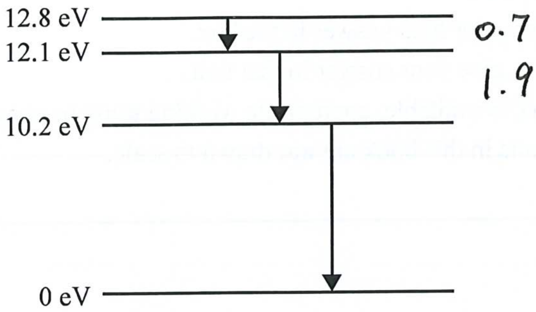
Question 17

Some of the energy levels of the hydrogen atom are shown in the diagram below. A hydrogen atom has been excited to the 12.8 eV energy level. It returns to the ground state via the three transitions shown.



Which of the following indicates the energies of the emitted photons?

A. 0.7 eV, 2.6 eV, 10.2 eV
B. 0.7 eV, 1.9 eV, 10.2 eV
C. 1.9 eV, 2.6 eV, 10.2 eV
D. 10.2 eV, 12.1 eV, 12.8 eV

Question 18

Which one of the following best describes how laser light is produced?

A. by focusing solar radiation
B. by stimulating the emission of radiation
C. by accelerating positively charged particles
D. by heating a tungsten filament in an evacuated glass tube

Question 19

Diffraction is a property of waves. Electrons display wave-like properties when producing diffraction patterns.
This is because electrons

A. always carry an electric charge.
B. can move around nuclei in fixed orbits.
C. have a wavelength related to their momentum.
D. can jump between energy levels within an atom.

Question 20

The position and the momentum of an object cannot be measured precisely at exactly the same time, no matter how carefully the measurements are made.
This is explained by

A. Newton's laws of motion.
B. Young's double-slit experiment.
C. de Broglie's matter-wave equation.
D. Heisenberg's uncertainty principle.

END OF SECTION A
TURN OVER

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 (4 marks)

A particle with mass m and charge q is accelerated from rest by a potential difference, V. The only force acting on the particle is due to the electric field associated with this potential difference.

a. Show that the speed of the particle is given by $v = \sqrt{\frac{2qV}{m}}$ and state the principle of physics used in your answer. 2 marks

Conservation of energy

$qV = \frac{mv^2}{2}$

$v = \sqrt{\frac{2qV}{m}}$

b. Calculate the speed of an electron accelerated from rest by a potential difference of 200 V. 2 marks

$v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 200}{9.1 \times 10^{-31}}} =$

8.4 × 10^{6} m s^{-1}

Question 2 (7 marks)

The speed of a satellite in a circular orbit around a planet is given by $v = \sqrt{\frac{GM}{r}}$, where G is the universal gravitational constant, M is the mass of the planet and r is the orbital radius of the satellite.

Titan is the largest moon of Saturn and has an orbital radius of 1.2×10^9 m. The mass of Saturn is 5.7×10^{26} kg. Assume that Titan's orbit is circular.

a. Calculate Titan's orbital speed. 2 marks

$v = \sqrt{\frac{6.67\times10^{-11} \times 5.7\times10^{26}}{1.2\times10^9}}$

$= 5.6\times10^3$

5.6×10^3 m s^{-1}

Another moon of Saturn is Rhea. Rhea is in a circular orbit of radius 5.3×10^8 m.

b. Does Rhea travel faster than, at the same speed as or slower than Titan? Explain your answer. 2 marks

Faster

R↓ V↑

c. Titan's period around Saturn is 16 days.

Calculate Rhea's period around Saturn. Show your working. 3 marks

$\frac{r_R^3}{r_T^3} = \frac{T_R^2}{T_T^2}$

$T_R = \sqrt{\left(\frac{r_R}{r_T}\right)^3 T_T^2} = \sqrt{\left(\frac{5.3\times10^8}{1.2\times10^9}\right)^3} \times 16 = 4.7$

4.7 days

Question 3 (4 marks)

A positron and an electron are fired one at a time into a strong uniform magnetic field in an evacuated chamber. They are fired at the same speed but from opposite sides of the chamber.

Their initial velocities are initially perpendicular to the magnetic field and opposite in direction to each other, as shown in Figure 1.

A positron has the same mass as an electron (9.1×10^{-31} kg) and has the same magnitude of electric charge as an electron (-1.6×10^{-19} C) but is positively charged ($+1.6 \times 10^{-19}$ C).

On Figure 1, sketch and label the respective paths that the positron and the electron will take while in the uniform magnetic field.

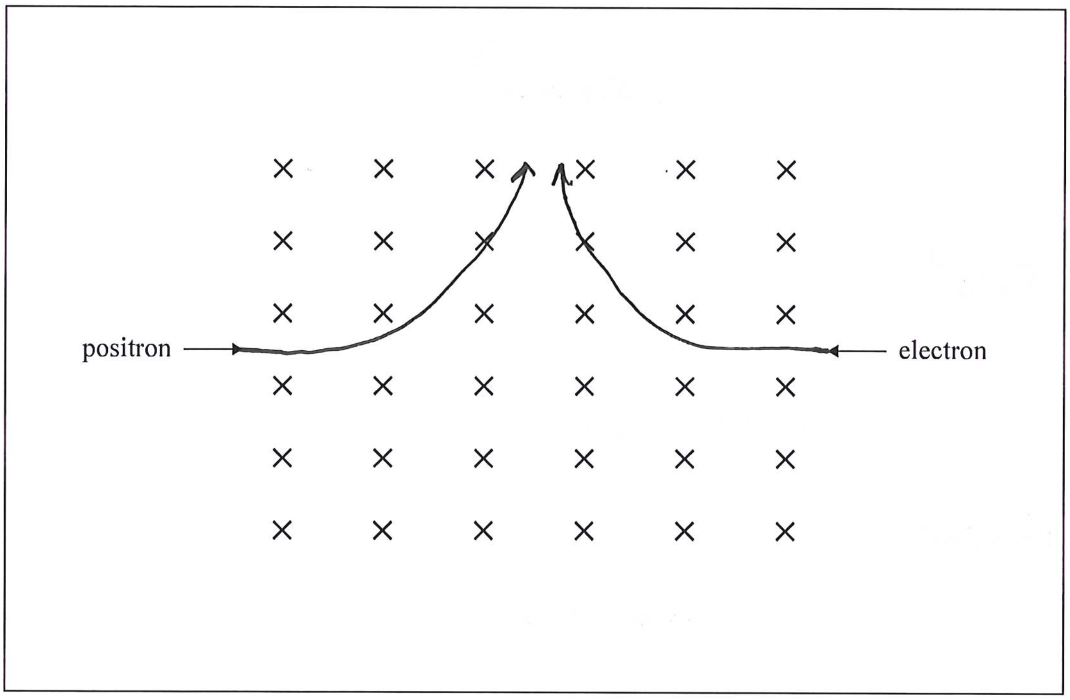


Figure 1

Question 4 (6 marks)

Figure 2 shows a schematic diagram of a simple DC generator with the output voltage connected to a cathode-ray oscilloscope (CRO).

The DC generator consists of a rectangular wire coil of 200 turns placed in a uniform magnetic field of strength 5.0 mT. The coil is rotated with a frequency of 60 Hz in the direction shown in Figure 2. The average EMF generated in the coil for the first quarter turn is 35 mV. The coil is initially in the position shown in Figure 2.

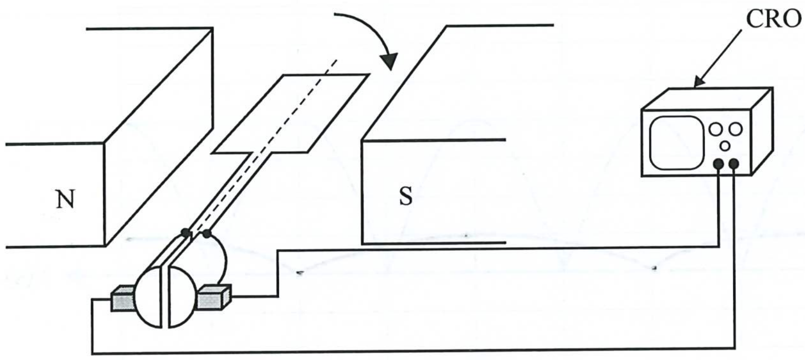


Figure 2

a. When viewed from above, will the induced current in the coil be clockwise or anticlockwise during the first quarter turn? 1 mark

Clockwise

b. Calculate the area of one loop of the rectangular wire coil. Show your working. 3 marks

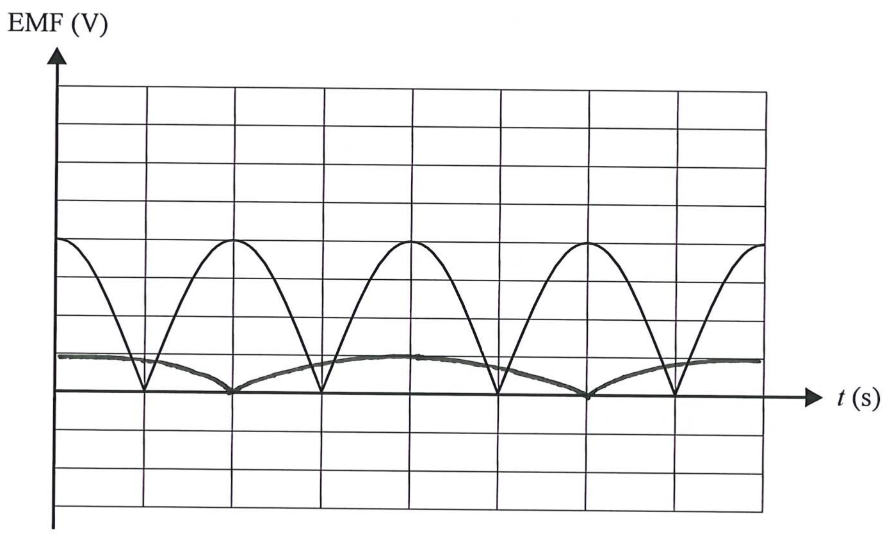
$\mathcal{E} = N\frac{\Delta\Phi}{\Delta t} = N\frac{BA}{\Delta t}$ $A = \frac{\mathcal{E}\Delta t}{NB}$

$A = \frac{0.035 \times \frac{1}{60\times4}}{200\times0.005} = 0.00015$

1.5×10^{-4} m^2

c. The graph below shows the EMF induced in the coil over two full turns.

On the same axes, sketch the output EMF that would result if the number of turns in the coil is changed to 100 turns and the frequency of rotation is changed to 30 Hz. 2 marks



Period × 2
N ÷ 2 } Amplitude ÷ 4

Question 5 (2 marks)

A bar magnet is moved towards a single closed loop of conducting wire with the bar magnet's south pole closest to the loop, as shown in Figure 3. The loop is stationary.

Figure 3

The area and the shape of the loop remain constant and the magnet is not changed.

Explain, in terms of magnetic flux, how a current is induced in the loop.

As magnet moving closer, magnetic field and so flux throug the coil increases. According to Faradayslaw as flux changes, current induced

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Question 6 (4 marks)

A laptop computer requires a transformer to reduce the voltage to its rechargeable battery while the battery is charging. The power point supplies an RMS voltage of 240 V and delivers an RMS current of 0.35 A. The transformer converts the voltage to an RMS voltage of 8.0 V. Assume that the transformer is ideal.

a. Calculate the ratio of the number of turns $\frac{N_p}{N_s}$. Show your working. 2 marks

$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{240}{8} = 30$

30 : 1

b. Calculate the RMS current delivered by the power point while the battery is charging. 2 marks

$\frac{I_s}{I_p} = \frac{N_p}{N_s}$ $I_s = 0.35 \times 30 = 10.5A$

or 0.35 A

or $\frac{0.35}{30} = 0.012 A$

A

Question 7 (7 marks)

A spherical mass of 2.0 kg is attached to a piece of string with a length of 2.0 m. The spherical mass is pulled back until it makes an angle of 60° with the vertical, as shown in Figure 4. The spherical mass is then released. Ignore the mass of the string.

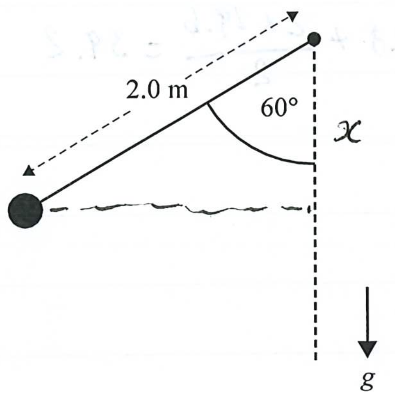

Figure 4

a. Show that the maximum speed of the spherical mass is 4.4 m s^{-1}. 2 marks

$x = 2\cos 60° = 1\ m$

$h = 2 - 1 = 1\ m$

$mgh = \frac{mv^2}{2}$

$v = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 1} = 4.4\ m\ s^{-1}$

b. At what part of its path is the spherical mass at its maximum speed? Explain your reasoning. 2 marks

Maximum v is at the lowest point as gravitational potential energy is minimum and so kinetic en. is max. as total en. remains const.

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c. Calculate the maximum tension in the string. 3 marks

$T - mg = \frac{mv^2}{r}$

$T = mg + \frac{mv^2}{r} = 2 \times 9.8 + \frac{2 \times 19.6}{2} = 39.2$

39.2 N

Question 8 (6 marks)

A satellite is moving in a stable circular orbit 25 Earth radii from the centre of Earth, as shown in Figure 5. The period of the satellite is T.

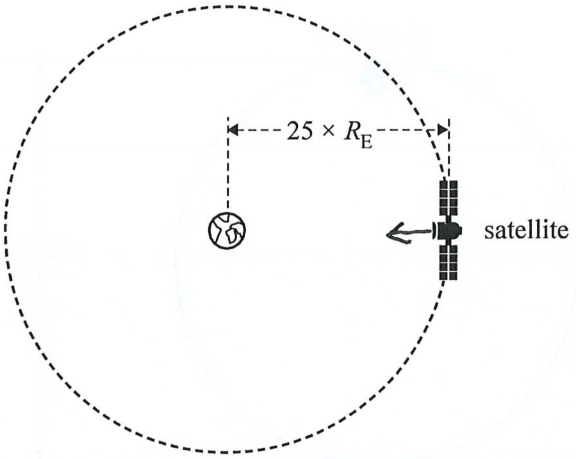

Figure 5

a. Calculate the magnitude of the acceleration of the satellite. Show your working. 2 marks

$g = \frac{GM}{r^2}$ $\frac{g_1}{g} = \frac{r^2}{(25r)^2}$

$g_1 = \frac{1}{25^2} \times 9.8$

1.6×10^{-2} m s^{-2}

b. Indicate the direction of the acceleration of the satellite by drawing an arrow on the satellite shown in Figure 5. 1 mark

c. Another identical satellite is placed in a stable circular orbit 30 Earth radii from the centre of Earth.

Using the terms 'less than', 'same as' or 'more than', complete the table below to describe the magnitude of the acceleration, the kinetic energy and the period of this satellite compared to those of the satellite that is orbiting at 25 Earth radii. 3 marks

Magnitude of acceleration	Less
Kinetic energy	Less
Period	More

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Question 9 (5 marks)

A small ball of mass 0.30 kg travels horizontally at a speed of 6 m s^{-1}. It enters a vertical circular loop of diameter 0.80 m, as shown in Figure 6. Assume that the radius of the ball and that the frictional forces are negligible.

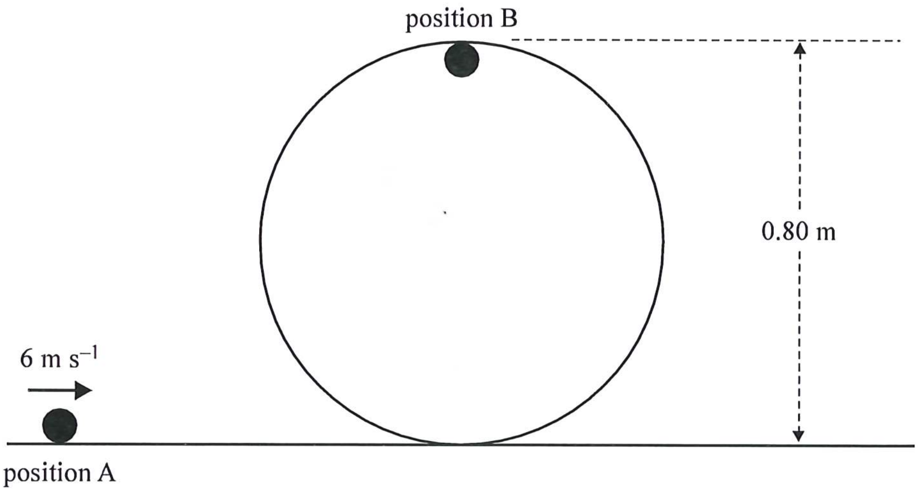

Figure 6

a. Show that the kinetic energy of the ball at position A in Figure 6 is 5.4 J. 1 mark

$\frac{mv^2}{2} = \frac{0.3 \times 6^2}{2} = 5.4$

b. Will the ball remain on the track at the top of the loop (position B in Figure 6)? Give your reasoning. 4 marks

$mg \times 0.8 + \frac{mv^2}{2} = 5.4$

$0.3 \times 9.8 \times 0.8 + 0.15v^2 = 5.4$

$0.15v^2 = 3.048$ $v = 4.5$ m s^{-1}

Minimum speed required $\sqrt{gr} = \sqrt{9.8 \times 0.4} = 1.98$

$4.5 > 2.8$, yes, will remain on track

or

$N = \frac{mv^2}{R} - mg = \frac{0.3 \times 4.5^2}{0.4} - 0.3 \times 9.8 = 12.2\ N > 0$

Question 10 (6 marks)

A basketball player throws a ball with an initial velocity of 7.0 m s^{-1} at an angle of 50° to the horizontal, as shown in Figure 7. The ball is 2.2 m above the ground when it is released. By the time the ball passes through the ring at the top of the basket, it has travelled a horizontal distance of 3.2 m. Ignore air resistance.

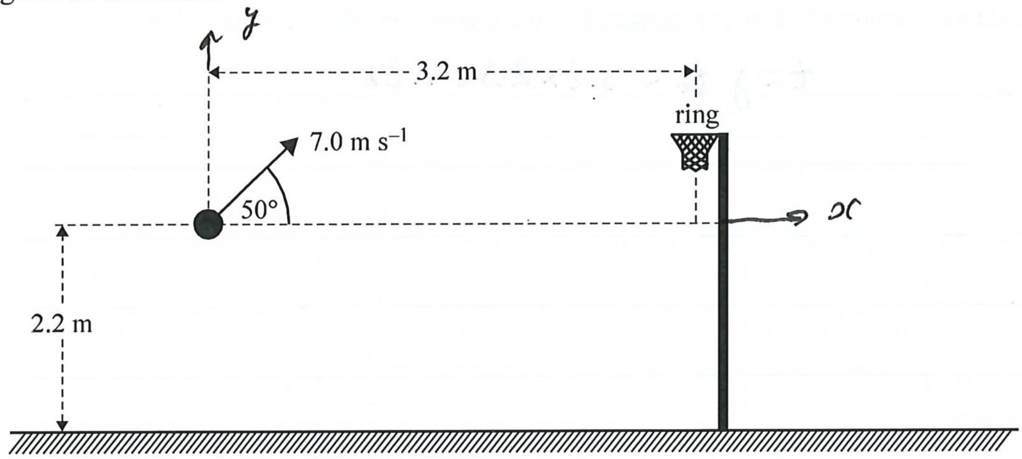

Figure 7

a. Show that the time taken for the ball's flight from launch to passing through the ring is 0.71 s. Show your working. 2 marks

$x = 7\cos 50° t \quad t = \frac{3.2}{7\cos 50°} = 0.71$ s

b. How far above the ground is the ring at the top of the basket? Show your working. 4 marks

~~y=y₀+ut~~ $y = 2.2 + 7\sin 50° \times 0.71 - 4.9 \times 0.71^2$

$= 3.54$

3.54 m

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Question 11 (4 marks)

An experiment is set up at a linear accelerator research facility to study muons. The muons created at the research facility are measured to have a speed of 0.950c ($\gamma = 3.20$).

a. One muon has a lifetime of 2.3 μs, as measured in the muon's frame of reference.

Calculate this muon's lifetime, as measured by the researchers. Show your working. 2 marks

$t = \gamma t_0 = 3.2 \times 2.3 = 7.36$

7.36 μs

b. In one observation, a 0.950c muon travels 1.5 km, as measured by the researchers.

If measured in the muon's frame of reference, would this length be the same, shorter or longer? Use a calculation to justify your answer. 2 marks

Length shorter

~~shorter due t~~ $L = \frac{L_0}{\gamma} = \frac{1.5}{3.2} = 0.47$ km

Question 12 (6 marks)

A transverse wave travels to the right along a length of string at a speed of 8.0 m s^{-1}. Figure 8 shows the wave at one instant in time.

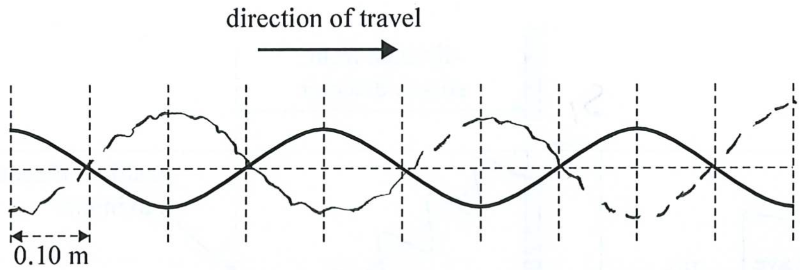

Figure 8

a. Calculate the frequency of the wave shown in Figure 8. 2 marks

$f = \frac{v}{\lambda} = \frac{8}{0.4} = 20$

20 Hz

b. On Figure 8, draw the wave as it would appear 25 ms after the instant shown. Show any calculations and state any assumptions that you have made. 2 marks

$T = \frac{1}{20} = 0.05 s = 50 ms \quad 25 ms = \frac{1}{2} T$

c. The wave source (not shown in Figure 8) is now adjusted to increase the frequency.

Explain the effect that this will have on the wavelength, stating any assumptions that you have made. 2 marks

Assump. $V = const$

$f \uparrow, \lambda \downarrow$

Question 13 (9 marks)

Students are investigating the interference of waves using a source of coherent microwaves, two narrow slits and a microwave detector. Figure 9 shows the microwaves travelling from the slits to the detector.

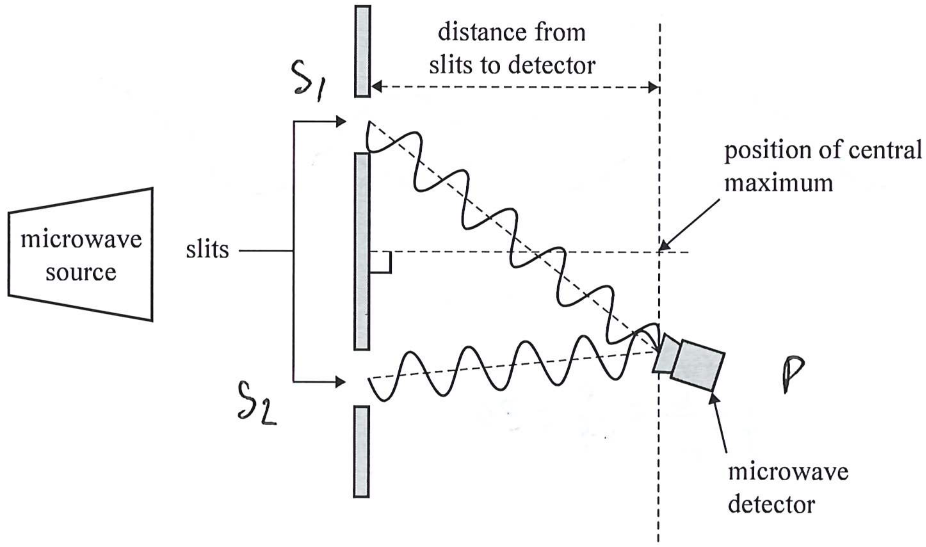

Figure 9

a. The frequency of the microwaves is 12.0 GHz.

Calculate the wavelength of the microwaves. Show your working. 2 marks

$\lambda = \frac{c}{f} = \frac{3\times10^8}{12\times10^9} = 0.025$

0.025 m

b. Using the information in Figure 9 and your answer to **part a.**, calculate the path difference between the two waves arriving at the detector. Give your reasoning. 2 marks

Pd = 1λ (6λ from S_1, 5λ from S_2)

0.025 m

c. Will the intensity of the microwaves at the detector's position, as shown in Figure 9, be a maximum or a minimum? Justify your answer. 2 marks

Max, constr. interf.

d. The frequency of the microwaves is now halved and the position of the detector is not changed.

Describe any changes in the intensity of the microwaves at the detector. Explain your answer. 3 marks

$\frac{f}{2} \rightarrow \lambda \times 2$

$S_1P = 3\lambda$ $S_2P = 2.5\lambda$

$Pd = 0.5\lambda$ ~ min

Question 14 (4 marks)

Students are conducting an experiment to investigate how the path of a light ray from a laser changes when the ray passes from one medium to another. They direct a light ray from air into a rectangular glass block and change the angle of the ray until it emerges back into the air, parallel to the surface of the block, as shown in Figure 10.

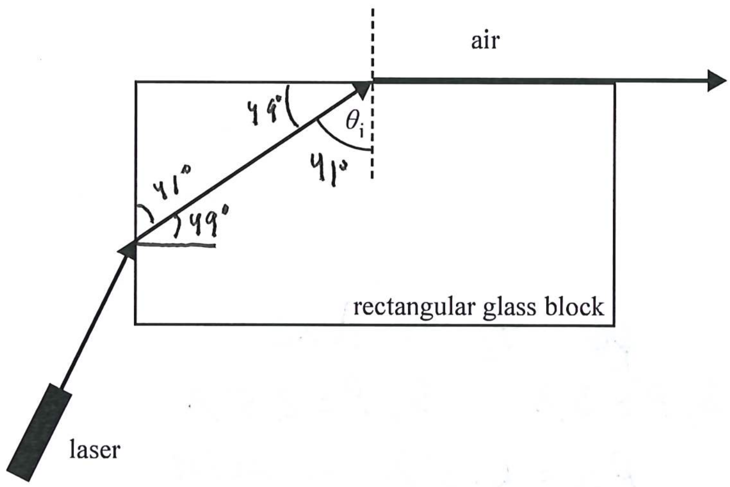

Figure 10

a. Describe how the speed of the light ray changes as it enters the glass block. 1 mark

Decrease

b. The students measure the angle θ_i, shown in Figure 10, to be 41°.

Use this information to determine if the glass is most likely to be crown glass (refractive index 1.52), normal flint glass (refractive index 1.59) or heavy flint glass (refractive index 1.66). Show your working. 3 marks

1.52 $\theta_c = \sin^{-1}\left(\frac{1}{1.52}\right) = 41.1°$

1.59 $\theta_c = \sin^{-1}\left(\frac{1}{1.59}\right) = 39.0°$

1.66 $\theta_c = \sin^{-1}\left(\frac{1}{1.66}\right) = 37.0°$

Type of glass	Crown

Question 15 (6 marks)

Figure 11 shows an apparatus used to study the photoelectric effect. Light of various frequencies and intensities can be shone onto the metal plate inside an evacuated cell. This sometimes results in the release of photoelectrons. The voltage of the power supply can be varied and the direction can be reversed.

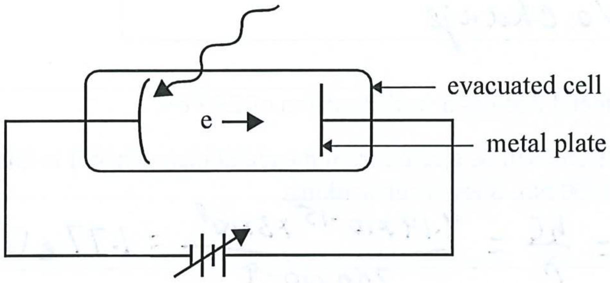

Figure 11

The graph in Figure 12 shows the variation of photocurrent with voltage for three experiments, A, B and C, using light of different frequency and intensity.

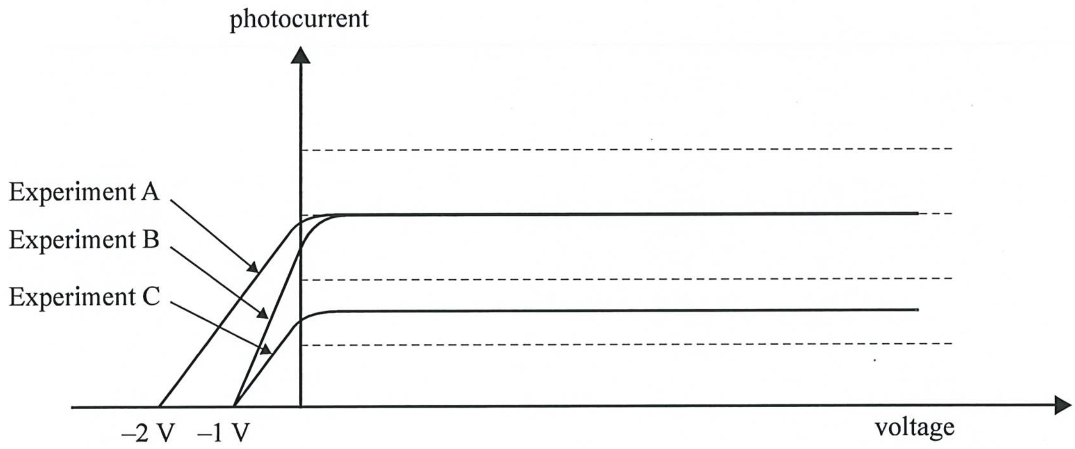

Figure 12

a. Using the terms 'halved', 'no change' or 'doubled', how would the intensity and frequency of the light used in Experiment B need to be changed so that Experiment B gives the same results as Experiment A in Figure 12? 2 marks

Intensity	No change
Frequency	Doubled

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b. Using the terms 'halved', 'no change' or 'doubled', how would the intensity and frequency of the light used in Experiment B need to be changed so that Experiment B gives the same results as Experiment C in Figure 12? 2 marks

Intensity	Halved
Frequency	No change

c. The metal plate is made of a metal that has a work function of 2.93 eV.

Determine whether photoelectrons will be ejected from the metal plate when it is illuminated by light with a wavelength of 700 nm. Show your working. 2 marks

$E = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{700 \times 10^{-9}} = 1.77 eV$

$1.77 < 2.93$

No emission

Question 16 (5 marks)

Figure 13 shows the diffraction pattern produced by an X-ray beam consisting of photons of energy 400 eV.

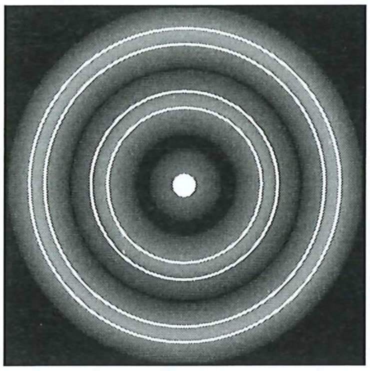

Figure 13

a. Show that the wavelength of an X-ray photon is approximately 3 nm. 2 marks

$E = \frac{hc}{\lambda}$ $\lambda = \frac{hc}{E} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{400} = 3.1 \times 10^{-9}$ m

b. A stream of electrons produces a diffraction pattern with the same spacing as the X-ray diffraction pattern shown in Figure 13.

Calculate the speed of an electron in the stream. Take the mass of the electron to be 9.1×10^{-31} kg. 3 marks

$mv = \frac{h}{\lambda}$ $v = \frac{h}{\lambda m} = \frac{6.63 \times 10^{-34}}{3.1 \times 10^{-9} \times 9.1 \times 10^{-31}}$

$= 2.4 \times 10^{5}$

2.4×10^{5} m s^{-1}

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Question 17 (3 marks)

Describe how absorption line spectra are produced and describe their relationship to electron transitions within atoms.

Question 18 (3 marks)

Provide an example of an instance in which classical laws of physics cannot describe motion at very small scales and explain why they cannot.

Question 19 (4 marks)

Figure 14 shows the energy levels of a sodium atom.

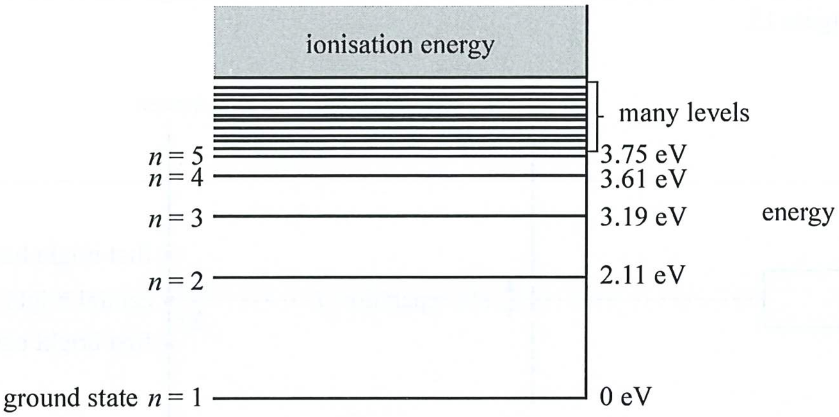


Figure 14

A sodium atom is initially in the $n = 4$ excited state.

a. Calculate the highest frequency of light that the sodium atom in this excited state could emit. 2 marks

$3.61 = 4.14 \times 10^{-15} \times f$

$f = 8.7 \times 10^{14}$

8.7×10^{14} Hz

b. Figure 14 shows some specific energy levels that electrons in a sodium atom can occupy.

Describe how the wave nature of electrons explains the existence of the energy levels shown in Figure 14. 2 marks

Question 20 (15 marks)

A group of Physics students used a double-slit interference experiment to measure the wavelength of the light from a laser. The laser was directed, at right angles, towards a double slit in a darkened room and an interference pattern was observed on a screen. The arrangement is shown schematically in Figure 15.

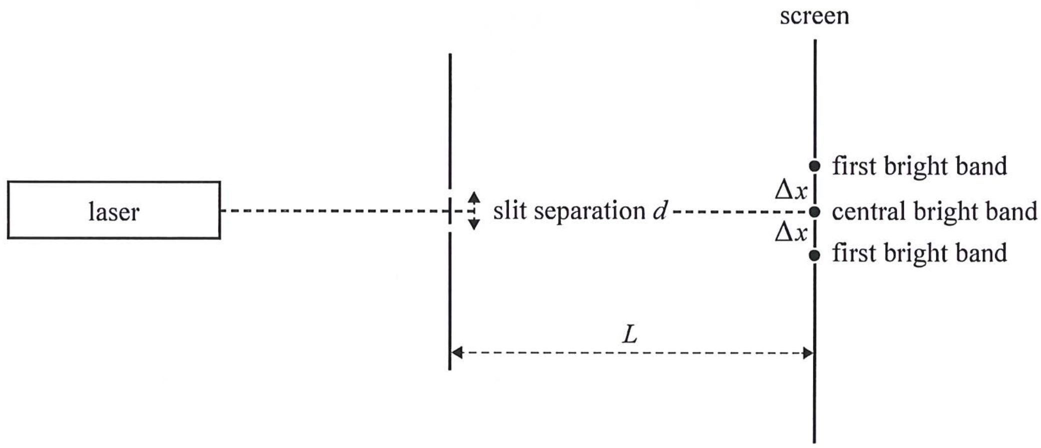


Figure 15

The students had access to two double-slit slides, one with a slit spacing of 0.16 mm and the other with a slit spacing of 0.26 mm. They placed the screen at distances of $L = 1.5$ m, 2.5 m and 3.5 m and measured the average distance, Δx, from the central bright band to the first bright band on either side.

a. Identify the dependent variable, the independent variables and **one** controlled variable in this experiment. 3 marks

Δx – dependant

L – independant + slit separation

λ

The experimental measurements taken are shown in Table 1.

Table 1

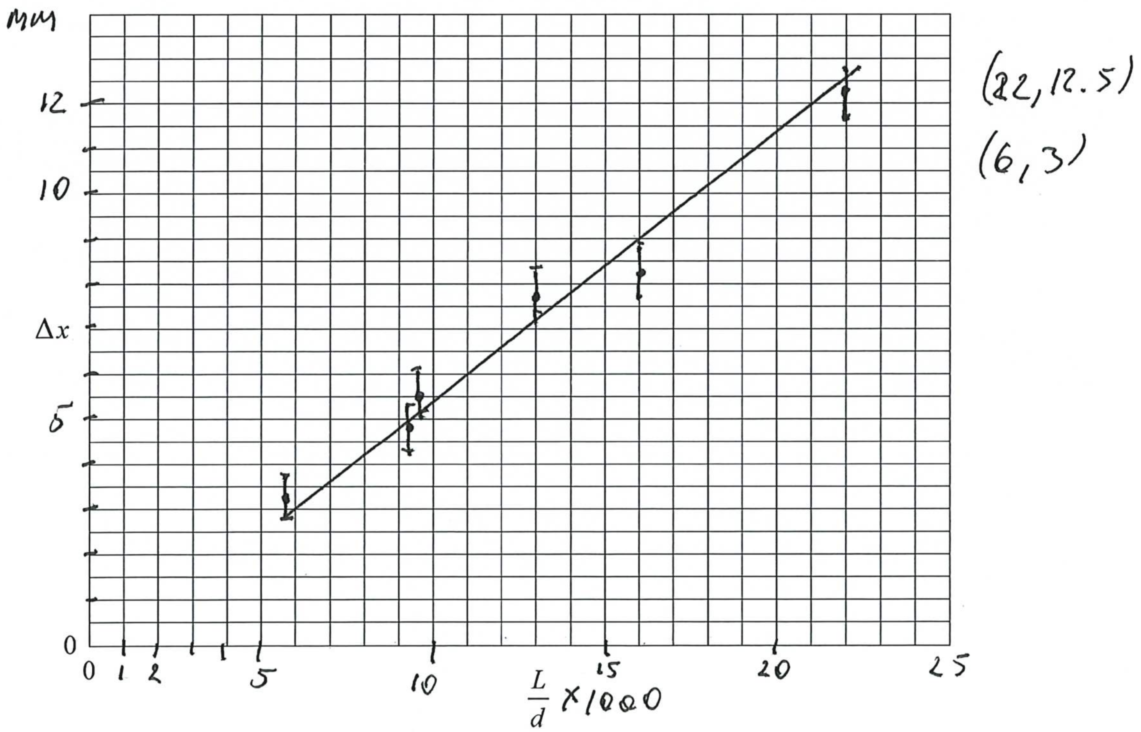
L (mm)	d (mm)	$\frac{L}{d}$ (no unit) (× 1000)	Δx (mm)
1500	0.26	5.8	3.3
2500	0.26	9.6	5.5
3500	0.26	13	7.7
1500	0.16	9.4	4.9
2500	0.16	16	8.2
3500	0.16	22	12.3

The students used the approximate equation $\lambda = \frac{\Delta x d}{L}$ and a graph of Δx plotted against $\frac{L}{d}$ to find a value for the wavelength λ.

b. Calculate the values of $\frac{L}{d}$ to two significant figures and write them in Table 1. 2 marks

c. Plot the values from Table 1 on the grid provided below.

- Include an appropriate scale, numbers and a unit on the y-axis.
- Include an appropriate scale and numbers on the x-axis.
- Include uncertainty bars in the y-direction of ± 0.5 mm. (No uncertainty bars are required in the x-direction.)
- Draw a linear trend line through the plotted points. 6 marks



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d. Calculate the gradient of the trend line. Show all the steps of your working. 2 marks

$\frac{12.5-3}{(22-6)\times 1000} = \frac{9.5}{16000} = 5.9\times 10^{-4}$

5.9×10^{-4} mm

e. Use the gradient from **part d.** to determine the wavelength of the laser light. Give all the steps of your reasoning. 2 marks

$\Delta x = \frac{\lambda L}{d}$ $\lambda = \Delta x \times \frac{d}{L} = 5.9\times 10^{-7}$ m

5.9×10^{-7} m

END OF QUESTION AND ANSWER BOOK