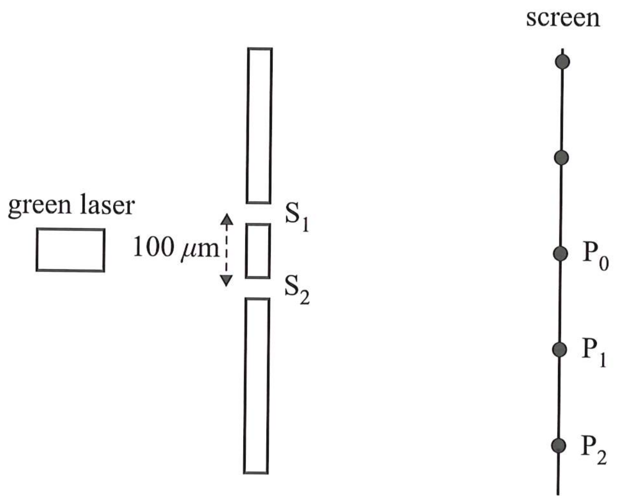

Figure 15

An interference pattern is observed on a screen with points P_0, P_1 and P_2 being the locations of adjacent bright bands, shown in Figure 15. Point P_0 is the central bright band.

a. Calculate the path difference between S_1P_2 and S_2P_2. Give your answer in metres. Show your working. 2 marks

$2\lambda = 1020$ nm

1.02×10^{-6} m

b. The green laser is replaced by a red laser.

Describe the effect of this change on the spacing between adjacent bright bands. 1 mark

$\lambda \uparrow \quad x = \frac{\lambda L}{w} \quad x \uparrow \quad \lambda \uparrow$

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c. Explain how Young's double-slit experiment provides evidence for the wave-like nature of light and not the particle-like nature of light. 3 marks

There is an interference pattern observed on the screen which is exclusively a wave phenomenon. Particles will not produce interference pattern.

Question 14 (6 marks)

Neutrons are subatomic particles and, like electrons, they can exhibit both particle-like and wave-like behaviour. Ignore any relativistic effects.

A beam of neutrons that can be used for scientific experiments is produced by a nuclear research reactor.

The mass of a neutron is 1.67×10^{-27} kg.

The de Broglie wavelength of the neutrons produced by the nuclear reactor is 3.02×10^{-10} m.

a. Calculate the speed of the neutrons. 2 marks

$\lambda = \frac{h}{p} = \frac{h}{mv}$ $v = \frac{h}{m\lambda} = \frac{6.63\times10^{-34}}{1.67\times10^{-27} \times 3.02\times10^{-10}}$

$= 1.3\times10^{3}$

1.3×10^{3} m s^{-1}

b. The neutron beam is sent through a crystal with an interatomic spacing of 3.62×10^{-10} m.

Would you expect to observe a diffraction pattern? Justify your answer. 2 marks

Yes as wavelength is similar to spacing

SECTION B – Question 14 – continued

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c. Consider an electron beam with the same de Broglie wavelength as the neutron beam, 3.02×10^{-10} m.

Which will have the greater speed: an electron in the electron beam or a neutron in the neutron beam? Justify your answer. 2 marks

$v = \frac{h}{m\lambda}$ m↓ v↑

Question 15 (8 marks)

In a photoelectric effect experiment, a team of physics students investigated the relationship between the maximum kinetic energy of ejected electrons and the frequency of the light incident on calcium metal. Their results are shown in Figure 16.

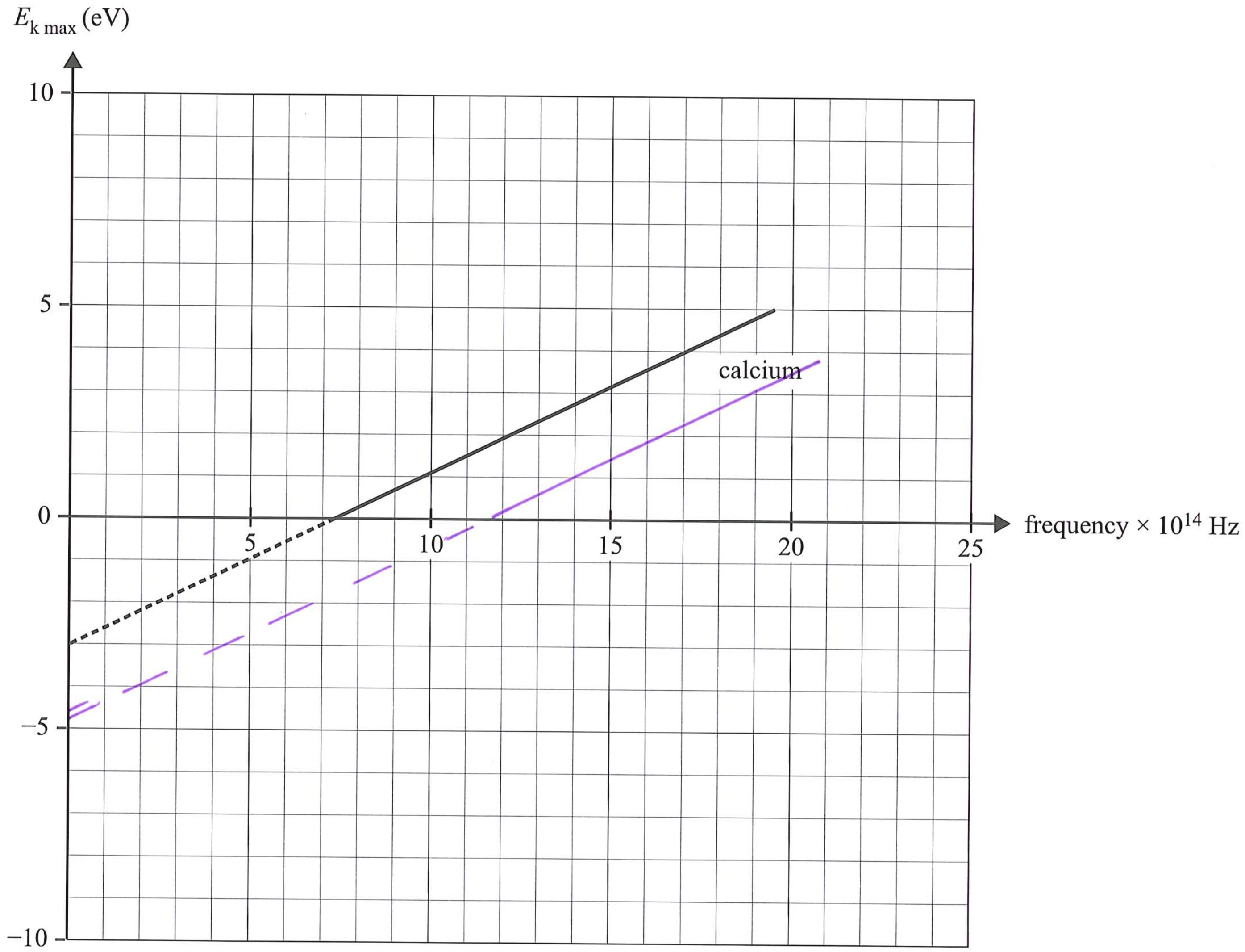

Figure 16

a. Using data from the graph in Figure 16, estimate the work function for calcium. 1 mark

3 eV

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b. Using data from the graph in Figure 16, determine the maximum wavelength of the light that can emit photoelectrons from the calcium surface. 2 marks

$f_0 = \frac{W}{h} = \frac{3}{4.14 \times 10^{-15}}$

$\lambda = \frac{c}{f} = \frac{ch}{W} = \frac{3 \times 10^8 \times 4.14 \times 10^{-15}}{3}$

$= 4.14 \times 10^{-7}$

4.14×10^{-7} m

The calcium metal was replaced with copper metal with a work function of 4.70 eV.

c. On the grid in Figure 16, draw the graph that would result when the calcium metal was replaced with copper metal. 2 marks

d. The copper metal is illuminated by photons of wavelength 380 nm.

Will photoelectrons be ejected? Justify your answer using a calculation and any relevant data from the graph in Figure 16. 3 marks

$E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{380 \times 10^{-9}} = 3.26\,eV < W$

No

Question 16 (6 marks)

Fluorescent lights, when operating, contain gaseous mercury atoms, as shown in Figure 17.

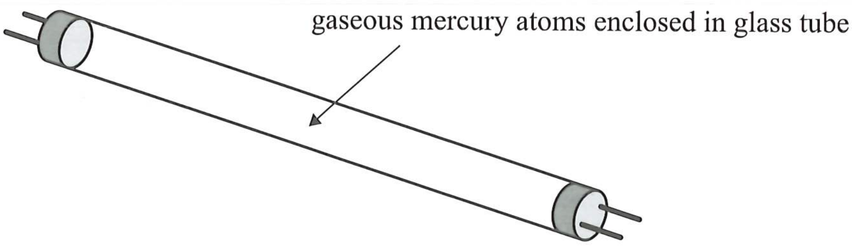

Figure 17

Analysis of the light produced by fluorescent lights shows a number of emission spectral lines, including a prominent line representing a wavelength of 436.6 nm.

a. Calculate the energy of the photons represented by the emission spectral line representing a wavelength of 436.6 nm. 2 marks

$E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{436.6 \times 10^{-9}} = 2.8$

2.84 eV

Figure 18 shows the lowest five energy levels for mercury.

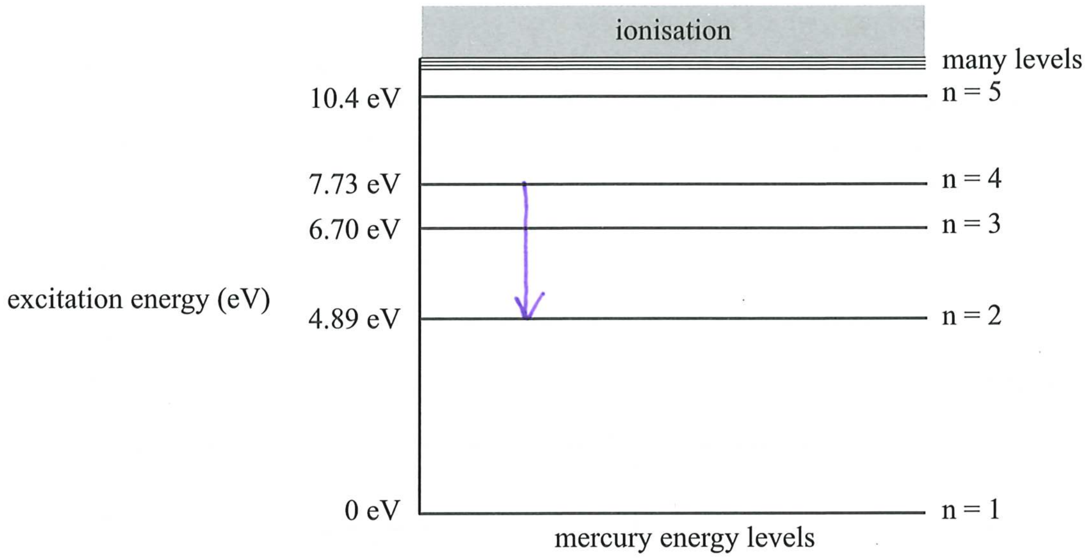

Figure 18

b. On the energy level diagram in Figure 18, draw an arrow showing the energy level transition that corresponds to the production of the spectral line representing a wavelength of 436.6 nm. 1 mark

c. A 6.7 eV photon is absorbed by a mercury atom in the ground state and then the atom transitions back to the ground state.

Identify the energies, in eV, of all the possible photons that could be produced. 3 marks

6.7, 4.89, 1.81