INSIGHT

Trial Exam Paper

2011

PHYSICS

Written examination 2

Worked Solutions

This book presents:

- worked solutions, giving you a series of points to show you how to work through the questions
- mark allocation details

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SECTION A – Core

Area of study 1 – Electric power

Use the following information to answer Questions 1 and 2.

A solenoid, which is a coil of wire, is connected to a variable DC power supply, as shown in Figure 1.

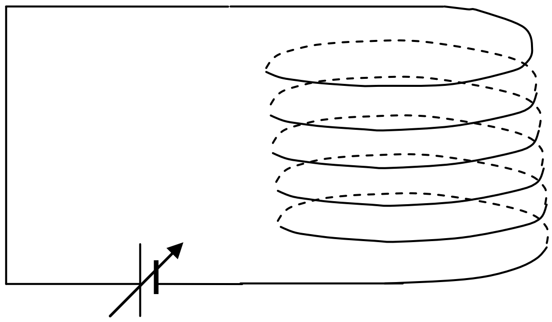
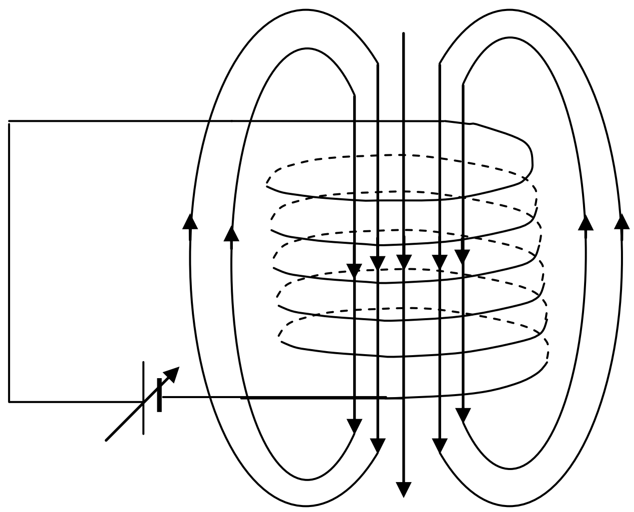


Figure 1

Question 1

Complete the diagram by sketching five magnetic field lines, with appropriate arrows, which illustrate the magnetic field inside and around the coils.

Worked solution



2 marks

Mark allocation

- 2 marks for appropriate complete lines with arrows from north to south poles.
- Take 1 mark off if lines are crossing or touching.

Question 2

Describe what changes will occur to the density of the magnetic field lines when a bar made of iron is placed inside the solenoid and the voltage of the battery is increased.

Worked solution

The increased voltage will cause an increase in current. The magnetic field lines will become closer together as the strength of the field increases owing to the bar and the increased voltage.

2 marks

Mark allocation

- 1 mark for stating an increase in current will occur.
- 1 mark for stating the field lines will become denser.

Tips

- *Magnetic field in an electromagnet is increased by an increase in current.*
- *Ensure magnetic field lines do not cross or touch.*
- *Higher magnetic flux regions must have a higher density of field lines.*

Use the following information to answer Questions 3 and 4.

The following apparatus in Figure 2 shows a metal rod placed between two magnets. The pole pieces of the magnet are 20 cm long and 5 cm high and the uniform magnetic field between them is 3 mT. A current of 1.2 A flows in the rod from *P* to *Q* and a force is experienced by the rod pushing it in one of the directions *A*, *B*, *C* or *D*.

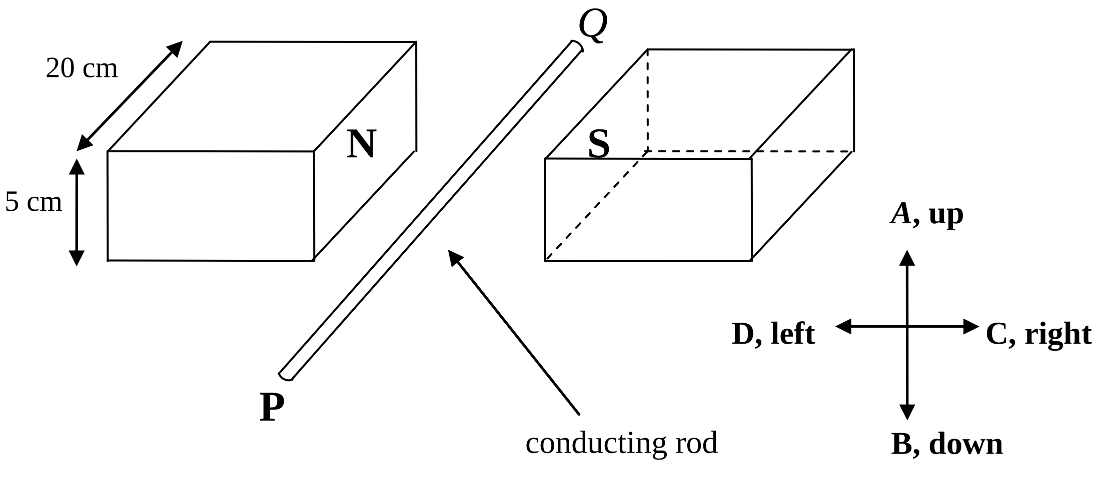


Figure 2

Question 3

Estimate the magnitude and direction of the force on the rod, the direction being stated as A, B, C or D.

Worked solution

Magnitude of force, $F = BIl = 0.003 \times 1.2 \times 0.2 = 0.72$ mN.

Direction of force is B.

3 marks

Mark allocation

- 1 mark for substituting values correctly into formula.
- 1 mark for correct magnitude of force.
- 1 mark for correct direction.

Question 4

Explain the primary cause of the force experienced by the rod. In your explanation you must refer to the magnetic field generated by the current.

Worked solution

Owing to the moving charges of the current in the conducting rod, a magnetic field is generated in accordance with the right-hand grip rule. This magnetic field then superimposes onto the external magnetic field, resulting in a net magnetic field that has a varying intensity. The conductor then experiences a force in the direction of the weaker region of the field and the direction is given by the right-hand slap rule.

2 marks

Mark allocation

- 1 mark for discussing that creation of the magnetic field is due to moving charges.
- 1 mark for relating two magnetic fields to resultant force.

Tip

- *Use the right-hand rule to determine the direction of force on a current-carrying conductor in an external field.*

Use the following information to answer Questions 5 to 7.

A square coil, *ABCD*, with sides of 3 cm and consisting of a single turn, is moved at a uniform speed of 3 cm s^{-1} into a region of constant magnetic field and continues to move through it to the other side. The magnetic region is 12 cm long. For simplicity of analysis, assume the magnetic field drops from a uniform magnitude of 0.25 T to zero at the end of the field.

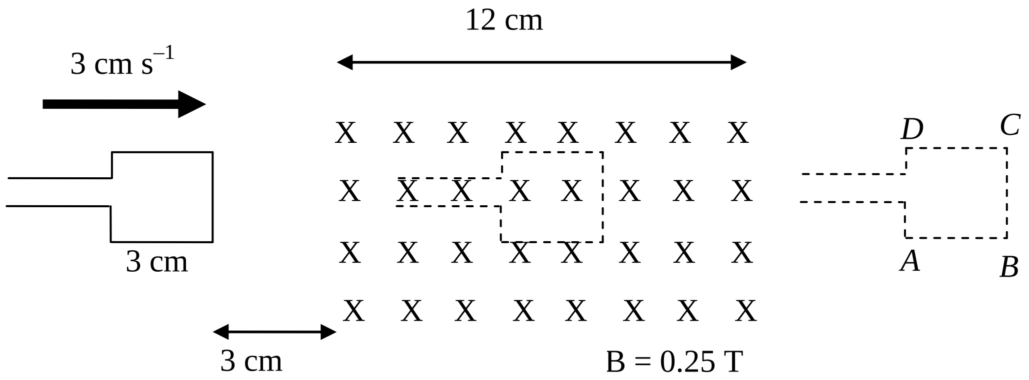
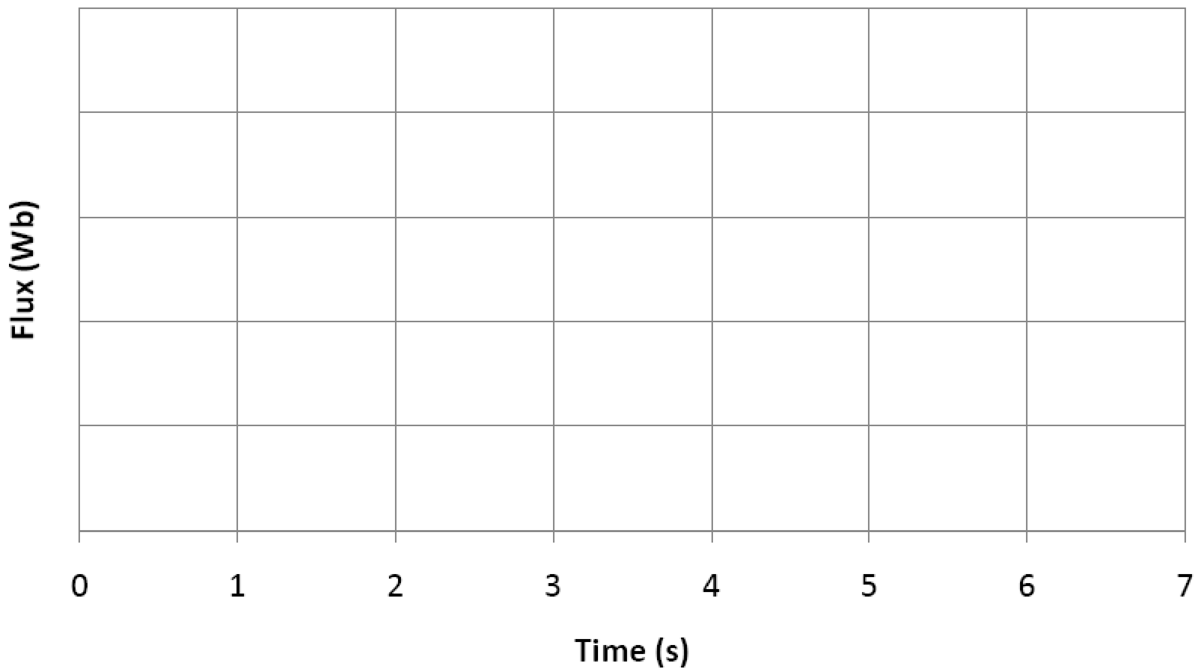


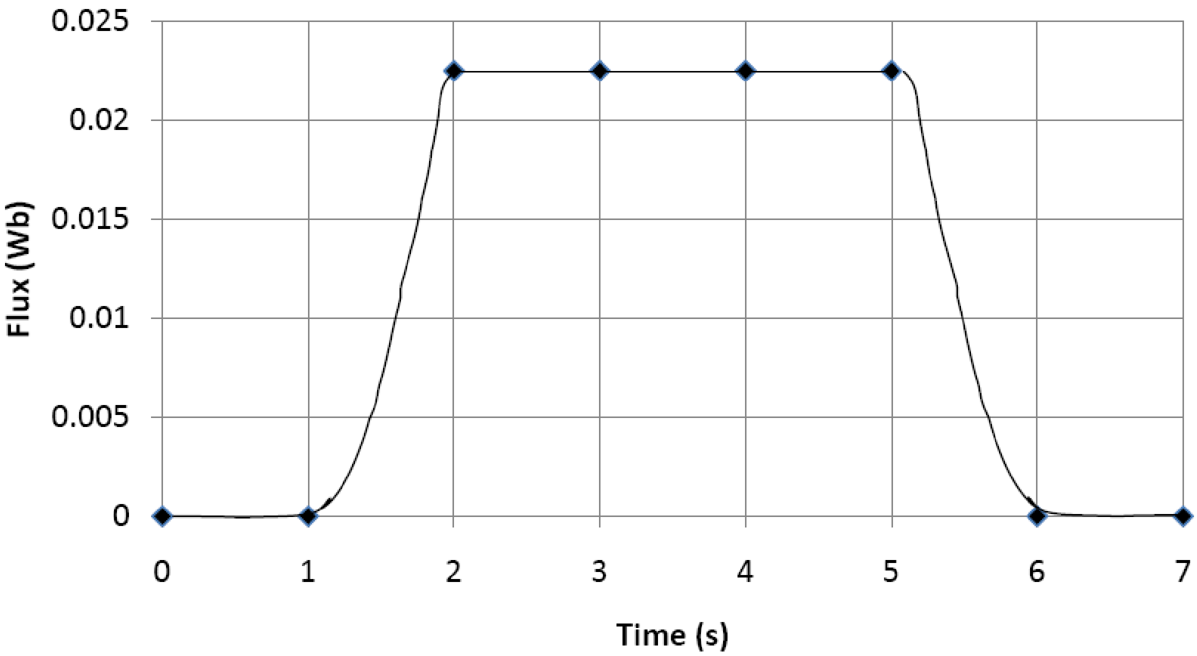
Figure 3

Question 5

On the axes below, draw a graph showing the flux through the coil as a function of time for the first 7 seconds of its motion, from the time it starts at the initial location (shown on the left side of the figure) and continues through the magnetic field emerging from the other side (shown on the right).



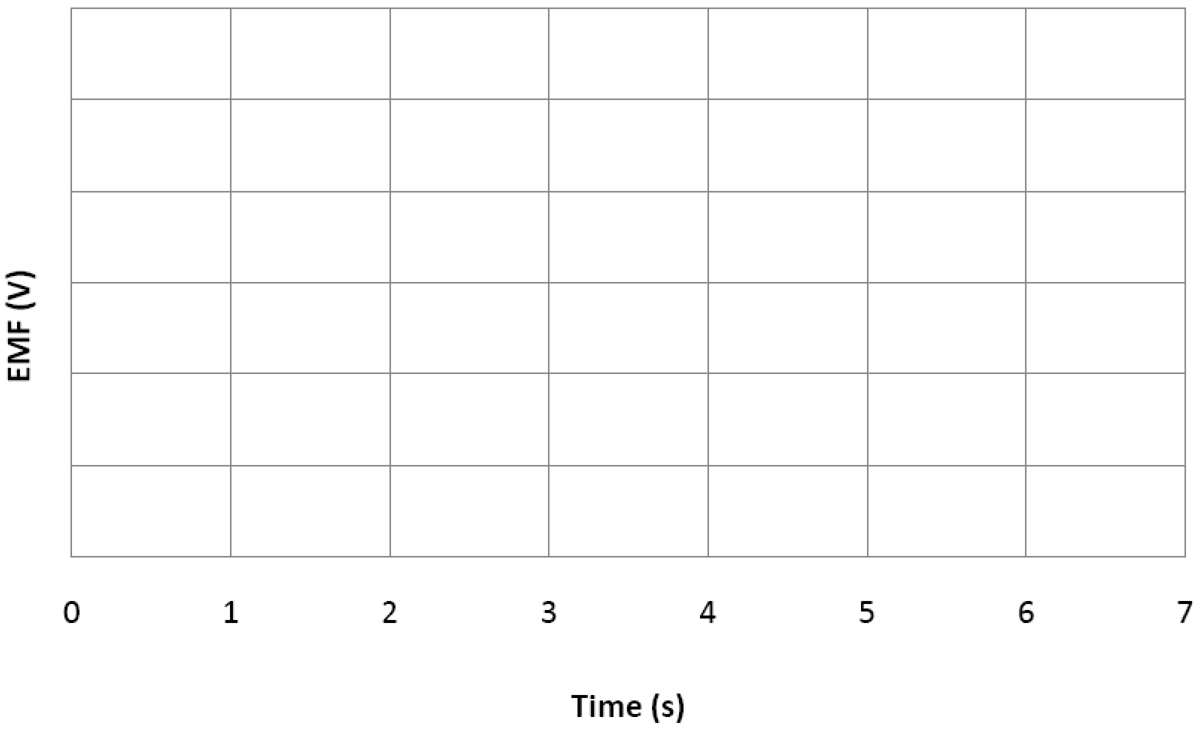
Worked solution
At constant speed, the coil will take 1 second to start entering the field. This is when the flux changes from 0 to a finite value, increasing to 0.0225 Wb when fully immersed in the magnetic field.



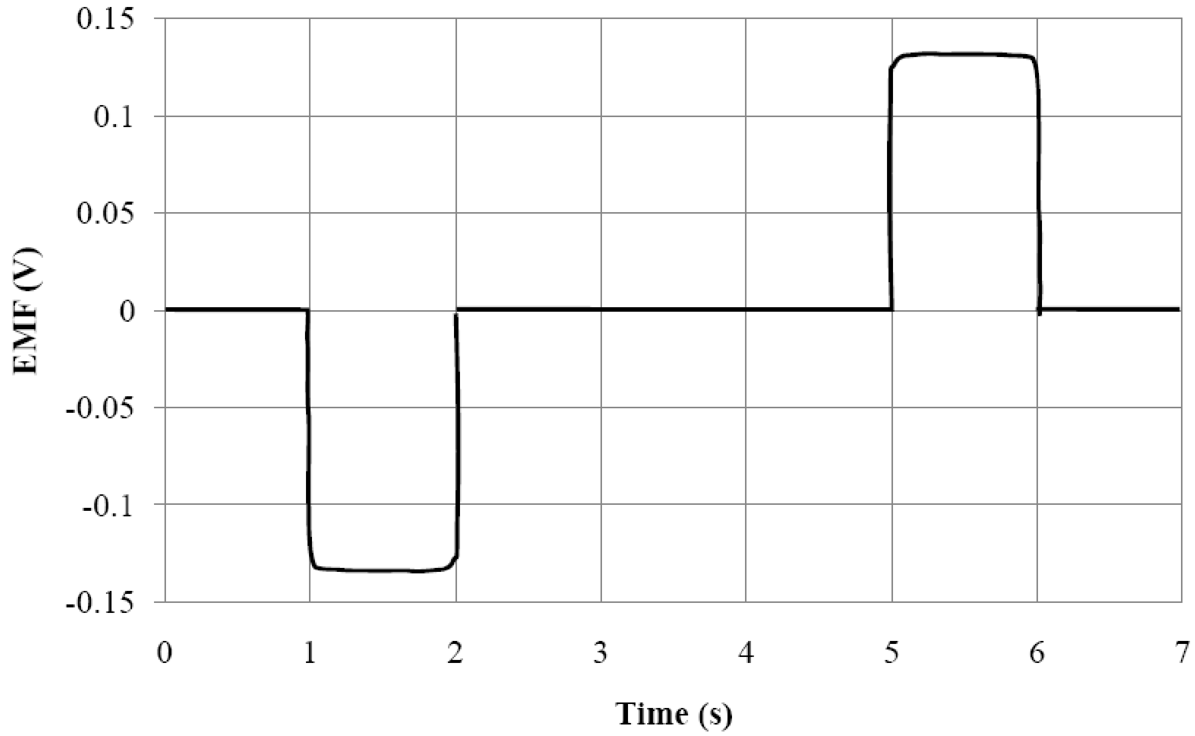
3 marks

Mark allocation
- 1 mark for correct magnitude of maximum flux.
- 1 mark for correct values of time.
- 1 mark for correct shape of graph.

Question 6
The coil is now replaced with another coil of the same size but consisting of six turns instead of one. Again, the coil is moved with the same constant speed through the magnetic region. On the axes below, draw the induced EMF in the coil for the first 7 seconds of its motion.



Worked solution
The shape of the induced EMF is given as the negative gradient of the flux–time graph. The maximum value of induced EMF is $= -N\dfrac{\Delta\varphi}{\Delta t} = -N\varphi_{\max} = 0.135\ \text{V}$.



3 marks

Mark allocation

- 1 mark for correct magnitude of flux.
- 1 mark for correct values of times.
- 1 mark for correct shape.

Question 7

When the coil first enters the magnetic field, will the direction of induced current be from *A* to *B* or from *D* to *C*? Explain your reasoning clearly.

Worked solution

When the coil first enters the field, it encounters magnetic field lines going into the page. According to Lenz's law, the induced EMF will oppose this change and thus generate a current that would create magnetic field lines coming out of the page. This would be an anti-clockwise direction; i.e. in the direction *A*–*B*–*C*–*D*.

2 marks

Mark allocation

- 1 mark for the correct answer.
- 1 mark for giving the correct explanation based on Lenz's law.

Tips

- *Whenever possible, draw the flux–time graph first and this will help when drawing the EMF–time graph.*
- *Remember: Lenz's law states that induced EMF will oppose the change in flux. Hence, induced EMF will be the negative gradient of flux.*

Use the following information to answer Questions 8 and 9.

A simple DC motor has a square coil with sides of 5 cm. It has 50 turns and carries a current of 1.5 A in a uniform magnetic field of strength 5 mT, which is provided between two poles of a permanent magnet. Initially, it is positioned as shown in Figure 4 below.

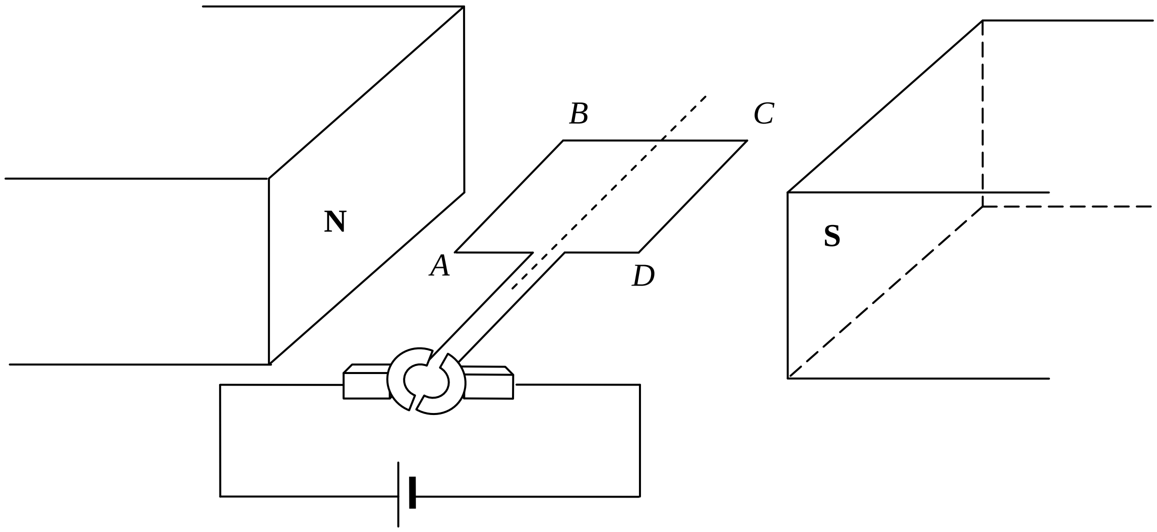


Figure 4

Question 8

What is the magnitude and direction of force on the side *AB* when the coil is in the position shown?

Worked solution

Magnitude of force, $F = BIl = 50 \times 0.005 \times 1.5 \times 0.05 = 0.01875$ N = 0.019 N.

Direction is down.

2 marks

Mark allocation

- 1 mark for the correct numerical answer.
- 1 mark for the direction.

Question 9
Which one of the graphs **A** to **D** best illustrates the magnitude of force on the side *AB* as the coil rotates through a cycle? Explain your reasoning.

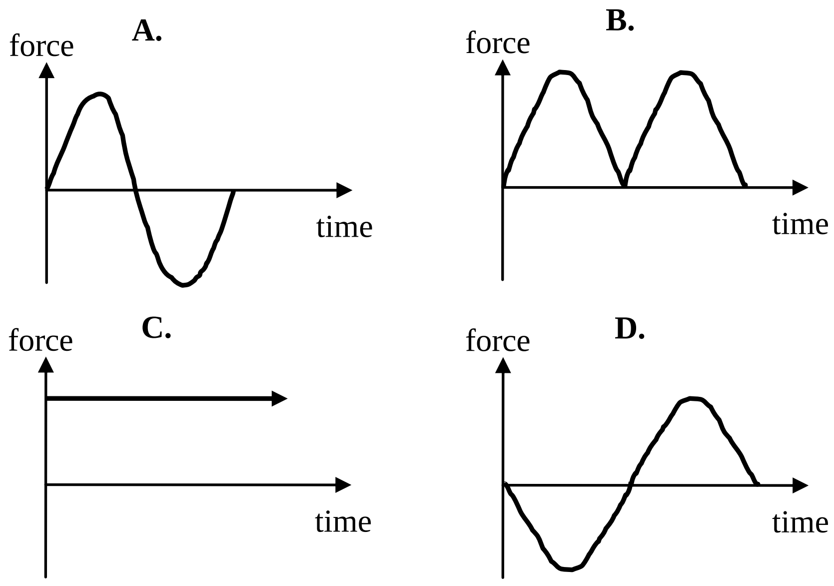


Figure 5

Worked solution
After a quarter-turn rotation, inertia carries the coil to the half-turn point, where the commutator changes the direction of current. Hence, the force on the side *AB* remains constant due to the use of the commutator, which changes current every half-cycle. The correct answer is therefore graph **C**.

C

2 marks

Mark allocation
- 1 mark for the correct answer.
- 1 mark for the correct explanation.

Tip
- *Remember to use number of turns when calculating force, but not when calculating for flux.*

Use the following information to answer Questions 10 to 13.

A power station generates AC power of 500 MW at 25 000 V to power a village 80 km away. Two ideal transformers, T1 and T2, are used to assist with power transmission. Transformer T1 has a turn ratio of 1 : 100. The total resistance of the power lines between the two transformers is a total of 5 Ω.

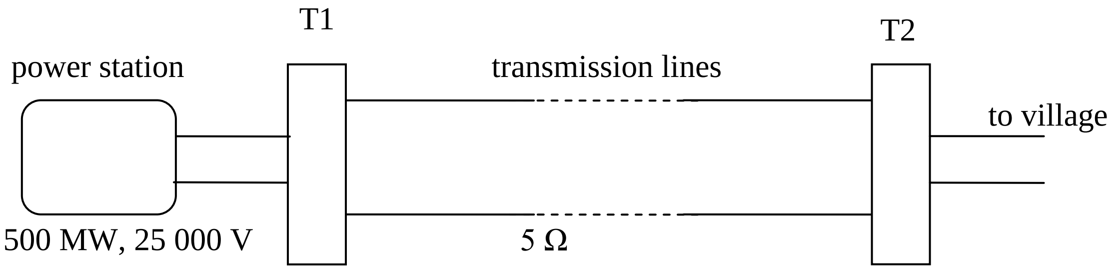


Figure 6

Question 10

What is the current in the transmission lines?

Worked solution

Current in the primary coil of T1 = $\frac{500\times10^6}{25\,000}$ = 20 000 A.

Current in the transmission lines = $\frac{20\,000}{100}$ = 200 A

200 A

2 marks

Mark allocation

- 1 mark for correctly calculating the current in the primary coil of T1.
- 1 mark for correctly evaluating the current in the transmission lines.

Question 11

Calculate the power loss in the transmission lines.

Worked solution

Power loss = I^2R = $200^2 \times 5$ = 200 000 W = 0.2 MW

0.2 MW

2 marks

Mark allocation

- 1 mark for correct use of the power loss formula.
- 1 mark for the correct answer.

Question 12

What is the voltage in the primary coil of transformer T2? Show your working.

Worked solution

Power remaining = 500 MW – 0.2 MW = 499.8 MW
Current in the transmission lines = 200 A
$\therefore$ Voltage in the primary coil of T2 = $\frac{P}{I}$ = 2499 kV

2499 kV

2 marks

Mark allocation

- 1 mark for correctly estimating the power remaining.
- 1 mark for correctly estimating the voltage as = $\frac{P}{I}$.
- Consequential marks awarded if incorrect value of current used from Question 10 or incorrect value of power loss used from Question 11.
- Full marks awarded if an alternative method of voltage loss is used to get the correct answer.

Question 13

Suggest two ways to reduce power loss in the transmission lines, explaining clearly why the amount of power lost will be reduced.

Worked solution

Suggestion 1: Increase voltage in the transmission lines by increasing the relative number of turns in the secondary coil of T1. This will decrease the current, thereby reducing power loss, which is I^2R.

Suggestion 2: Check the quality of the transmission lines. If there is corrosion of wires, then resistance could increase. If there is corrosion, then segments of the corroded wire should be replaced.

3 marks

Mark allocation

- 1 mark for each suggestion.
- 1 mark for the explanation.
- Deduct 1 mark if the explanation is inadequate or does not refer to the power loss expression.

Tips

- *Develop a systematic method to calculate transmission line problems, such as estimating transmission current → power loss → remaining power → voltage output and so on.*
- *Take care to check units for quantities such as kV and MW.*

Use the following information to answer Questions 14 and 15.

A coil of wire is connected to a DC power supply, as shown in Figure 7 below.

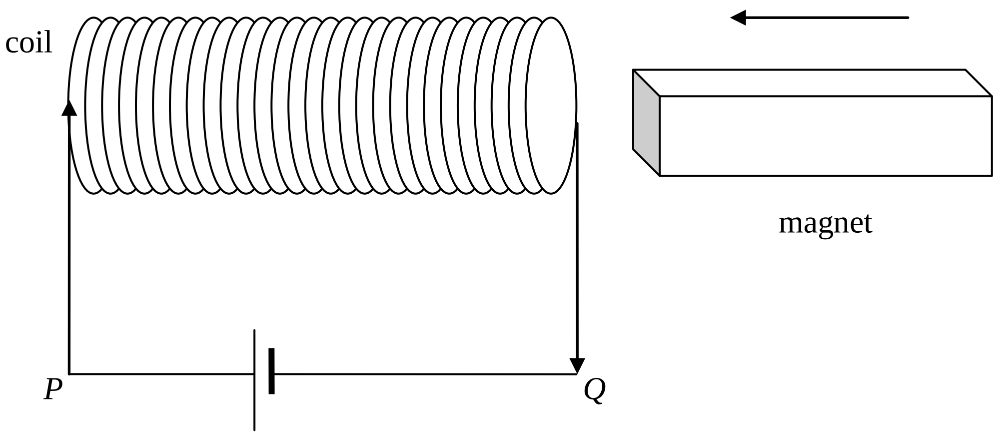


Figure 7

Question 14

In the first instance, a DC current flows in the coil. To determine the direction of the current, a magnet is brought to the coil and is found to be repelled. Is it a north or a south pole of the magnet that is inserted into the coil? Explain your answer.

Worked solution

According to the right-hand grip rule, the coil is an electromagnet with the coil facing towards the magnet, being a south pole. Since the magnet is repelled, the incoming face of the magnet must be a south pole as well.

2 marks

Mark allocation

- 1 mark for the correct answer.
- 1 mark for an explanation based on right-hand rule.

Question 15
With the current now switched off and the power supply replaced by an ammeter, a current is found to be induced when the magnet is re-inserted with the North Pole facing towards the coils. See Figure 8.

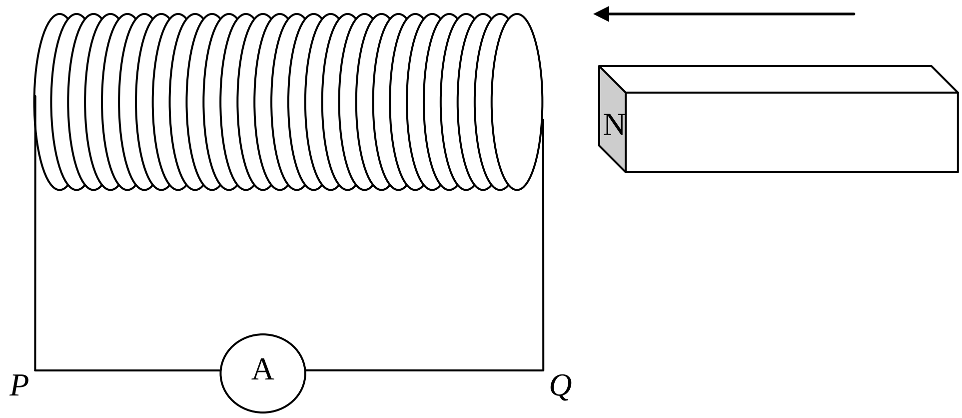


Figure 8

Will the current now flow from *P* to *Q* or from *Q* to *P* through the ammeter? Explain your answer.

Worked solution
Current will flow from *P* to *Q* through the ammeter. The coil will repel the incoming magnet by inducing a current such that the face of the coil facing the incoming magnet is north pole, as in accordance with Lenz's law. This will occur when the current in that face is anti-clockwise and the current in the external circuit is from *P* to *Q*.

3 marks

Mark allocation
- 1 mark for the correct answer.
- 1 mark for the correct determination of current based on Lenz's law.
- 1 mark for the correct conclusion.

Tip
- *Remember: Induced current will be such that it creates a magnetic field to oppose the changing flux that caused it.*

END OF AREA OF STUDY 1

Area of study 2 – Interactions of light and matter

Use the following information to answer Questions 1 to 5.

A photoelectric experiment is carried out using the equipment shown in Figure 1 below, in which a powerful light source of variable frequency is shone on a metal electrode enclosed in an evacuated glass tube. By changing the voltage of the variable battery, the photocurrent can be reduced to zero.

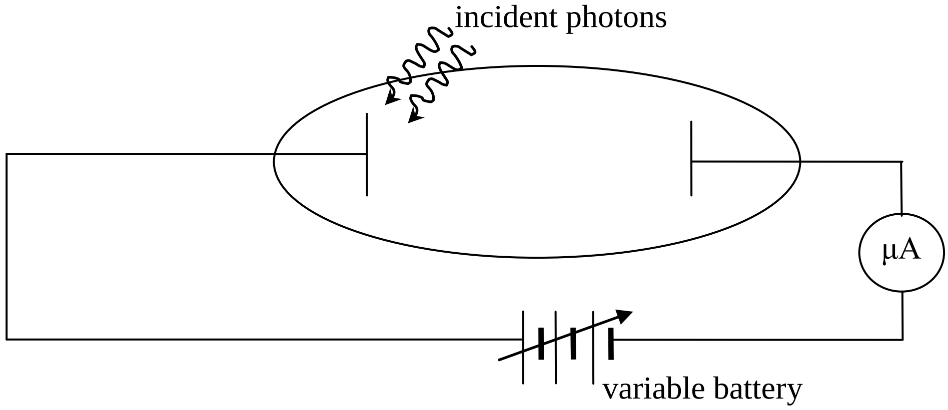


Figure 1

As the frequency and/or intensity of the incident light is changed, the voltage required to make the photocurrent zero is recorded. A graph is then plotted showing the measured photocurrent against the voltage of the variable battery that just reduces the current to zero. The shape of the graph is shown in Figure 2.

At a frequency of 5×10^{14} Hz, a cut-off voltage of –1.1 V is recorded. The work function of the metal is 1.5 eV.

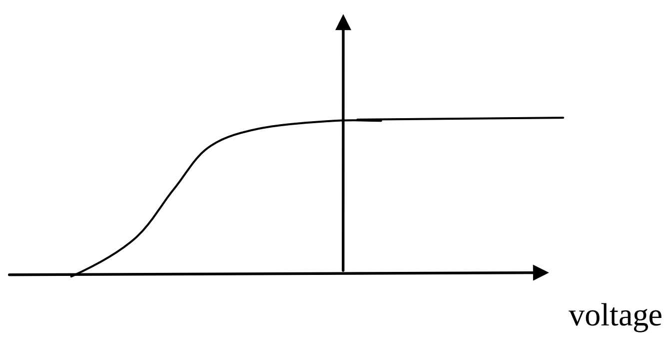


Figure 2

Question 1
What is the energy, in J, of one photon of the light beam of frequency 5×10^{14} Hz?

Worked solution
Energy of one photon is:
$E = hf = 6.63 \times 10^{-34} \times 5 \times 10^{14} = 3.315 \times 10^{-19}$ J

3.3×10^{-19} **J**

2 marks

Mark allocation
- 1 mark for using the equation correctly.
- 1 mark for the correct answer.

Question 2
What is the speed of the fastest moving photoelectron that required a cut-off voltage of –1.1 eV?

Worked solution
$E_{k,\max} = \frac{1}{2}mv^2 = q_e V_c$.

Therefore $v_{\max} = \sqrt{\frac{2q_e V_c}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 1.1}{9.1 \times 10^{-31}}} = 6.2 \times 10^5$ m s^{-1}.

6.2×10^5 **m s^{-1}**

3 marks

Mark allocation
- 1 mark for establishing the link between cut-off voltage and energy of electron.
- 1 mark for developing the equation for maximum speed.
- 1 mark for the correct answer.

Question 3

Using the data collected in this experiment, estimate the value of Planck's constant, in eV s.

Worked solution

$E_{k,\max} = hf - W$

Hence $h = \dfrac{E_{k,\max} + W}{f} = \dfrac{1.1 + 1.5}{5 \times 10^{14}} = 5.2 \times 10^{-15}$ eV s

5.2×10^{-15} **eV s**

2 marks

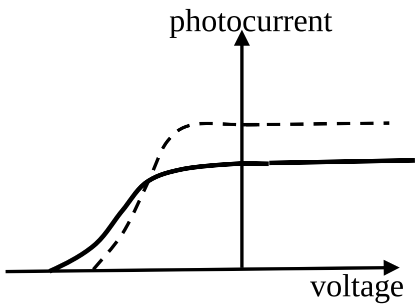
Mark allocation

- 1 mark for using correct expression or Planck's constant.
- 1 mark for the correct answer.

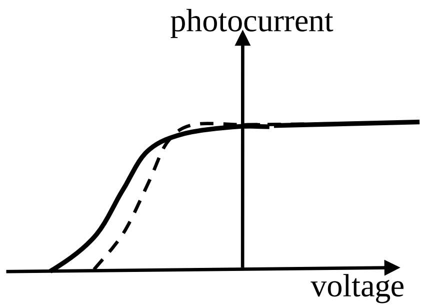
Question 4

In a subsequent experiment, the frequency of the light source is now increased and the intensity is reduced. When compared to the original graph (shown for comparison as the dashed line), which one of the graphs **A** to **D** (showing a solid line) is most likely to be observed now? Explain your answer.

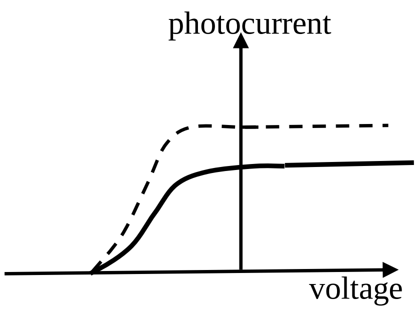
A.



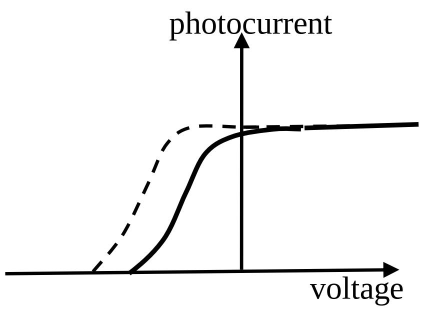
B.



C.



D.



Worked solution

The increase in frequency causes electrons from deeper energy levels to be ejected, causing a higher magnitude of cut-off voltage. A simultaneous decrease in intensity will cause fewer electrons to be ejected, therefore causing reduced current. Hence, correct answer is graph A.

A

3 marks

Mark allocation

- 1 mark for the correct answer.
- 1 mark for the correct explanation for change in cut-off voltage.
- 1 mark for the correct explanation for change in photocurrent.

Question 5

Does this experiment better demonstrate the wave-like or particle-like nature of light? Explain your reasoning.

Worked solution

The model proposing the wave-like behaviour of light suggests that light of any frequency, if incident for a long-enough time, will cause photocurrent. However, actual observation is that a minimum cut-off frequency is necessary. The wave model also suggests that increasing the light frequency will result in more photoelectrons and that increasing the light intensity will make no difference. In contrast, the particle model explains that increased frequency will result in a tighter-bound electron to be released and increased intensity will result in an increase in photocurrent. Hence, the particle model offers a better explanation.

2 marks

Mark allocation

- 1 mark for the correct answer.
- 1 mark for giving a valid reason.

Tips

- *Remember how the photoelectric equation is an expression for energy balance.*
- *Clarify which properties are best explained as wave-like behaviour (i.e. diffraction) and which are best explained with particle-like behaviour (i.e. photoelectric effect) and why.*
- *Remember that photocurrent is a one-to-one collision between a photon and an electron.*

Use the following information to answer Questions 6 to 8.

In an experiment to study diffraction, a beam of electrons with energy 450 eV strikes a crystal with inter-atomic distance 1.1×10^{-10} m.

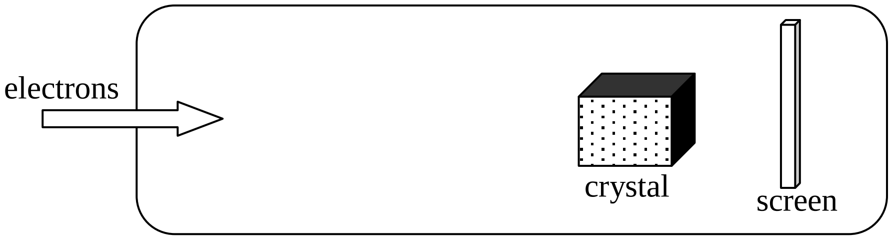


Figure 3

Question 6

Will the extent of diffraction be **significant**? Use suitable calculations to determine your answer.

Worked solution

Diffraction will be significant when the wavelength is about the same order of magnitude as the spacing *and* when the wavelength is slightly more than the spacing.

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2E_{k,\max}}{m}}} = \frac{h}{\sqrt{2E_{k,\max}m}}$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 450 \times 1.6 \times 10^{-19} \times 9.1 \times 10^{-31}}}$$

$$= 5.8 \times 10^{-11} \text{ m}$$

In this case, the wavelength is about the same order of magnitude but the ratio of wavelength to opening λ/w is = 0.53, which is *less* than 1. Hence, diffraction will *not* be significant.

3 marks

Mark allocation

- 1 mark for arriving at the correct conclusion.
- 1 mark for linking inter-atomic distance and wavelength with diffraction.
- 1 mark for adequate and correct calculations.

Question 7
What is the frequency of an electromagnetic wave that will produce the same wavelength as a 450 eV electron?

Worked solution

$$f = \frac{c}{\lambda} = \frac{3\times10^{8}}{5.8\times10^{-11}} = 5.15\times10^{18}\ \text{Hz}$$

5.2×10^{18} Hz

2 marks

Mark allocation

- 1 mark for correctly using the wavelength value from Question 6. Award consequential marks.
- 1 mark for the correct answer.

Question 8
Calculate the momentum of a photon of energy 450 eV.

Worked solution

Momentum of photon = $p = \dfrac{h}{\lambda} = \dfrac{h}{hc/E} = \dfrac{E}{c} = \dfrac{450\times1.6\times10^{-19}}{3\times10^{8}} = 2.4\times10^{-25}$ N s

2.4×10^{-25} **N s**

2 marks

Mark allocation

- 1 mark for correctly establishing the relationship between momentum and energy.
- 1 mark for the correct answer.

Tips

- *Take care to use the correct value for Planck's constant.*
- *Take care when using your scientific calculator to solve problems with large indices.*

Use the following information to answer Questions 9 and 10.

Figure 4 below represents Young's double slit experiment, which is used here to find the wavelength of a laser light source. When the laser light is shone through the double slits S_1 and S_2, a pattern of fringes is observed on the screen. A point, *P*, on the third dark band is being considered. The distance from S_1 to *P* is greater by 1150 nm when compared to the distance from *P* to S_2.

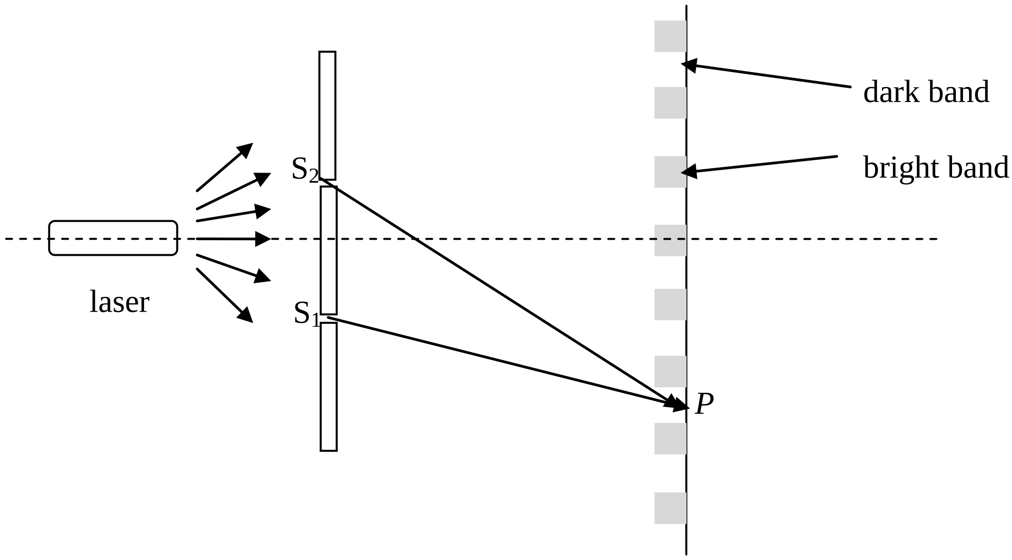


Figure 4

Question 9

Calculate the wavelength of the light emitted by the laser.

Worked solution

For constructive interference resulting in the third order dark band:

Path difference = $1150 \times 10^{-9} = 2.5 \times \lambda$

Therefore $\lambda = 460$ nm.

460 nm

2 marks

Mark allocation

- 1 mark for correctly linking path difference to wavelength.
- 1 mark for the correct answer.

Question 10
The laser is then exchanged for one with a higher wavelength. Which one of the following statements best describes the change that will now occur in the pattern of dark and bright bands?

A. The bands will move closer together.
B. The bands will become more intense.
C. The bands will become less intense.
D. The bands will move farther apart.

Worked solution

According to the equation for bright fringes; i.e. $\frac{x}{L} = \frac{n\lambda}{d}$, as the light wavelength increases, the bands (quantity *x*) will move farther apart. Hence, the correct answer is D.

D

2 marks

Mark allocation
- 2 marks for the correct answer. No partial marks.

Tip
- *Remember that the path difference for constructive interference must be an integral multiple of wavelength.*

Use the following information to answer Questions 11 to 13.

Figure 5 represents part of the energy level spectrum of a gas at room temperature. A sample of the gas is enclosed in a partially evacuated tube, upon which a beam of photons is shone.

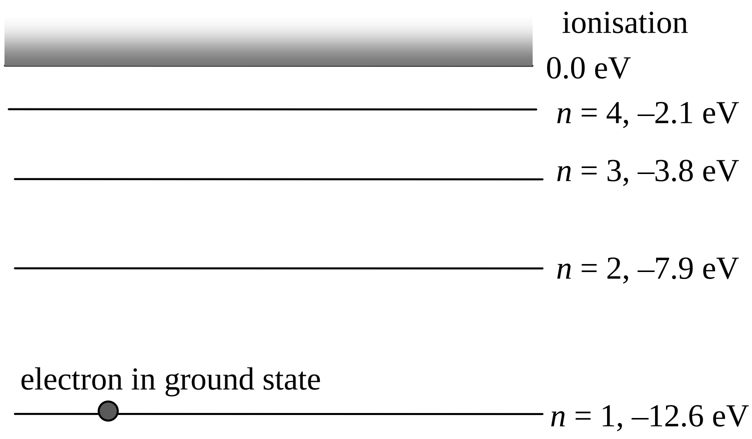


Figure 5

Question 11

Calculate the wavelengths of all of the emitted radiation when photons of 8.8 eV are shone onto the gas that is at room temperature. Express your answer in nm.

Worked solution

There will be three transitions: $n = 3 \rightarrow 2$; $n = 2 \rightarrow 1$; and $n = 3 \rightarrow 1$.

The wavelengths are:

$$\lambda_{3\rightarrow 2} = \frac{hc}{E} = \frac{4.14\times 10^{-15}\times 3\times 10^{8}}{4.1} = 302.9\text{ nm}$$

$$\lambda_{2\rightarrow 1} = \frac{hc}{E} = \frac{4.14\times 10^{-15}\times 3\times 10^{8}}{4.7} = 264.2\text{ nm}$$

$$\lambda_{3\rightarrow 1} = \frac{hc}{E} = \frac{4.14\times 10^{-15}\times 3\times 10^{8}}{8.8} = 141.1\text{ nm}$$

3 marks

Mark allocation

- 1 mark for each correct derivation of the wavelengths.

Question 12
Explain, using suitable calculations, what the effect will be on an electron at ground level when photons of energy 14.2 eV are shone onto the gas at room temperature.

Worked solution
The energy of the incident photons is now more than the band gap, so the outcome will be that the electron will be ejected with an energy of 14.2 – 12.6 = 1.6 eV.

2 marks

Mark allocation
- 1 mark for correctly relating excess energy to band gap and to energy of the ejected photoelectron.
- 1 mark for correctly identifying the 'effect' on the electron as ejection with an energy of 1.6 eV

Question 13
Determine the energy of the incident photons which will result in just one spectral line in the emission spectrum.

Worked solution
ΔE = 12.6 – 7.9 = 4.7 eV
It will be the transition from n = 1 to n = 2 in absorption and n = 2 to n = 1 in the emission spectrum.

4.7 eV

1 mark

Mark allocation
- 1 mark for correctly identifying the transition from n = 2 to n = 1 and the corresponding energy as 4.7 eV. No partial marks.

Tips
- *Label energy transitions clearly in order to minimise potential errors.*
- *Pay attention to units; i.e. eV versus J.*
- *Read the question carefully to ascertain whether emission or absorption transitions are being discussed.*

END OF AREA OF STUDY 2
END OF SECTION A

SECTION B – Detailed studies

Detailed study 1 – Synchrotron and its application

Use the following information to answer Questions 1 to 3.

Two parallel metal electrodes are 4 cm apart and are enclosed in a partially evacuated tube. When powered by a 9.0 V DC battery, a uniform electric field is created between the electrodes. An electron is placed upon one electrode, as shown in Figure 1, and experiences a force as a result of the electric field.

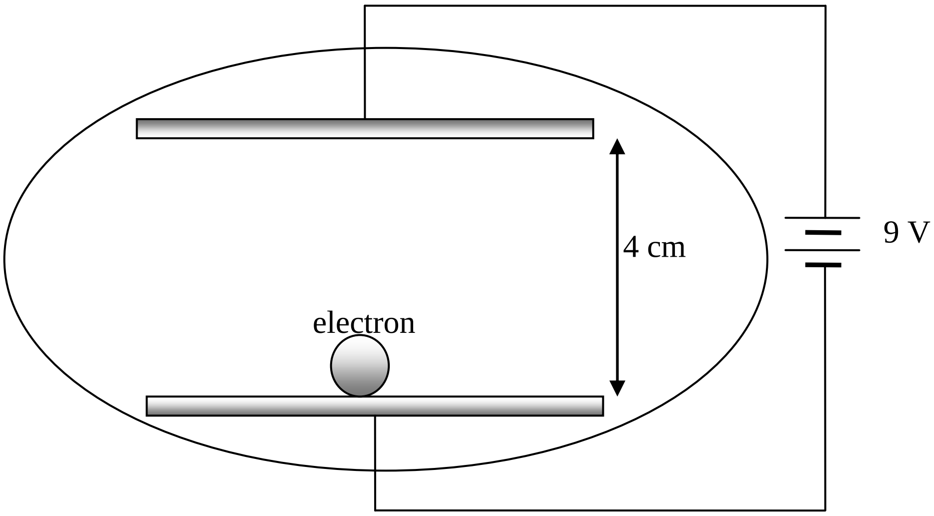


Figure 1

Question 1

The magnitude of the electric field created by the parallel plates is closest to

A. 0.36 V m^{-1}
B. 2.25 V m^{-1}
C. 36 V m^{-1}
D. **225 V m^{-1}**

D

Worked solution

Electric field strength, $E = \frac{V}{d} = \frac{9}{0.04} = 225 \text{ V m}^{-1}$.

Question 2
The speed with which the electron will strike the positive plate as a result of the electric field is nearest in magnitude to

A. **1.8×10^6 m s^{-1}**
B. 3.6×10^6 m s^{-1}
C. 1.8×10^7 m s^{-1}
D. 3.6×10^7 m s^{-1}

A

Worked solution
Work done = gain in energy

$$q_e V = \frac{1}{2} m v^2$$

$$v = \sqrt{\frac{2q_e V}{m}} = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 9}{9.1 \times 10^{-31}}}$$

$$= 1.78 \times 10^6 \text{ m s}^{-1}$$

Question 3
If the voltage across the plates is increased 10 times, the speed of the electron will

A. decrease by a factor of about 3.2.
B. increase by a factor of 10.
C. **increase by a factor of about 3.2.**
D. decrease by a factor of 10.

C

Worked solution
The speed of the electron varies as $V^{\frac{1}{2}}$ = 3.2.

Tips

- *Take care when solving expressions with large indices.*
- *Always check units.*

Use the following information to answer Questions 4 and 5.

In a synchrotron, a beam of electrons, travelling at constant speed, enter a uniform magnetic field of 35 mT at right angles to the field. As a result of the magnetic field, the electrons experience a force that causes them to bend in a radius of 0.4 m.

Question 4

The energy of the electrons entering the field is closest to

A. 10.3 MeV
B. **17.2 MeV**
C. 21.4 MeV
D. 1.1 MeV

B

Worked solution

Combining the equations $Bqv = \frac{mv^2}{R}$ and $E_k = \frac{mv^2}{2}$, we get:

$$E_k = \frac{B^2q^2R^2}{2m} = \frac{0.035^2 \times (1.6\times10^{-19})^2 \times 0.4^2}{2\times9.1\times10^{-31}} = 2.757\times10^{-12}\ \text{J} = 17.2\ \text{MeV}$$

Question 5

The magnetic field is now doubled and the speed of the electrons is halved. The radius of the beam in the magnetic field will now be

A. half of the original radius.
B. double the original radius.
C. **one-quarter of the original radius.**
D. four times the original radius.

C

Worked solution

$$E_k = \frac{B^2q^2R^2}{2m}$$

Therefore, $R^2 = \frac{2mE_k}{q^2B^2} = \frac{m^2v^2}{q^2B^2}$.

So, $R = \frac{mv}{qB}$.

When speed is halved and B is doubled, the radius will be one-quarter of its original magnitude.

Tips

- *Re-arrange relevant equations so that the value you wish to find becomes the subject, thus minimising errors. For example, in Question 5, make R the subject.*
- *Use clear working, even in multiple-choice questions, to minimise errors, and then check your answers.*

Questions 6 to 9 relate to the Australian Synchrotron.

Question 6

In the Australian Synchrotron, electrons are generated in the

A. linac.
B. wiggler.
C. **electron gun.**
D. booster ring.

C

Worked solution

The electron gun is where electrons are produced.

Question 7

The electrons achieve a speed of about 99.99% of the speed of light in the

A. **linac.**
B. wiggler.
C. undulator.
D. storage ring.

A

Worked solution

The linac (i.e. linear accelerator) is where most of the acceleration occurs.

Question 8

Synchrotron radiation is best described as an intense

A. beam of electrons of synchronised energy.
B. beam of photons of synchronised energy.
C. **beam of photons produced by the synchronised use of magnetic fields.**
D. pulse of photons of coherent and synchronised radiation.

C

Worked solution

Synchrotron radiation is a beam of photons – not electrons. The word ‘synchronised’ is used because of the synchronisation of magnetic fields. A range of photon energies are produced. Hence, C is the best answer here.

Question 9

Which one of the following best describes the advantages of using synchrotron radiation over a conventional X-ray beam?

A. Synchrotron radiation is polarised and coherent.

B. Synchrotron radiation has high intensity, has a range of tuneable energies and can be pulsed for time-resolved studies.

C. Synchrotron radiation consists of high-intensity radiation, containing the entire electromagnetic spectrum.

D. Synchrotron radiation is intense and can be filtered for time-resolved studies

B

Worked solution

The best answer is B. As well as the radiation being intense, the significant advantage of the synchrotron is the range of photon energies produced, thus enabling a variety of precision studies to be carried out.

Tips

- *List the parts of the synchrotron and specify their specific roles clearly.*
- *Remember why synchrotron radiation is so called and that it consists of photons – not charged particles.*

Use the following information to answer Questions 10 and 11.

A beam of X-rays of wavelength 0.15 nm is fired at an unknown crystal in a diffractometer. The crystal is rotated to vary the incident angle, θ, between the X-rays and the crystal planes. A diffraction pattern is obtained which gives a number of peaks at various incident angles.

Question 10

The $n = 1$ peak is obtained at an incident angle of 14.1°. The corresponding d spacing between the crystal planes is closest to

A. 0.3 nm

B. 0.6 nm

C. 1.2 nm

D. 1.8 nm

B

Worked solution

Bragg's diffraction gives $d = \frac{n\lambda}{\sin\theta} = \frac{1 \times 0.15 \times 10^{-9}}{\sin 14.1°} = 0.62$ nm.

Question 11
A crystal is now placed in the diffractometer with a known *d* spacing of 0.8 nm. Which one of the following statements best lists the incident angles, θ, at which a Bragg diffraction peak would be observed?

A. 5.38°, 10.81°, 16.33°
B. 5.37°, 21.62°, 32.66°
C. 10.74°, 10.81°, 16.33°
D. 5.37°, 10.74°, 16.11°

A

Worked solution
Use Bragg's condition for n = 1, 2 and 3, to find θ.

When n = 1: $\theta = \sin^{-1}\frac{n\lambda}{d} = \sin^{-1}\frac{1\times 0.15\times 10^{-9}}{0.8\times 10^{-9}} = 5.38°$

When n = 2: $\theta = \sin^{-1}\frac{n\lambda}{d} = \sin^{-1}\frac{2\times 0.15\times 10^{-9}}{0.8\times 10^{-9}} = 10.81°$

When n = 3: $\theta = \sin^{-1}\frac{n\lambda}{d} = \sin^{-1}\frac{3\times 0.15\times 10^{-9}}{0.8\times 10^{-9}} = 16.33°$

Tips
- *Ensure your calculator is set to degrees and not radians.*

Use the following information to answer questions 12 and 13.

A beam of X-ray photons of frequency 4.2×10^{18} Hz are scattered by a thin metal foil. Both Thomson and Compton scattering are observed. The frequency of the scattered photons and/or electrons are also measured.

Question 12

Which is the closest in value to the frequency of the scattered X-rays upon undergoing Thomson scattering?

A. **4.2×10^{18} Hz**
B. 2.1×10^{18} Hz
C. 8.4×10^{18} Hz
D. 1.0×10^{18} Hz

A

Worked solution

There is no change in frequency of the scattered X-ray in Thomson scattering.

Question 13

Upon undergoing Compton scattering by the X-ray photon, an electron is emitted at a speed of 1.8×10^{7} m s^{-1}. The energy of the scattered X-ray photon is closest in magnitude to

A. 1650 eV
B. 2480 eV
C. 15000 eV
D. **16500 eV**

D

Worked solution

Applying conservation of energy laws to the incident photon, scattered photon and emitted electron: $hf_{\text{incident}} = E_{\text{photon, scattered}} + \frac{1}{2}mv^2_{\text{electron}}$

$$6.63\times10^{-34}\times4.2\times10^{18} = E_{\text{photon, scattered}} + \frac{1}{2}\times9.1\times10^{-31}\times(1.8\times10^{7})^2$$

Therefore, energy of the scattered X-ray photon is 2.637×10^{-15} J = 16 481 eV ≈ 16 500 eV.

Tips

- *Differentiate clearly between Thomson and Compton scattering.*
- *Check units carefully, particularly when using eV and J.*

END OF DETAILED STUDY 1

SECTION B - END OF DETAILED STUDY 1

Detailed study 2 – Photonics

Use the following information to answer Questions 1 and 2.

A light-emitting diode (LED) emits light when it is connected in forward bias and a current flows through it. A band diagram of a LED and its *I–V* characteristic are shown in Figure 1.

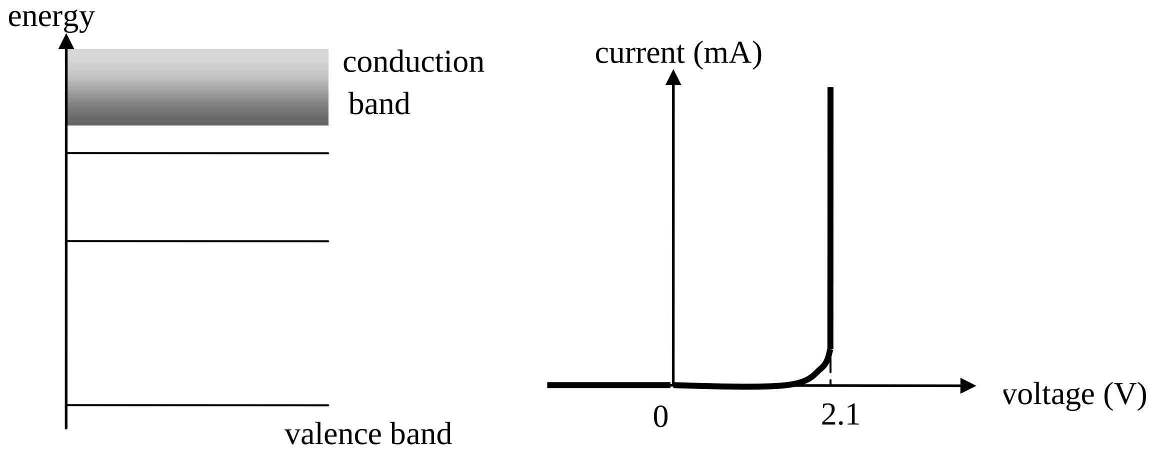


Figure 1

Question 1

The magnitude of energy between the valence band and conduction band is

A. 2.1 J
B. 1.31×10^{-19} J
C. 3.36×10^{19} J
D. **3.36×10^{-19} J**

D

Worked solution

Band gap, $E_g = 2.1 \text{ eV} = 2.1 \times 1.6 \times 10^{-19} = 3.36 \times 10^{-19}$ J

Question 2

In the spectrum of the LED, the wavelength corresponding to the highest intensity will be closest to

A. 450 nm
B. 510 nm
C. **590 nm**
D. 700 nm

C

Worked solution

$$\lambda = \frac{hc}{E_{\mathrm{g}}} = \frac{4.14\times10^{-15}\times3\times10^{8}}{2.1} = 5.91\times10^{-7}\ \mathrm{m} = 591\ \mathrm{nm}$$

Use the following information to answer Questions 3 and 4.
Figure 2 below shows a laser that has a discharge cavity and two mirrors, one of which is partially reflecting. Laser light is emitted through the partially reflecting mirror.

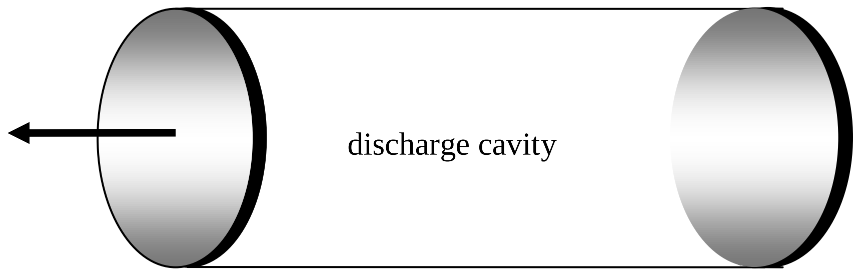


Figure 2

Question 3
Laser light is best described as
A. intense, incoherent and collimated.
B. intense, coherent and monochromatic.
C. in phase, single wavelength and very intense.
D. **the amplified light of a single wavelength and in phase.**

D

Worked solution
Studying the acronym of LASER, laser light is amplified and in phase. The intensity of laser light can be adjusted from weak to intense.

Question 4
Which one of the following best describes the important purpose performed by the mirrors?
A. **The mirrors reflect photons back and forth in the chamber to amplify light by the stimulation of photons.**
B. The mirrors trap photons for a longer time in the cavity so that they gain more energy.
C. The mirrors reflect photons in the chamber so that they can all get in phase.
D. The mirrors ensure that laser light emerges from only one end.

A

Worked solution
The mirrors reflect photons repeatedly so that maximum amplification can occur.

Tip
- *Learn the full form of LASER and understand each of the terms.*

Use the following information to answer Questions 5 to 8.

Figure 3 shows an optical fibre that is constructed from a core, cladding and a jacket. The refractive index of the core and cladding material is 1.48 and 1.51, although not necessarily in this sequence.

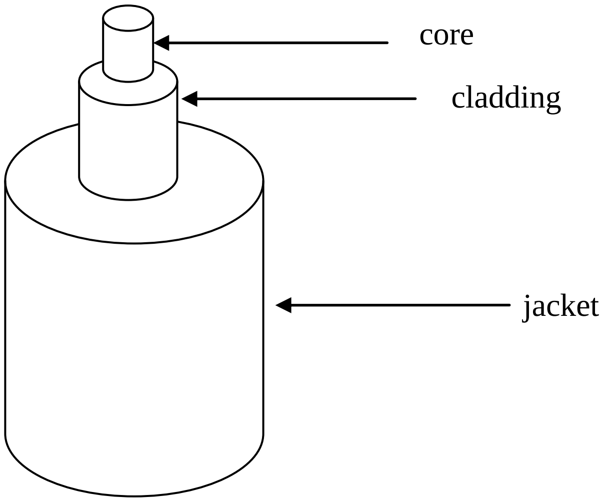
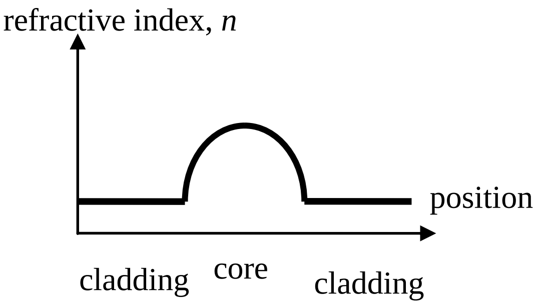


Figure 3

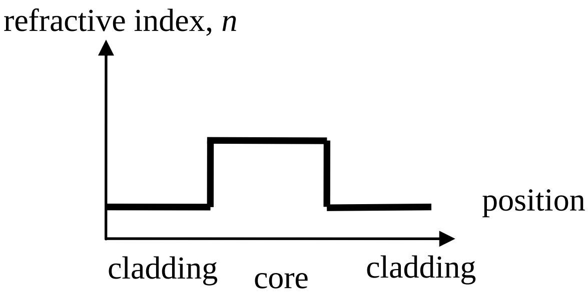
Question 5

Which one of the following best represents the refractive index of the core and cladding as a function of cross-section for a graded-index multimode (GIMM) fibre?

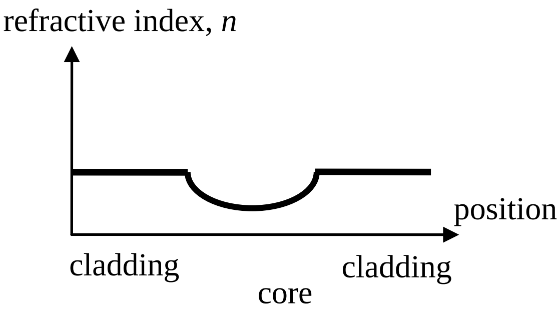
A.



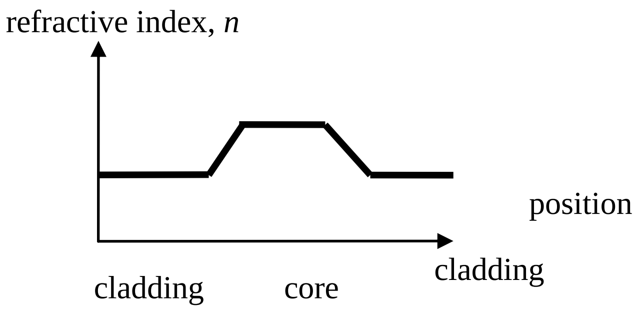
B.



C.



D.



A

Worked solution
Graded index is a gradual change of refractive index from core to cladding. Hence, A is the best answer.

Question 6
For a light beam entering the core and reflecting off the cladding, the critical angle is closest to
A. 64.9°
B. 72.6°
C. **78.6°**
D. 83.2°

C

Worked solution
Critical angle, $\theta_{\text{critical}} = \sin^{-1}\frac{1.48}{1.51} = 78.56°$

Question 7
The numerical aperture for the optical fibre is closest in value to
A. **0.3**
B. 0.25
C. 0.2
D. 0.15

A

Worked solution
Numerical aperture, $NA = \sqrt{1.51^2 - 1.48^2} = 0.3$

Question 8
The attenuation of this optical fibre is 0.4 dB km^{-1}. A signal of 3.5 mW is sent through a 6 km fibre. The output signal will be closest to
A. 3.0 mW
B. 2.5 mW
C. **2.0 mW**
D. 1.5 mW

C

Worked solution

Attenuation over 6 km = 2.4 dB

$$\text{Attenuation, dB} = 10\log\frac{P_{\text{output}}}{P_{\text{input}}}$$

$$2.4 = -10\ \log\frac{P_{\text{output}}}{3.5}$$

Therefore, output power = 2.01 mW.

Tips

- *Differentiate clearly and establish relationships between similar terms such as graded index versus step index; numerical aperture versus acceptance angle; and critical angle versus acceptance angle.*
- *Check your calculator is in degrees.*
- *Verify whether attenuation is total attenuation or attenuation per km.*

Use the following information to answer Questions 9 to 13.

Optical fibres are of different types, such as step index and single mode, single mode or multimode. Their application depends on factors such as cost, distance of communication and amount of dispersion.

Question 9

Modal dispersion is most significant in

A. single-mode fibre.
B. **multimode, step-index fibre.**
C. multimode, graded-index fibre.
D. single-mode, graded-index fibre.

B

Worked solution

Modal dispersion does not occur in single-mode fibres and graded index reduces modal dispersion. Hence, modal dispersion is most significant in multimode, step-index fibre.

Question 10

Modal dispersion can be minimised best using

A. multimode fibre.
B. multimode, graded-index fibre.
C. multimode, step-index fibre.
D. **single-mode fibre.**

D

Worked solution

Although graded-index fibre will also reduce modal dispersion, the most significant reduction will be achieved using single-mode fibre.

Question 11

Material dispersion is most significant in

A. **single-mode fibre.**
B. multimode, step-index fibre.
C. multimode, graded-index fibre.
D. multimode, single-index fibre.

A

Worked solution

Single-mode fibres have no method of reducing material dispersion unless a laser light source is used.

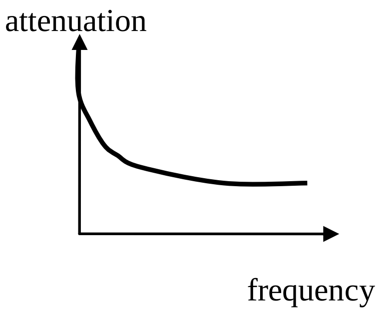
Question 12
Multimode fibres often have a graded index. The principal reason for this is to
A. reduce material dispersion.
B. increase material dispersion.
C. increase modal dispersion.
D. reduce modal dispersion.

D

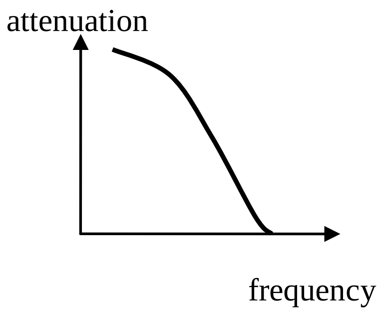
Worked solution
The refractive index is gradually reduced from the core to the edge, so that modes travelling a longer distance are in a region of the fibre where speed is higher. Therefore, modal dispersion is reduced and D is the best answer.

Question 13
Rayleigh scattering is best represented by which of the following attenuation graphs, all of which are drawn on the same scale?

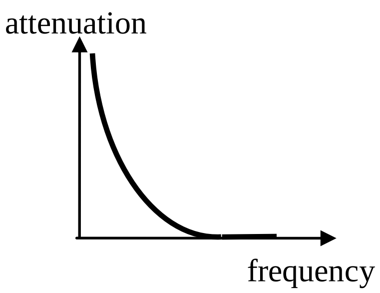
A.



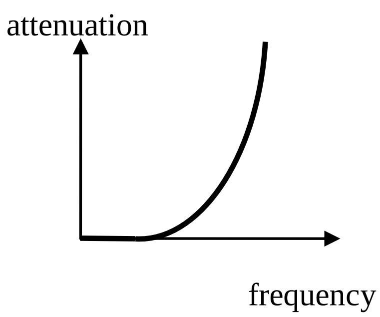
B.



C.



D.



D

Worked solution

Rayleigh scattering increases as frequency increases, so the best answer is D.

Tips

- *Remember that Rayleigh scattering occurs most at low wavelengths, which is high frequency.*
- *It will be useful to create a table of the different types of fibres, the relevant causes of dispersions in each case and the suggested methods for reducing dispersions.*

END OF DETAILED STUDY 2

Detailed Study 3 – Sound

Use the following information to answer Questions 1 to 4.

A flute can be considered to act as a pipe that is open at both ends. When the length of the air column in a particular flute is 1.5 m, the fundamental note detected is 120 Hz.

Question 1

Under these conditions, the speed of sound in the air column of the flute is closest to

A. 340 m s^{-1}
B. 350 m s^{-1}
C. **360 m s^{-1}**
D. 370 m s^{-1}

C

Worked solution

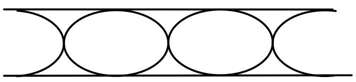
For a pipe open at both ends, $f_0 = \dfrac{v}{2L}$.

$\therefore \quad v = 2L f_0 = 2 \times 1.5 \times 120 = 360 \text{ m s}^{-1}$

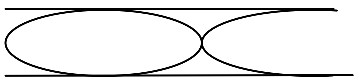
Question 2

When the air column in the flute is resonating so as to set up the third harmonic, which one of the following diagrams best shows the variation of air pressure along the distance of the pipe?

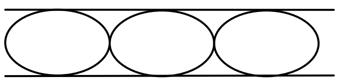
A.



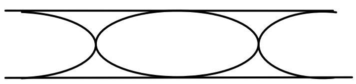
B.



C.



D.



C

Worked solution

The pressure difference between the ends of the column and the atmosphere is minimal. The third harmonic will have 1½ wavelengths, so the correct answer is C.

Question 3
Which statement best describes the other frequencies that will also resonate in the flute?
A. 240 Hz but not 360 Hz.
B. 240 and 360 Hz but not 480 Hz.
C. **240 Hz, 360 Hz and 480 Hz.**
D. 360 Hz but not 240 Hz.

C

Worked solution
All frequencies satisfying the relationship $f = nf_0$, where n = integer, will resonate.
Therefore, 240 Hz, 360 Hz and 480 Hz will resonate.

Question 4
A clarinet is an example of a pipe closed at one end. In another experiment, one end of the flute is closed so that it models a clarinet. The length of the flute is now reduced to 0.81 m and the speed of sound is measured to be 340 m s^{-1}. Under these conditions, which one of the following values is closest to the fundamental frequency?
A. 209.9 Hz
B. 52.5 Hz
C. 184 Hz
D. **104.9 Hz**

D

Worked solution
$$f_0 = \frac{v}{4L} = \frac{340}{4 \times 0.81} = 104.9 \text{ Hz}$$

Tips
- *Remember to differentiate between pressure and amplitude variations for standing waves in pipes and strings.*
- *Remember to differentiate between a pipe closed at one end and a pipe open at both ends.*
- *Remember that strings and pipes, open at both ends, will resonate all harmonics but pipes closed at one end will resonate only odd harmonics.*

Use the following information to answer Questions 5 to 7.

In order to study the inverse square law and the addition of two sound waves, an experiment is carried out using two loudspeakers. The two loudspeakers, labelled L_1 and L_2, emit a frequency of 1000 Hz. A detector is placed at a position, *P*, which is 5.0 m equidistant from the two loudspeakers (see Figure 1).

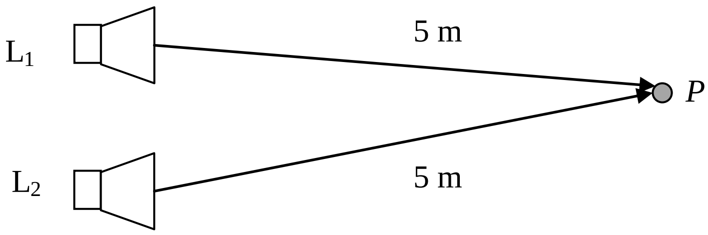


Figure 1

Question 5

The loudspeaker L_1 is switched on first and a loudness of 65 dB is recorded at *P*. A moment later, the second loudspeaker L_2 is turned on and L_1 is turned off. The loudness is then recorded as 70 dB at *P*. The ratio of the intensity from L_2 to that of the intensity from L_1 at *P* is closest to

A. 1 : 1.1
B. 5 : 16
C. **16 : 5**
D. 1.1 : 1

C

Worked solution

We need to calculate the ratio of intensities that correspond to 70 dB and 65 dB.

$$65 = 10\log\frac{I_1}{10^{-12}}$$

$$70 = 10\log\frac{I_2}{10^{-12}}$$

$$70 - 65 = 10\log\frac{I_2}{I_1}$$

$$\frac{I_2}{I_1} = 10^{0.5} = 3.16$$

$$I_2 : I_1 = 3.16 : 1 \approx 16 : 5$$

Question 6

With loudspeaker L_2 still turned off, the volume of loudspeaker L_1 is adjusted such that the intensity at *P* is now 4.2×10^{-5} W m^{-2}. How far will the detector need to be placed from L_1 to record an intensity of 8.6×10^{-6} W m^{-2}? Select the answer that is closest to your calculations.

A. 9 m
B. **11 m**
C. 13 m
D. 15 m

B

Worked solution

Use the inverse square law.

$$I_1 r_1^2 = I_2 r_2^2$$
$$4.2\times10^{-5}\times(5)^2 = 8.6\times10^{-6}\times(r_2)^2$$
$$r_2 = 11.04 \text{ m}$$

Question 7

In a different experiment, the two loudspeakers are both switched on and the sound waves of 65 dB and 70 dB from the two loudspeakers add on constructively at point *P*. The sound intensity level of the combined L_1 and L_2 speakers at point *P* is closest to

A. **71 dB**
B. 73 dB
C. 75 dB
D. 77 dB

A

Worked solution

We need to add the intensities and then convert the answer to decibels.
Using $I = 10^{(L/10 - 12)}$, $I_1 + I_2 = 10^{-5.5} + 10^{-5} = 1.316 \times 10^{-5}$ W m^{-2} = 71.2 dB.

Tips

- *Remember that dB is a log scale, so small changes in decibels are large changes in intensities.*
- *Revise log rules.*

Use the following information to answer Questions 8 to 11.

In order to study the response of a particular loudspeaker to sounds of different frequencies, the loudspeaker, a dynamic microphone and a frequency synthesizer are connected, as shown in Figure 2.

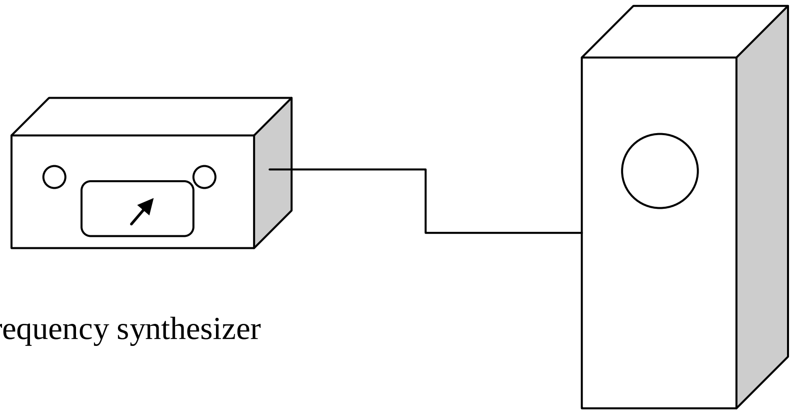


Figure 2

Question 8

A sound wave emitted from the loudspeaker has a power of 3×10^{-7} W. The sound wave is incident on a detector over an area of 5×10^{-5} m^2. Assuming that all output is directed at the detector, the loudness, *L*, measured by the detector will be closest to

A. **97.8 dB**
B. 87.9 dB
C. 79.8 dB
D. 76.9 dB

A

Worked solution

Intensity, $I = \dfrac{P}{A} = \dfrac{3 \times 10^{-7}\ \text{W}}{5 \times 10^{-5}\ \text{m}^2} = 0.006\ \text{W m}^{-2}$.

Loudness, *L*, is calculated as $L = 10\ \log \dfrac{I}{I_0} = 10 \log \dfrac{0.006}{10^{-12}} = 97.8$ dB.

Question 9

At a certain frequency, the diaphragm of the loudspeaker is seen to move forward and backward in an oscillating cycle. Ten such oscillations are observed in 0.1 s and in a range of frequencies around this, the loudspeaker has high fidelity. This loudspeaker is most likely to be

A. **a woofer.**
B. mid-range.
C. a tweeter.
D. an ultrasound.

A

Worked solution
The frequency range is around 100 Hz, which is clearly a woofer.

Question 10
In another experiment, the frequency synthesizer generates a sound wave, whose shape is shown in Figure 3 below.

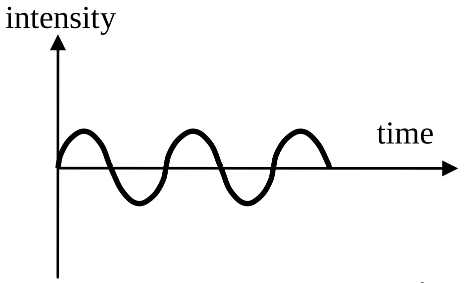
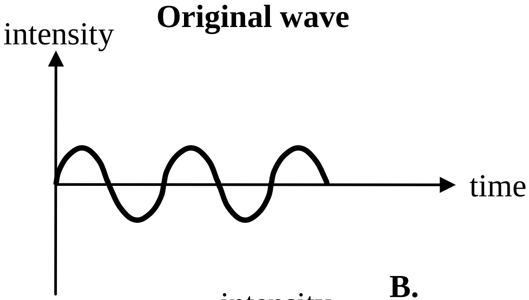


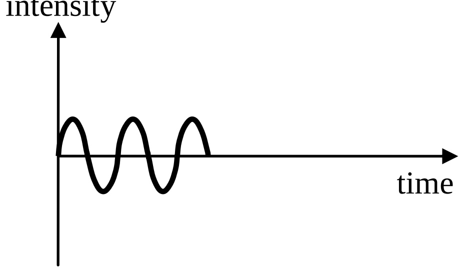
Figure 3

The following four waves are drawn on the same scale as the original wave. For ease of comparison, the original wave is also reproduced. Which one of the following (**A**–**D**) best represents a sound wave having half the frequency and double the amplitude of the original wave?

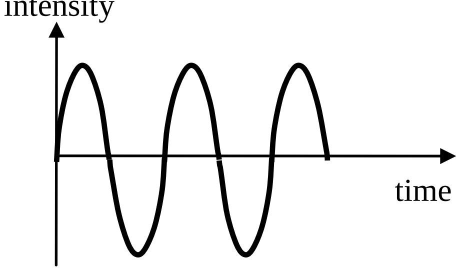
Original wave



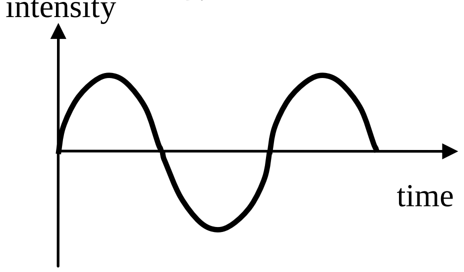
A.



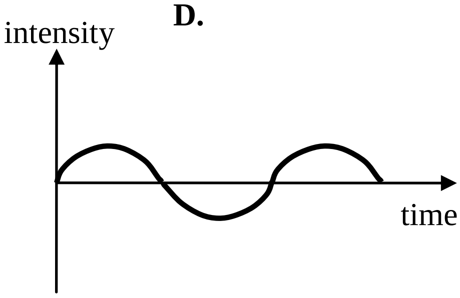
B.



C.



D.



C

Worked solution
Half the frequency will double the time period (i.e. x-axis), and doubling the amplitude will increase the intensity (i.e. y-axis).

Question 11
The frequency response of the speaker at a constant power is shown in Figure 4 below.

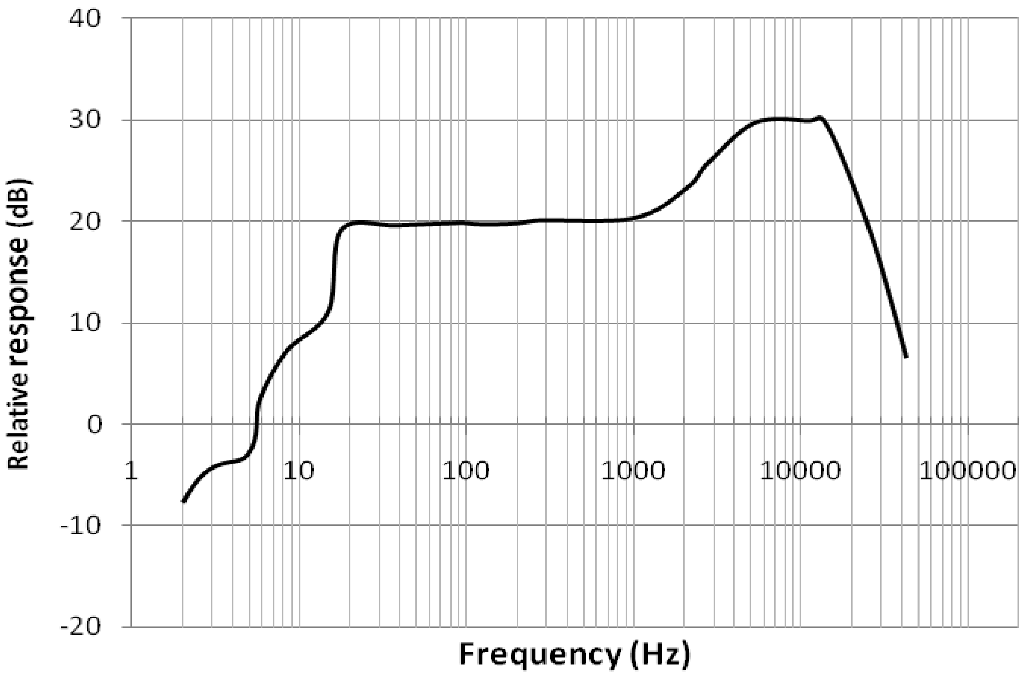


Figure 4

The **difference** in intensity between the response at 500 Hz and 5000 Hz is closest to
A. $\mathbf{9 \times 10^{-10}}$ **W m^{-2}.**
B. 9×10^{-9} W m^{-2}.
C. 1×10^{-10} W m^{-2}.
D. 1×10^{-9} W m^{-2}.

A

Worked solution
Loudness at 500 Hz is 20 dB and at 5000 Hz is 29 dB to 30 dB.
We need to find $\Delta I = I_{30\text{ dB}} - I_{20\text{ dB}}$.
Intensity at 30 dB = 10^{-9} W m^{-2}; and intensity at 20 dB = 10^{-10} W m^{-2}.
Therefore, the difference is 9×10^{-10} W m^{-2}.

Tips
- *When two sound waves superimpose, sound intensities (W m^{-2}) are added – not sound intensity levels (dB).*
- *When reading graphs, check the quantities and units on the axes carefully.*

Use the following information to answer Questions 12 and 13.

Figure 5 below indicates lines of equal perceived loudness, as measured for Tony. The perceived loudness (phon) is based on 1000 Hz intensity and the threshold of hearing as 10^{-12} W m^{-2} at 1000 Hz.

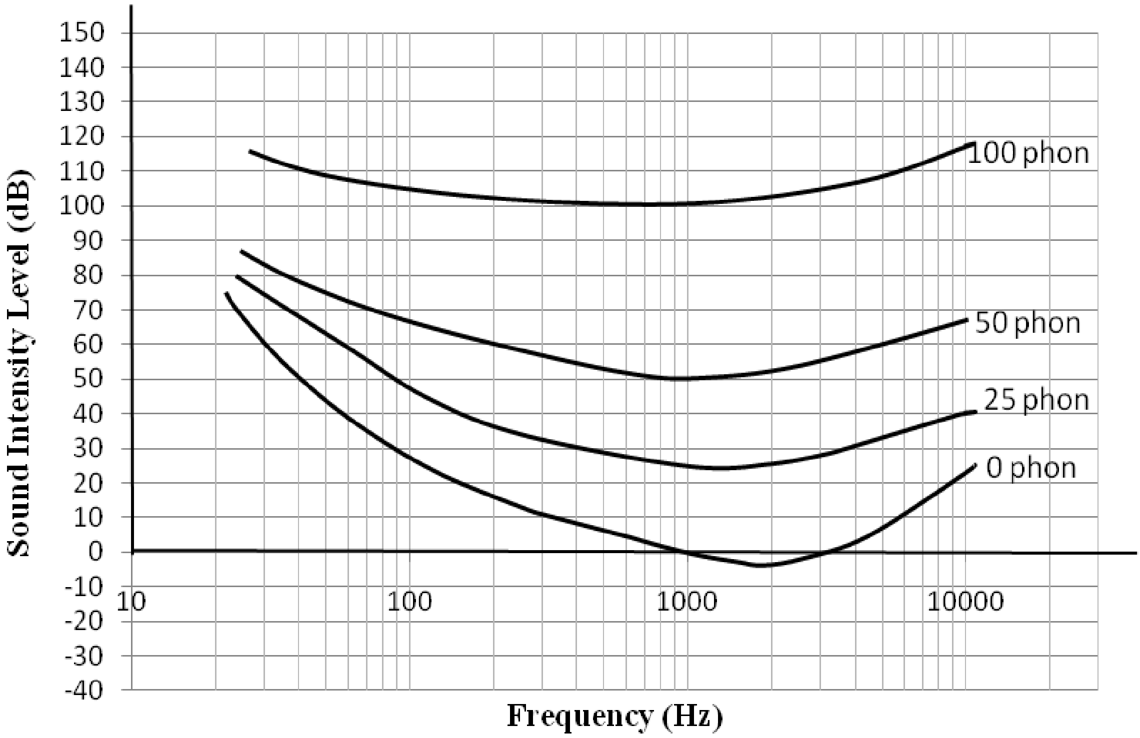


Figure 5

Question 12

Which one of the following statements is **not** true?

A. For the same power emitted by a loudspeaker, as the frequency increases from 100 Hz to 1000 Hz, Tony will perceive an increase in loudness.

B. Tony can hear a 20 dB sound at 300 Hz but not at 100 Hz.

C. A 50 dB sound at 90 Hz appears to Tony to be as equally loud as 30 dB at 400 Hz.

D. Tony can clearly hear a 60 dB sound at 60 Hz but not at 1000 Hz.

D

Worked solution

These are statements based on the graphs, such that a point above the line is clearly heard but a point below is not. Hence, only D is *not* true.

Question 13
A constant 40 dB sound is produced by the loudspeaker. At this sound intensity level, which one of the following frequencies would Tony **not** be able to hear clearly?

A. 9000 Hz
B. 2000 Hz
C. 100 Hz
D. **50 Hz**

D

Worked solution
A 40 dB sound will be heard at all the frequencies listed above, other than at 50 Hz.

Tips

- *Phon lines represent iso-phonic points; i.e. all points on the lines sound as if they are of equal loudness.*
- *Points above the phon lines are clearly heard, whereas points below the phon lines are not heard.*

END OF DETAILED STUDY 3
END OF SECTION B

END OF ANSWER BOOK