INSIGHT

Trial Exam Paper

2010

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

SECTION A – Core

Area of study 1 – Electric Power

The following information relates to Questions 1 and 2.

Two permanent magnets of different magnetic field strengths are placed as shown in Figure 1. Magnet Q has about double the magnetic field strength as that of magnet P.

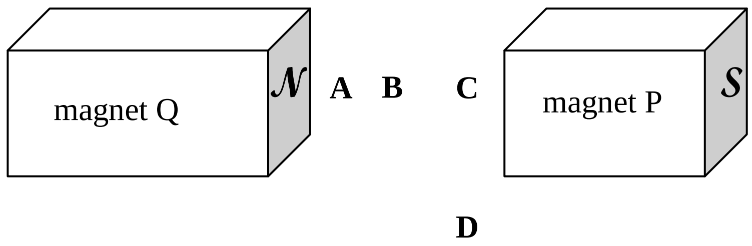
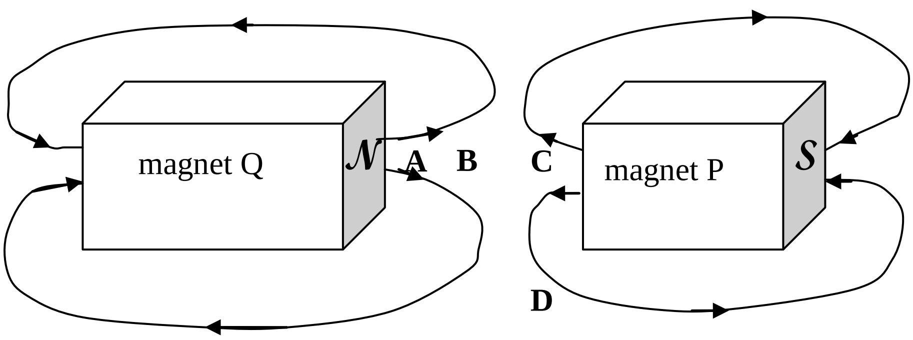


Figure 1

Question 1

Complete the diagram by sketching four magnetic field lines, with appropriate arrows, that would illustrate the magnetic field between and around the two magnets.

Worked solution



2 marks

Mark allocation

- 1 mark for appropriate complete lines with arrows from north to south poles.
- 1 mark for showing a greater line density for the stronger magnet or a stronger field.
- Take 1 mark off if lines are crossing or touching.

Question 2

Which one of the locations A, B, C or D would have the **lowest** magnetic field strength?

Worked solution

The stronger magnet has a higher flux density and would result in the point of lowest field strength closer to the weaker magnet. Hence, correct answer is C.

C

2 marks

Mark allocation

- 2 marks for correct answer.
- No part marks.

Tips

- *Magnetic field lines do not touch or cross.*
- *Magnetic field lines are complete loops from north to south poles. Arrows indicating this direction must be shown.*

Use the following information to answer Questions 3 – 5.

In an effort to light a small light bulb, a magician slides a 30 cm metal bundle consisting of three thin rods over conducting rails immersed in an external magnetic field of 30 mT, as shown in Figure 2.

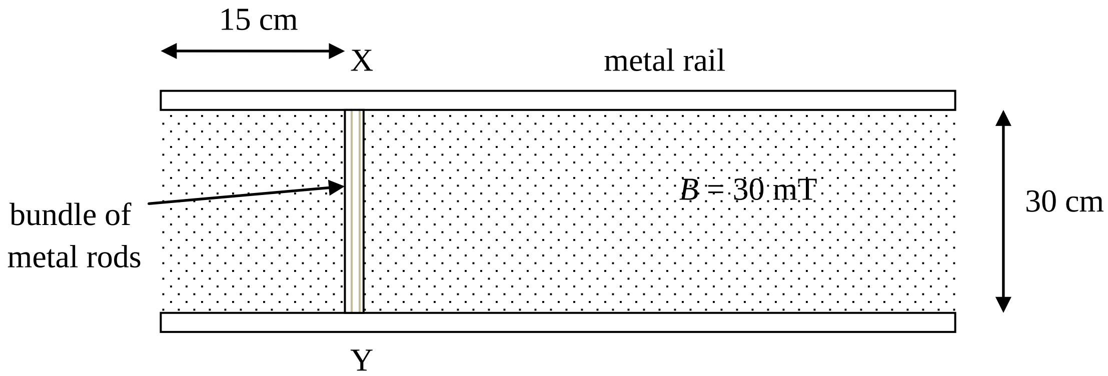


Figure 2

Question 3

As the first ‘act’, the magician turns off the external field from its strength of 30 mT to 0 in a time of 6 ms. What is the magnitude of induced emf across the ends of the bundle of three metal rods?

Worked solution

$$\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t} = N\frac{A\Delta B}{\Delta t} = -3\times\frac{30\times10^{-3}\times0.15\times0.30}{6\times10^{-3}} = 0.68\text{ V}$$

0.68 V

3 marks

Mark allocation

- 1 mark for using the correct formula and substituting correct values for *B* and *t*.
- 1 mark for using the correct value for *N*, which is 3.
- 1 mark for correct magnitude of emf.

Question 4

In the next 'act' the magician slides the metal rod to the left with a uniform speed of 5.0 cm s^{-1}. The magnitude and direction of the magnetic field is unchanged. What is the magnitude of the induced emf in the bundle of metal rods now?

Worked solution

$$\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t} = N\frac{B\Delta A}{\Delta t} = -3 \times \frac{30\times10^{-3}\times0.3\times0.05}{1} = 0.001\,35\text{ V} = 1.35\text{ mV}$$

1.35 mV

3 marks

Mark allocation

- 1 mark for using N = 3 and correct expression for emf.
- 1 mark for substituting correct values into the expression for emf, other than N = 3.
- 1 mark for correct answer.

Question 5

When the magician slides the rod to the left as described in Question 4 and an emf is induced in the metal rods, which of the ends, X or Y, is at a higher potential? Explain your reasoning.

Worked solution

Current direction will be such that the force it generates will push the rods from left to right. This will occur when the current is from X to Y. Hence, X is at a higher potential.

X

2 marks

Mark allocation

- 1 mark for correct answer.
- 1 mark for reasoning. Reference to the negative sign in Lenz's law is adequate for full 2 marks if correct conclusion is reached.

Tips

- *Induced emf opposes the flux change that causes it.*
- *Remember to convert all units to SI (e.g. cm to m and mV to V).*

Use the following information to answer Questions 6 – 8.

A flat square coil with sides 20 cm and consisting of 100 turns rotates in an external magnetic field with a frequency of 50 Hz. The magnitude of the external magnetic field is 0.25 T. As the coil rotates, the flux through it changes, as shown in Figure 3.

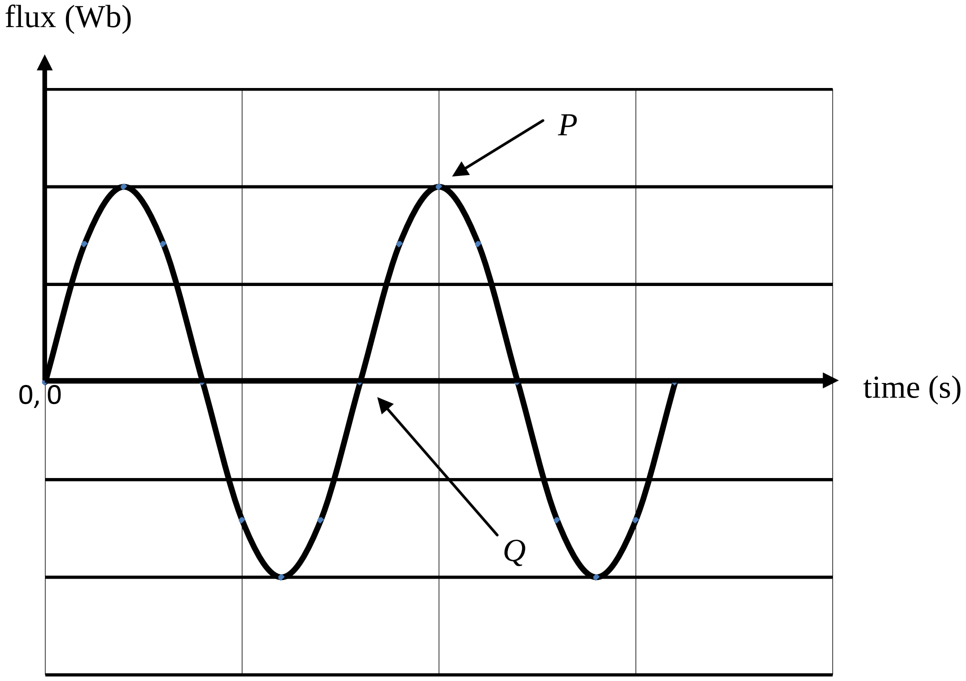


Figure 3

Question 6

On the axes of Figure 3, indicate the numerical values on the *y*-axis and the *x*-axis where indicated by the arrows *P* and *Q*.

Worked solution

Point *P* is maximum flux, $\Phi_{max} = BA = 0.25 \times 0.2 \times 0.2 = 0.01\,\text{Wb}$

Point *Q* is time period, $T = \frac{1}{f} = \frac{1}{50} = 0.02\text{ s}$

0.01 Wb, 0.02 s

2 marks

Mark allocation

- 1 mark for correct magnitude of flux.
- 1 mark for correct magnitude of time period.

Question 7

On the axes re-drawn below in Figure 4, draw the shape of the induced emf as a function of time.

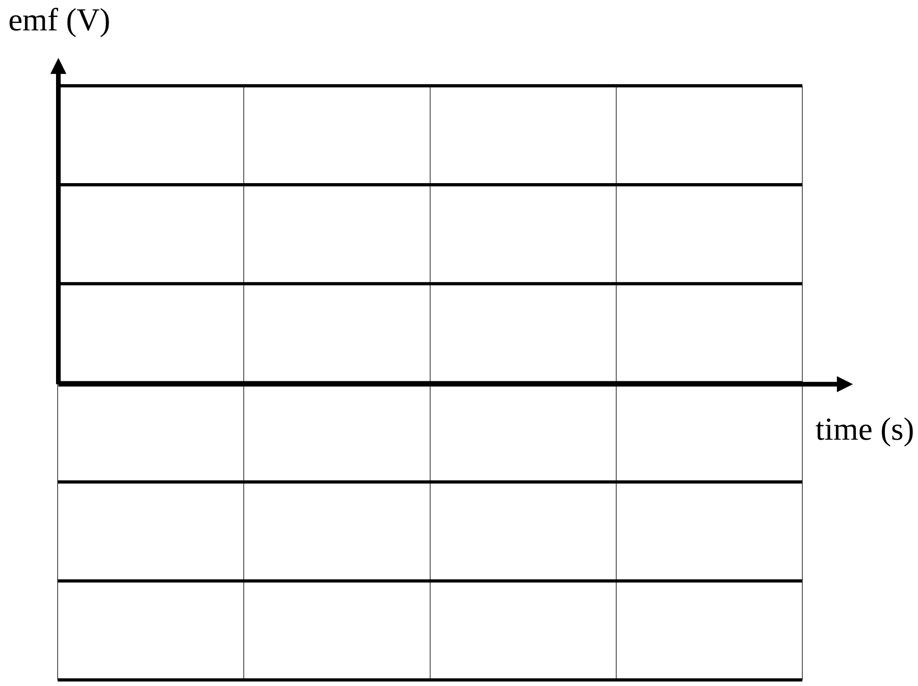
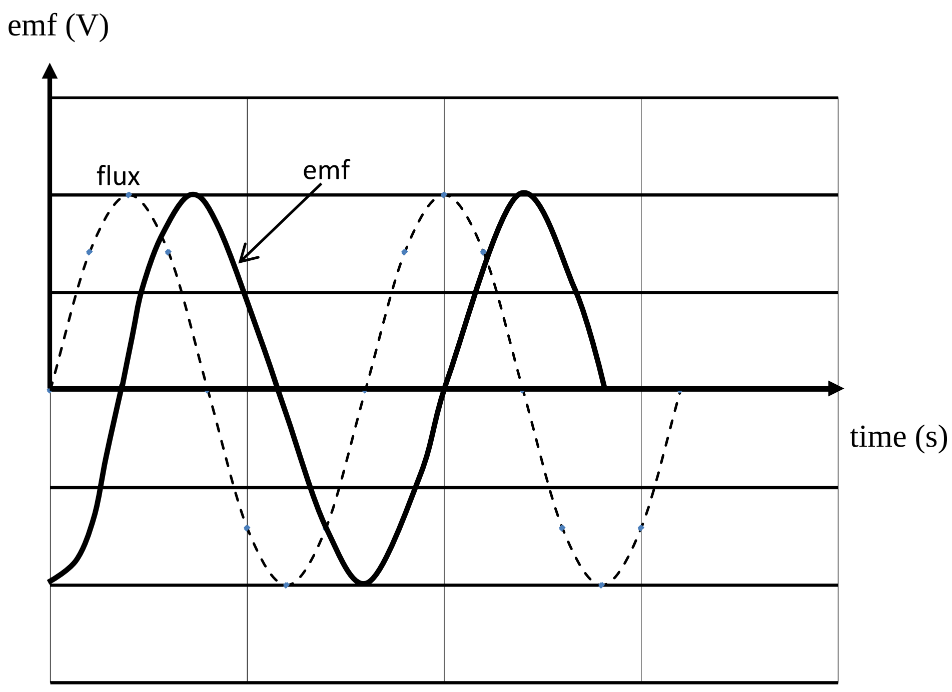


Figure 4

Worked solution



2 marks

Mark allocation

- 1 mark for correct negative gradient.
- 1 mark for maintaining the same time period.

SECTION A – Area of study 1 – continued
TURN OVER

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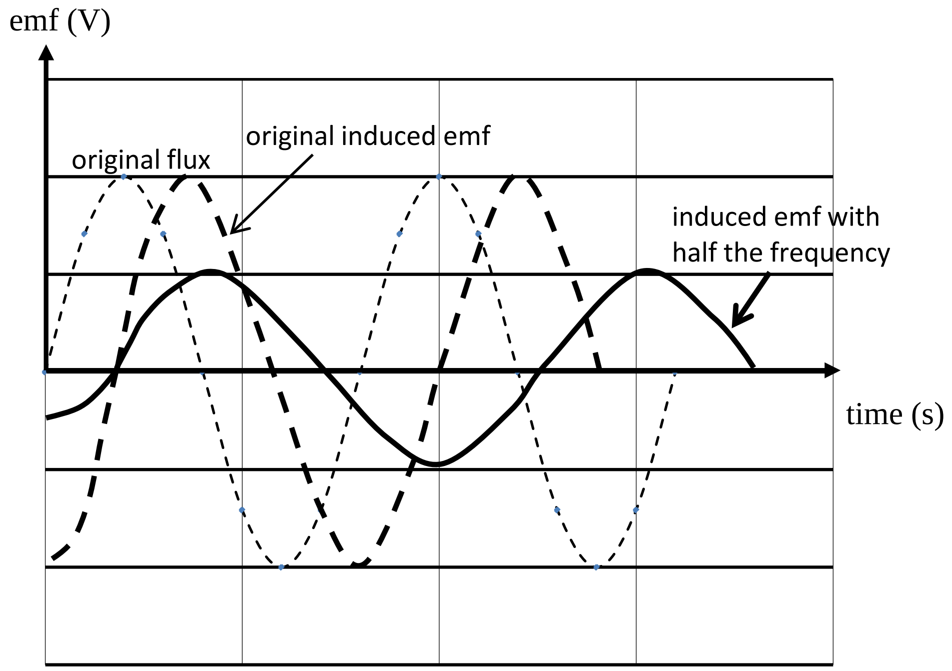
Question 8

The frequency of rotation is now halved. Using the same axes supplied in Figure 4, draw the shape of the induced emf as a function of time.

Worked solution

By halving the frequency, the time period will double. Also, the induced emf will halve in accordance with Lenz's law.



2 marks

Mark allocation

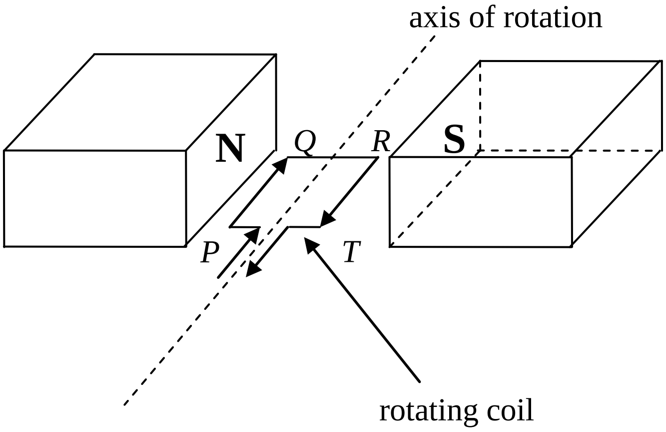
- 1 mark for doubling the emf.
- 1 mark for halving the time period.

Tips

- *Remember to analyse both the y-axis (emf) and the x-axis (time) when solving problems on induced emf.*
- *Remember to take the negative gradient of flux as the induced emf.*

Use the following information to answer Questions 9 – 11.

A square coil, *PQRT*, with sides 20.0 cm and consisting of 100 turns is rotated in the field of a uniform permanent magnet of field strength 30 mT, as shown in Figure 5, so as to operate as a DC motor. The current through the arm *PQ* is measured as 2.0 A.



Arrows show direction of current.

Figure 5

Question 9

With reference to the external magnetic field and the effect of current in the coil, explain **why** there is a force on the arm *PQ* in the position shown.

Worked solution

When current passes through the conductor *PQ*, a magnetic field will be generated around the conducting wire, which will add vectorially with the external field, forming a net magnetic field. The conductor will experience a force in the direction of the net magnetic field.

2 marks

Mark allocation

- 1 mark for describing the addition of self and external field.
- 1 mark for drawing the correct conclusion about generation of force.
- Give only 1 mark if $F = nBIl$ is used without further explanation.

Question 10

In the position shown, what is the magnitude of net force on the arms *PQ* and *QR*?

	Side *PQ*	**Side *QR***
Magnitude of force	N	N

Worked solution

Using the right-hand rule, force on *PQ* is down and has a magnitude of
$F = BIl = 0.03 \times 2 \times 0.2 = 1.2$ N
Force on *QR* = 0 N.

PQ: 1.2 N
QR: 0 N

2 marks

Mark allocation

- 1 mark for correct magnitude of force on *PQ*.
- 1 mark for correct magnitude of force on *QR*.

Question 11

Explain, with reference to the force on the side *PQ* as it turns through 180°, what device is built in the design of the motor to ensure that the motor keeps spinning in the same direction?

Worked solution

Force on the side *PQ* is down in the current position. As it turns through 90°, momentum carries it across. At 180°, the force will reverse it. Hence, a DC split ring commutator is used, which will reverse the current every half cycle. This will keep the motor spinning in one direction.

3 marks

Mark allocation

- 1 mark for description of force and/or momentum.
- 1 mark for describing the role of commutator in reversing current every half cycle.
- 1 mark for concluding that the commutator keeps the motor spinning.

Tips

- *Ensure that the description for the commutator refers to the question; i.e. motor or generator.*
- *Remember to give appropriate depth to your answer, which requires explanations. Simply stating the relevant law is sometimes not adequate.*

Use the following information to answer Questions 12 – 16.

A power station produces 350 MW at 15 kV. Power lines transmit the power to a small village 10 km away using overhead power transmitting cables, which have a total resistance of 4.5 Ω. Two transformers are used in the process. From the first transformer, called transformer 1 and which is at the site of the power station, the voltage output is 450 kV. A schematic diagram of the station, transformers and transmission lines to the village is shown in Figure 6.

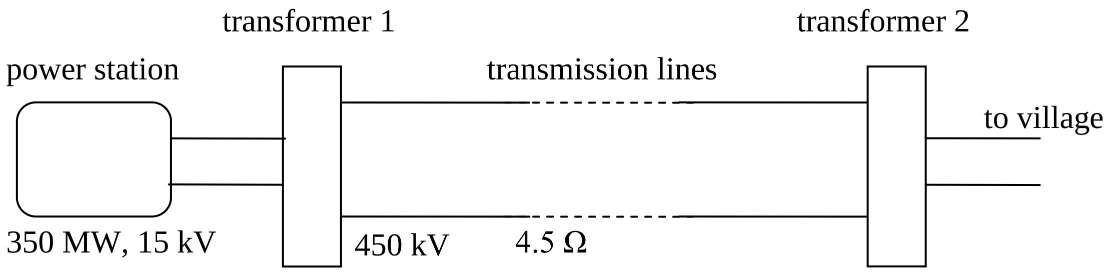


Figure 6

Question 12

Calculate the ratio of number of primary turns to that of secondary turns for the transformer 1 used at the site of the power station.

Worked solution

Transformer 1 is a step up transformer:

$$\frac{N_p}{N_p} = \frac{V_p}{V_p} = \frac{15}{450} = 1:30$$

1: 30

2 marks

Mark allocation

- 1 mark for correct use of formula with correct substitution.
- 1 mark for correct answer.

Question 13

What is the current in the transmission lines between transformer 1 and transformer 2?

Worked solution

$$I_p = \frac{P}{V_p} = \frac{350 \times 10^6}{15\,000} = 23\,333.3 \text{ A}$$

$$I_s = \frac{I_p}{30} = \frac{23\,333.33}{30} = 777.78 \text{ A}$$

$\boxed{777.8 \text{ A}}$

2 marks

Mark allocation

- 1 mark for correctly estimating the current in the primary coil.
- 1 mark for correctly estimating the current in the secondary coil.

Question 14

What is the power lost by the transmission lines from transformer 1 to transformer 2? Show your working.

Worked solution

Current in the transmission lines = 777.78 A
Therefore, power lost = $I^2R = (777.78)^2 \times 4.5 = 2.7 \text{ MW}$

$\boxed{2.7 \text{ MW}}$

2 marks

Mark allocation

- 1 mark for correct use of primary current (no need to complete calculation if values are substituted into expression for secondary current) in the expression for power lost.
- 1 mark for correct answer.

Question 15

What is the voltage at the primary coil of transformer 2?

Worked solution

Current in the transmission lines = 777.78 A and
power lost = $I^2R = (777.78)^2 \times 4.5 = 2.7$ MW
Therefore, power at primary end of transformer 2 (i.e. the end of transmission lines) is
350 – 2.7 = 347.3 MW

Therefore, $V = \frac{P}{I} = \frac{347.3 \times 10^6}{777.8} = 446.5\text{ kV}$

446.5 kV

3 marks

Mark allocation

- 1 mark for using power loss to work out power at transformer 2.
- 1 mark for correctly estimating power at transformer 2 by subtracting power loss from power supplied.
- 1 mark for correctly estimating voltage at transformer 2.
- Give 1 mark if all answers are incorrect but a value of power loss is subtracted from power generated.
- Give 2 marks maximum for consequential when correct formula is used but incorrect value of *P or I* is substituted. Give 1 mark consequential only if *both P* and *I* have incorrect values.

Question 16

Outline two appropriate methods that could be used to further reduce power loss, without changing the power production.

Worked solution

Use a transformer with a greater ratio of turns.
Reduce resistance of power lines by using a lower resistance wire, such as those used for underground power lines.
Reduce losses in transformers by cooling and using better quality transformers.

2 marks

Mark allocation

- 1 mark for suggesting greater ratio of turns in transformer.
- 1 mark for any of the other two methods.

Tips

- *Use power loss, not voltage drop, to work out voltage across power lines.*
- *Remember to use the resistance of the entire transmission lines, not just one arm.*

Use the following information to answer Questions 17 and 18.

In Mariah's room there are three lights, two of which are on the ceiling and one is her study lamp. The room is supplied by a power supply of 30 V_{RMS}. The three lights are connected as shown in the circuit (Figure 7). The two ceiling lights have a resistance of 50 Ω each. When all three lights are on, Mariah measures the current by a meter in the circuit, as shown in the circuit diagram, to be 0.5 A.

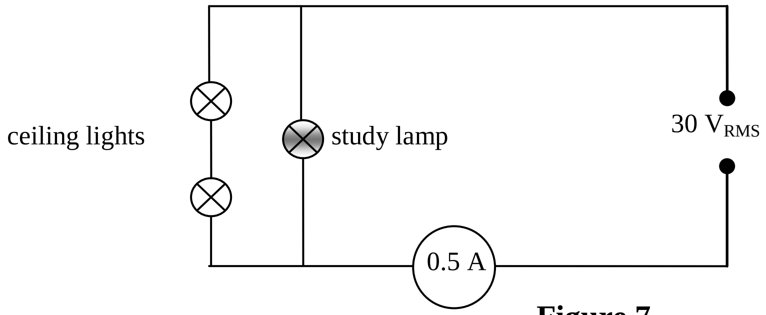


Figure 7

Question 17

What is the resistance of the study lamp?

Worked solution

Use Ohm's law $V = IR$.

Current in the ceiling lights = $\frac{30}{100}$ = 0.3 A

Therefore, current in the reading lamp = 0.5 – 0.3 = 0.2 A

Therefore, resistance of the reading lamp = $\frac{30}{0.2}$ = 600 Ω

$\boxed{600\ \Omega}$

2 marks

Mark allocation

- 1 mark for correct current in the reading lamp.
- 1 mark for correctly calculating resistance.

Question 18

What will be the energy consumed by the room when all three lights are turned on for 1 hour?

Worked solution

Using $E = I^2Rt$ for all three lights, energy consumed in 3600 s is

$[(2 \times 0.3^2 \times 50) + (0.2^2 \times 600)] \times 3600 = 1.19 \times 10^5$ J = 0.12 MJ

$\boxed{0.12\text{ MJ}}$

2 marks

Mark allocation

- 1 mark for using all resistors and currents in the calculations.
- 1 mark for correct answer.

Tips

- *Remember to identify series and parallel resistors in a circuit, re-drawing the circuit if it is helpful.*
- *Check the units in which energy is to be stated.*

END OF AREA OF STUDY 1

TURN OVER

Area of study 2 – Interactions of light and matter

Use the following information to answer Questions 1 – 3.

Photons are considered to have both wave-like and particle-like properties. A photon is also called as ‘a bundle of energy’. In order to estimate the energy, wavelength and momentum of photons, a 1 mW laser beam is used to emit a beam of light of wavelength 480 nm. Each photon emitted by the laser beam can be considered to be identical.

Question 1

What is the energy of a single photon emitted by the laser?

Worked solution

Energy of one photon is

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{480 \times 10^{-9}} = 4.14 \times 10^{-19} \text{ J}$$

$\boxed{4.14 \times 10^{-19} \text{ J}}$

2 marks

Mark allocation

- 1 mark for correct substitution of values into expression for energy of one photon.
- 1 mark for correct answer.

Question 2

How many photons are emitted by the laser in 40 seconds?

Worked solution

Number of photons emitted = $\dfrac{\text{energy emitted by the beam per second}}{\text{energy of one photon}}$

= s^{-1}

Therefore, photons emitted in 40 s = 9.66×10^{16}.

$\boxed{9.7 \times 10^{16}}$

2 marks

Mark allocation

- 1 mark for relating number of photons to energy.
- 1 mark for correct answer.

Question 3

Calculate the momentum of one photon emitted by the laser beam.

Worked solution

Momentum of photon = $p = \dfrac{h}{\lambda} = \dfrac{6.63 \times 10^{-34}}{480 \times 10^{-9}} = 1.38 \times 10^{-27}$ N s

1.4×10^{-27} N s

2 marks

Mark allocation

- 1 mark for correctly substituting values into the expression for momentum.
- 1 mark for correct answer.

Tips

- *Use appropriate numerical value for Planck's constant.*
- *Remember to practise using your scientific calculator for indices, such as those used in this section.*

Use the following information to answer Questions 4 – 6.

An illustration of Young's double slit experiment is shown in Figure 1. A 520 nm laser was used to obtain dark and bright bands on a screen from two narrow slits, S_1 and S_2. At a certain point, *P*, a bright band is observed. This point, *P*, is at a distance, d_1, of 1.5 m from one slit, as shown in the Figure 1.

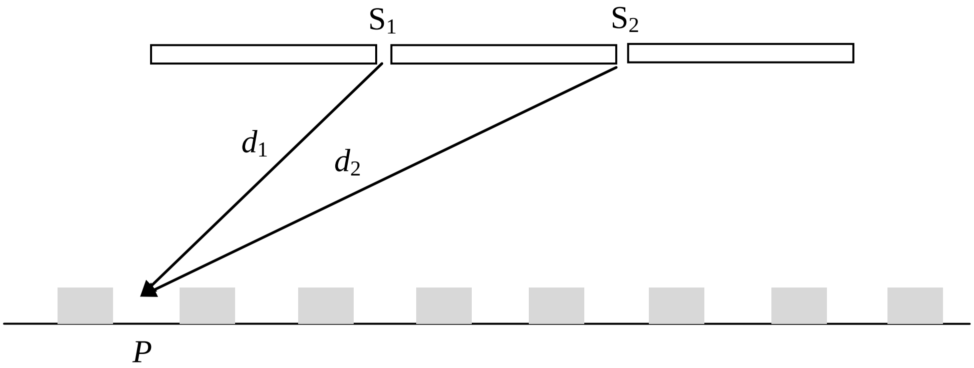


Figure 1

Question 4

Discuss whether the production of bright and dark bands is best explained by the wave-like or particle-like nature of light. Your explanation must refer to the **reason** why these dark and bright bands form.

Worked solution

The bright and dark bands are formed due to interference, which is a wave property. Here, crests line up with crests and troughs line up with troughs for constructive interference, while crests and troughs line up for destructive interference.

2 marks

Mark allocation

- 1 mark for identifying interference.
- 1 mark for explanation for interference, including reference to crests and troughs.

Question 5

Estimate the path difference of the beams from the two slits arriving at point *P*. Show your working.

Worked solution

For constructive interference resulting in the fourth order bright band
Path difference = $4 \times \lambda = 4 \times 520 \times 10^{-9} = 2.08 \times 10^{-6}$ m

$\boxed{2.1 \times 10^{-6} \text{ m}}$

2 marks

Mark allocation

- 1 mark for correct conclusion about path difference and wavelength.
- 1 mark for correct answer.

Question 6

Which one of the following statements best describes the change that would occur in the pattern of dark and bright bands if the frequency emitted by the laser **increased**?

A. Bands will move closer together.

B. The bands will become more intense.

C. The bands will become less intense.

D. The bands will move further apart.

Worked solution

According to the equation for bright fringes, $\frac{x}{L} = \frac{n\lambda}{d}$, as frequency of the light increases, the wavelength decreases and the bands (quantity *x*) will move closer together. Hence, correct answer is A.

A

2 marks

Mark allocation

- 2 marks for correct answer.
- No part marks.

Tip

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

Use the following information to answer Questions 7 and 8.

Results from a photoelectric effect experiment are shown in Figures 2a and 2b. The effects of changing light intensity and frequency on photocurrent shows behaviour represented in Figure 2a. The maximum kinetic energy of an emitted electron as a function of frequency is shown in Figure 2b.

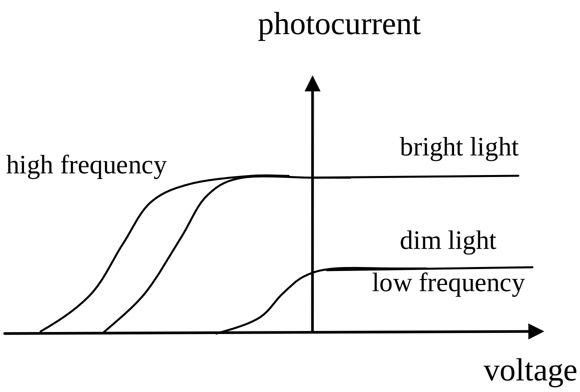


Figure 2a

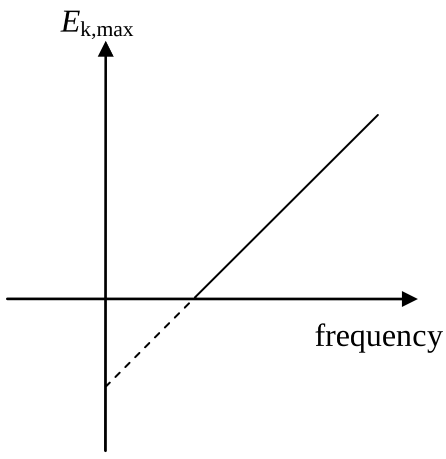


Figure 2b

Question 7

According to the results seen in Figures 2a and 2b, the bright light gives a higher photocurrent than dim light, and a higher frequency of incident light requires a more negative-stopping potential. Explain how these observations are best explained by the particle-like nature of light. You will need to refer to Figures 2a and 2b in your explanation.

Worked solution

The model proposing wave-like behaviour of light would suggest that increasing the frequency of light would result in more photoelectrons, whereas increasing the intensity of light would make no difference. However, the particle model explains that an increased frequency would result in a tighter-bound electron to be released and increased intensity would result in an increase in photocurrent. Hence, the particle model offers a better explanation.

2 marks

Mark allocation

- 1 mark for explaining the reasoning behind the two models.
- 1 mark for correctly concluding that particle model better explains the photoelectric effect.

Question 8

The threshold frequency for a metal is measured as 3.5×10^{14} Hz. When light of frequency 7.2×10^{14} Hz shines on the metal, what is the maximum speed of an ejected electron? Show your working.

Worked solution

Work function, $W = hf_0 = 6.63 \times 10^{-34} \times 3.5 \times 10^{14} = 2.32 \times 10^{-19}$ J

$E_{k,\max} = hf - W = (6.63 \times 10^{-34} \times 7.2 \times 10^{14}) - (2.32 \times 10^{-19}) = 2.45 \times 10^{-19}$ J

$$v_{\max} = \sqrt{\frac{2E_{k,\max}}{m}} = \sqrt{\frac{2 \times 2.45 \times 10^{-19}}{9.1 \times 10^{-31}}} = 7.3 \times 10^{5} \text{ ms}^{-1}$$

$\boxed{7.3 \times 10^{5} \text{ m s}^{-1}}$

3 marks

Mark allocation

- 1 mark for correct use or calculation of work function.
- 1 mark for correctly determining maximum kinetic energy.
- 1 mark for correct answer.

Tips

- *Remember to use the correct value for Planck's constant.*
- *It is better practice to derive an expression for a required quantity, such as speed, before substituting all values in order to find the quantity.*

Use the following information to answer Questions 9 and 10.

The energy levels for a particular gas at room temperature are illustrated in an energy level diagram (Figure 3). The ground state and ionisations states are shown with two other energy levels between them.

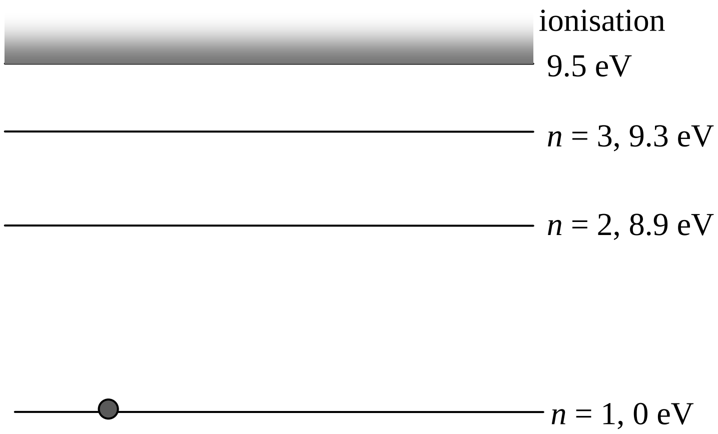


Figure 3

Question 9

Calculate the shortest wavelength present in the emission spectra of this gas, while it is still at room temperature. Show your working.

Worked solution

Shortest wavelength corresponds to the largest energy transition, which is 9.3 eV.

$$\lambda = \frac{hc}{E} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{9.3} = 1.33\ \text{nm}$$

2 marks

Mark allocation

- 1 mark for correctly substituting all values into the expression for wavelength.
- 1 mark for correct answer.

Question 10

A beam of photons, with each photon of energy 9.3 eV, is now incident on a sample of this gas at room temperature. Determine the energies absorbed (in eV) or emitted (in eV) as a result of all electron transactions that will occur between energy levels as a result of this beam. Show your working clearly.

Absorption emission line(s):

Emission spectra line(s):

Worked solution

9.3 eV will be absorbed by an electron in ground state to jump to $n = 3$. This is the absorption spectral line and will be of 9.3 eV.

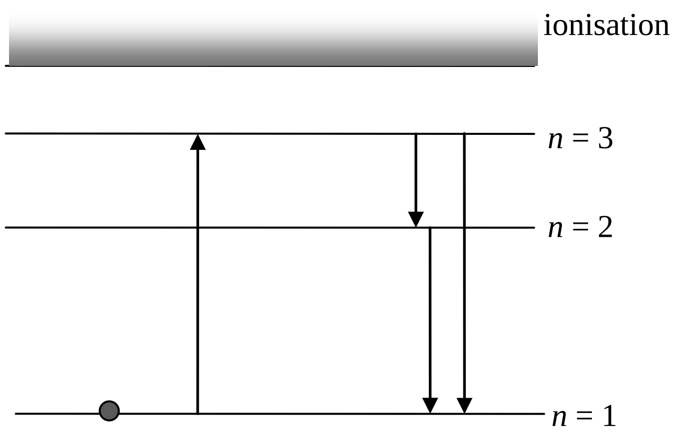
The emission spectral lines will correspond to:

$n = 3$ to $n = 2$ with $\Delta E = 0.4$ eV;

$n = 2$ to $n = 1$ with $\Delta E = 8.9$ eV; and

$n = 3$ to $n = 1$ with $\Delta E = 9.3$ eV.

The transitions are shown in the diagram below for clarification.



3 marks

Mark allocation

- 1 mark for correctly estimating absorption energy.
- 1 mark for correctly estimating at least two emission energies.
- 2 marks for correctly estimating all three.

Tips

- *Remember to check whether energy levels and transitions are in eV or J.*
- *An emission spectrum has more lines than an absorption spectrum.*

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Use the following information to answer Question 11.

X-rays have been used for decades to study crystal structure by diffraction. More recently, electrons have been used to study crystal structure as they too show diffraction.

Question 11

What is the de Broglie wavelength of electrons travelling at 8.9×10^{6} m s^{-1}? Mass of an electron is 9.1×10^{-31} kg.

Worked solution

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 8.9 \times 10^{6}} = 8.2 \times 10^{-11}\ \text{m}$$

$$\boxed{8.2 \times 10^{-11}\ \text{m}}$$

2 marks

Mark allocation

- 1 mark for substituting correctly all values into the expression for wavelength.
- 1 mark for correct answer.

Tip

- *Electrons show diffraction through crystals because their associated wavelength is about the same order of magnitude as inter-atomic distances.*

END OF SECTION A
TURN OVER

SECTION B – Detailed studies

Detailed study 1 – Synchrotron and its applications

Use the following information to answer Questions 1–3.

In an electron gun, electrons are produced and then accelerated using a high voltage source. A simplified diagram of an electron gun is given in Figure 1, showing electrons are accelerated from an initial speed of zero to 3×10^7 m s^{-1}.

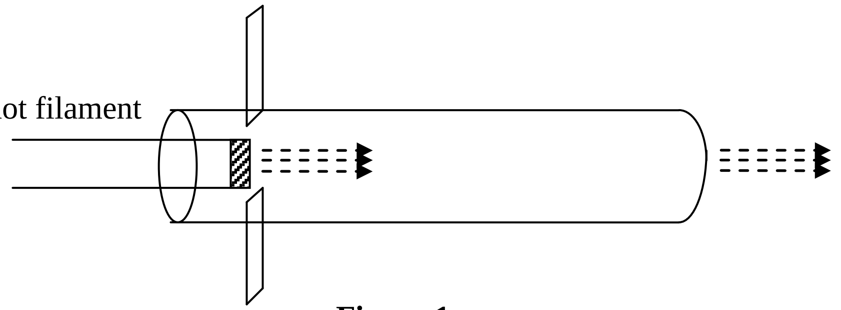


Figure 1

Question 1

Which one of the following gives the value of the accelerating voltage?

A. 1500 V

B. **2560 V**

C. 3500 V

D. 5000 V

B

Worked solution

Use conservation of energy.

$$qV = \frac{1}{2}mv^2$$

$$\therefore\ V = \frac{1}{2}mv^2 / q$$

$$= \frac{9.1\times10^{-31}\times(3\times10^7)^2}{2\times1.6\times10^{-19}} = 2559 \text{ V}$$

Question 2

Which one of the following gives the kinetic energy of an electron accelerated from rest by 500 kV?

A. 500 000 J

B. 8×10^{-16} J

C. 2.9×10^{-24} J

D. **8×10^{-14} J**

D

Worked solution

Kinetic energy gained is $qV = 1.6 \times 10^{-19} \times 500\,000 = 8 \times 10^{-14}$ J.

Question 3

What is the speed of an electron which has energy of 5 keV?

A. **4.2×10^{7} m s^{-1}**

B. 3×10^{8} m s^{-1}

C. 1.7×10^{7} m s^{-1}

D. 2.9×10^{7} m s^{-1}

A

Worked solution

At 5 keV, relativistic calculations are not needed and Newtonian calculations can be done.

$E = 5000 \times 1.6 \times 10 \text{ J} = \frac{1}{2}mv^2$

Therefore, $v = 4.2 \times 10^{7}$ m s^{-1}

Tip

- *Remember to convert eV to J when appropriate*

Use the following information to answer Questions 4–6.

In the Australian synchrotron, electrons are accelerated at speeds close to that of the speed of light.

Question 4

Where does most of the acceleration of the electron occur?

A. **linac**

B. booster ring

C. storage ring

D. wiggler

A

Worked solution

It is in the linac that most of the acceleration occurs, with electrons achieving speeds close to that of the speed of light. The insertion devices increase the intensity of light, and the booster ring increases the energy of electrons.

Question 5

The principal purpose of the insertion devices is best described as

A. to insert electrons at the right time into the storage chambers.

B. to increase the speed of electrons to be close to that of the speed of light.

C. **to increase the intensity of synchrotron light.**

D. to improve the bending of the electrons in near perfect circular paths.

C

Worked solution

Insertion devices are so called because they are inserted into the linac. They increase the intensity of the light by producing synchronised radiation by the use of wigglers and undulators.

Question 6

Diffraction is a technique used to study the crystal structure of materials. Which one of the following statements best describes the advantages of the synchrotron radiation over X-rays produced in a conventional laboratory instrument?

A. Synchrotron radiation has a high intensity and a large divergence.

B. Synchrotron radiation has a high intensity and a low divergence.

C. Synchrotron radiation has a high intensity, large divergence and cannot be tuned to select a desired wavelength for analysis.

D. **Synchrotron radiation has a high intensity, small divergence and can be tuned to select a desired wavelength for analysis.**

D

Worked solution

Its high intensity and small divergence, along with the vast range of photon energies available, make synchrotron radiation very useful.

Tip

- *Summarise the functions of all of the parts of the synchrotron.*

Use the following information to answer Questions 7–10.

An electron moving with a constant speed enters a magnetic field of 79 mT at right angles to the field, as shown in Figure 2.

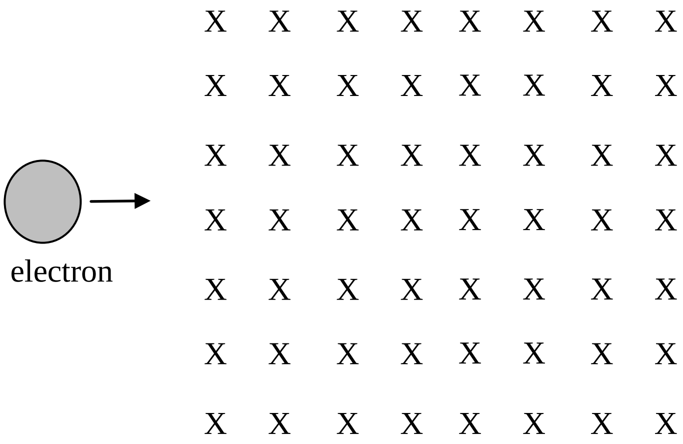


Figure 2

Question 7

Which one of the following best describes the direction in which the electron will move as it enters the magnetic field?

A. It will move up.

B. **It will move down.**

C. It will take a circular path and return back.

D. Its direction will be unchanged but its speed will increase.

B

Worked solution

Use the right-hand rule to determine direction on a positive charge travelling into the field. Then reverse the direction because the charged particle is negative.

Question 8

Which one of the following lists the physical quantities that will change as the electron enters the magnetic field?

A. energy, velocity and momentum

B. **velocity and momentum**

C. velocity only

D. energy and momentum

B

Worked solution

Since there is a change in direction, vector quantities such as velocity and momentum will also change. There is no change in the magnitude of these quantities.

Question 9

The force experienced by an electron as it enters the magnetic field is 0.8×10^{-12} N. The speed of the electron is closest to

A. **6.3×10^{7} m s^{-1}**

B. 1.0×10^{5} m s^{-1}

C. 3×10^{8} m s^{-1}

D. 5.0×10^{7} m s^{-1}

A

Worked solution

Use $F = Bqv$

$$\therefore\ v = \frac{F}{Bq} = \frac{0.8 \times 10^{-12}}{79 \times 10^{-3} \times 1.6 \times 10^{-19}}$$

$$= 6.33 \times 10^{7} \text{ m s}^{-1}$$

Question 10

An electron enters the magnetic field at right angles and moves in a radius of 7.5 m. Which one of the following is the closest in magnitude to the momentum of the electron?

A. 9.5×10^{-20} kg m s^{-1}

B. 6.0×10^{-16} kg m s^{-1}

C. 1.3×10^{-20} kg m s^{-1}

D. **9.5×10^{-20} kg m s^{-1}**

D

Worked solution

Use $p = Bqr$

$$= 79 \times 10^{-3} \times 1.6 \times 10^{-19} \times 7.5$$

$$= 9.5 \times 10^{-20} \text{ kg m s}^{-1}$$

Tips

- *Remember to modify the right-hand rule for a negative charge entering a magnetic field.*
- *Vector quantities may change due to the change in direction, not magnitude.*

SECTION B – Detailed study 1 – continued
TURN OVER

Use the following information to answer Questions 11–13.

Bragg diffraction uses X-rays to diffract from planes of crystalline materials in accordance with Bragg's law: $d \sin \theta = n\lambda$. The angle, θ, of the detector is systematically increased and the intensity of diffracted X-rays is recorded.

Question 11

In Figure 3, an X-ray diffraction trace for a crystalline material is shown. The peak corresponds to $n = 1$ reflection. The wavelength used is 40×10^{-10} m.

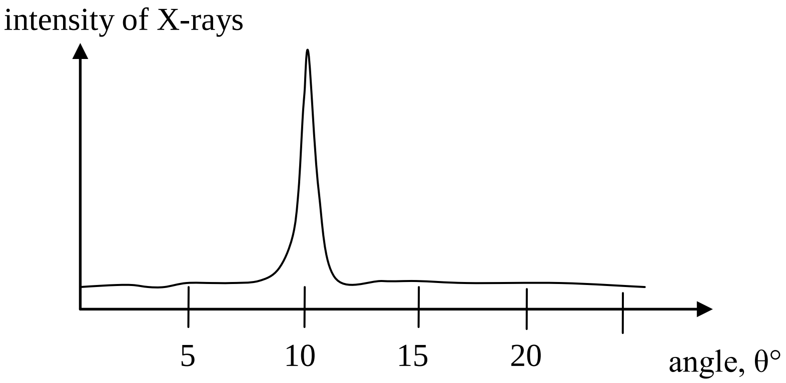


Figure 3

The inter-atomic distance of the crystalline material is closest to

A. 2.4×10^{-8} m

B. 3.2×10^{-10} m

C. **1.2×10^{-8} m**

D. 3.1×10^{-8} m

C

Worked solution

Use $d = \dfrac{n\lambda}{2\sin\theta}$

$$= \frac{1 \times 40 \times 10^{-10}}{2\sin 10^{\circ}} = 1.15 \times 10^{-8} \text{ m}$$

Question 12

Using an X-ray monochromatic beam of wavelength 40×10^{-10} m in another crystalline material of inter-atomic distance 6.0×10^{-9} m, which one of the following is the location of the second maxima, $n = 2$?

A. **41.8°**

B. 25.2°

C. 20.9°

D. 15.2°

$\boxed{\text{A}}$

Worked solution

Use $\sin\theta = \dfrac{n\lambda}{2d}$

$$= \frac{1 \times 40 \times 10^{-10}}{2 \times 6 \times 10^{-9}} = 0.6667$$

$\therefore\ \theta = 41.8°$

Question 13

A crystalline material has the first maxima peak at 10°. If this sample is replaced with one of greater inter-atomic distance, which one of the following best describes the new pattern for the first maxima peak, $n = 1$?

A. The peak will stay at the same angle but will have reduced intensity.

B. The peak will move to a higher angle.

C. **The peak will move to a lower angle.**

D. The peak will stay at the same angle but will have increased intensity.

$\boxed{\text{C}}$

Worked solution

Since $d \propto \dfrac{1}{\sin\theta}$, as the inter-atomic distance increases, the peak will move to a lower angle.

Tips

- *Remember to use degrees mode in your calculator, not radians.*
- *Bragg's law gives intensity for constructive interference.*

END OF DETAILED STUDY 1
TURN OVER

Detailed Study 2 – Sound

Use the following information to answer Questions 1–5.

A sound frequency generator broadcasts a single frequency note of 500 Hz through a loudspeaker in an open field. The speed of sound under these conditions is 348 m s^{-1}. The sound wave is detected by two students, Andy and Jill, who are 15.0 m and 21.0 m away, respectively. Assume that there is no loss of energy as the sound wave travels from the loudspeaker to the two students.

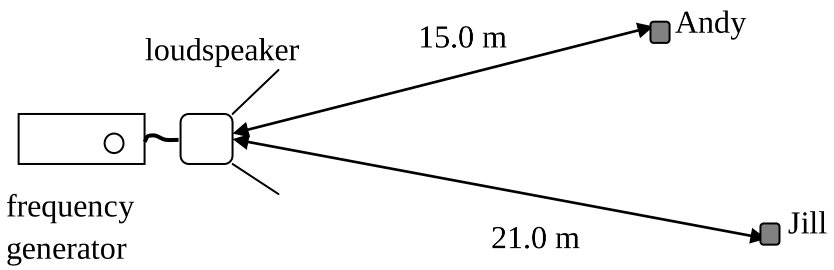


Figure 1

Question 1

Which one of the following is the wavelength of sound in air under the given conditions?

A. **0.7 m**

B. 0.35 m

C. 700 m

D. 1.7×10^5 m

A

Worked solution

Wavelength, $\lambda = \frac{v}{f} = \frac{348}{500} = 0.7$ m

Question 2

Andy measures the sound intensity level as 70 dB. Which one of the following is the intensity of the sound wave at his location?

A. 10^{-8} Wm^{-2}

B. 10^{-7} Wm^{-2}

C. **10^{-5} Wm^{-2}**

D. 10^{-2} Wm^{-2}

C

Worked solution

Since $L = 10\log\frac{I}{I_0}$

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

$$I = 10^{-5}\ \text{Wm}^{-2}$$

Question 3

Andy measures the sound intensity level as 70 dB. Which of the following is the best estimate of the sound intensity level that Jill will receive?

A. 70 dB

B. **67 dB**

C. 65 dB

D. 60 dB

B

Worked solution

Use the inverse square law.

$$I_1 r_1^2 = I_2 r_2^2$$

$$10^{-5} \times (15)^2 = I_2 \times (21)^2$$

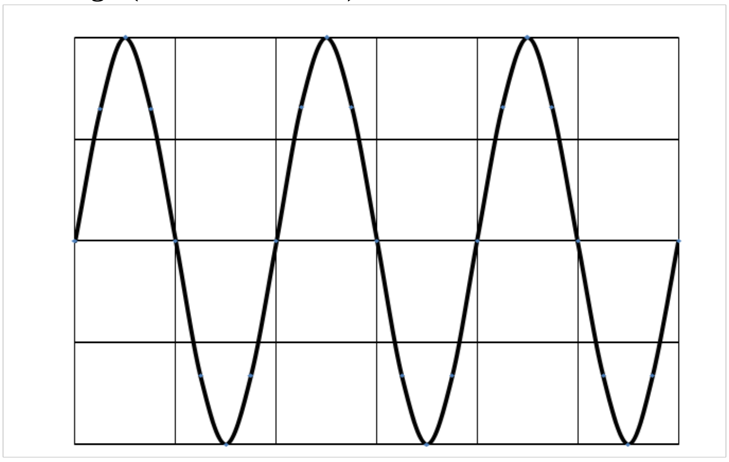
$$I_2 = 0.51 \times 10^{-5}\ \text{Wm}^{-2}$$

Since $L = 10\log\frac{I}{I_0}$

$$= 10\log\frac{0.51\times10^{-5}}{10^{-12}} = 67\ \text{dB}$$

The frequency generator is now set to another frequency and Andy measures the waveform of the sound wave form using a microphone and a cathode ray oscilloscope (CRO). He obtains a trace, given in Figure 2, showing voltage on the vertical scale and time on the horizontal scale

voltage (1 division = 1 V)



time (1 division = 0.2 m s^{-1})

Figure 2

Question 4

What is the frequency of the sound wave being emitted now?

A. **2500 Hz**

B. 1250 Hz

C. 5000 Hz

D. 2.5 Hz

A

Worked solution

Frequency, $f = \dfrac{1}{T} = \dfrac{1}{0.4 \times 10^{-3}} = 2500$ Hz

Question 5

The pressure variation of the sound wave observed is represented in Figure 3 at a certain time t_0 and it is moving to the right. Under the trace are shown four other possible waves, A, B, C and D. Which one of the traces, A, B, C or D, shows the variation of air pressure with time at a moment $\frac{t}{4}$ later, where t is the time period?

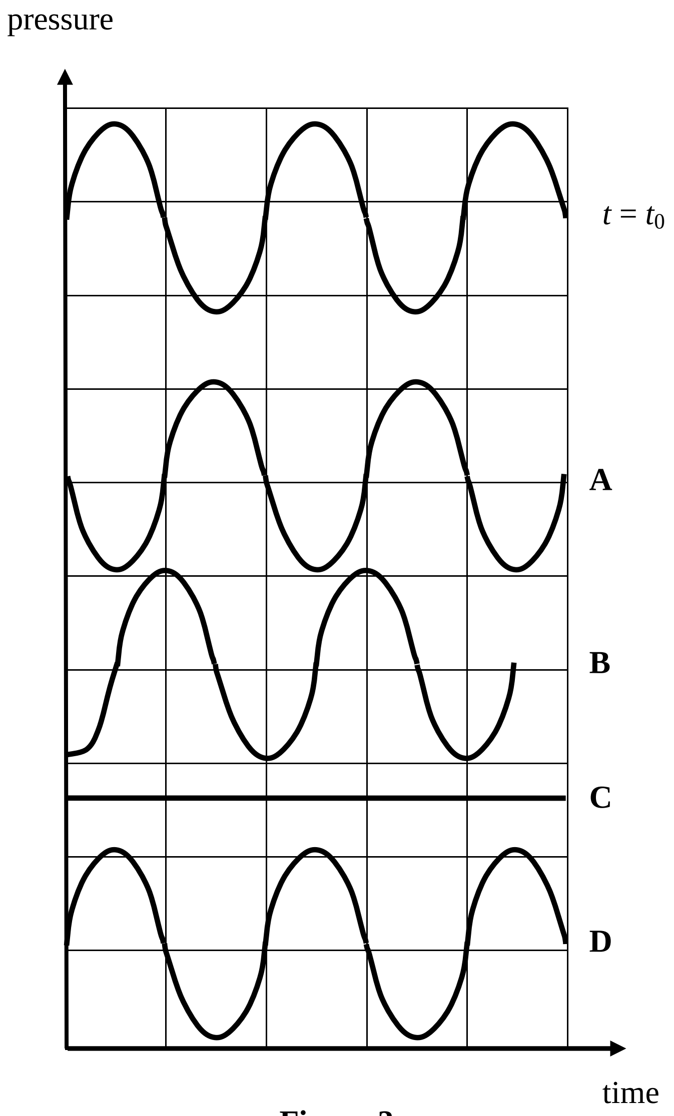


Figure 3

B

Worked solution

A crest would move one-quarter of a wavelength distance to the right.

Tip

- *Distinguish between travelling and standing wave; and between motion of medium versus movement of energy in transverse and longitudinal waves.*

Use the following information to answer Questions 6 and 7.

The response of Tina to sound is described in Figure 4.

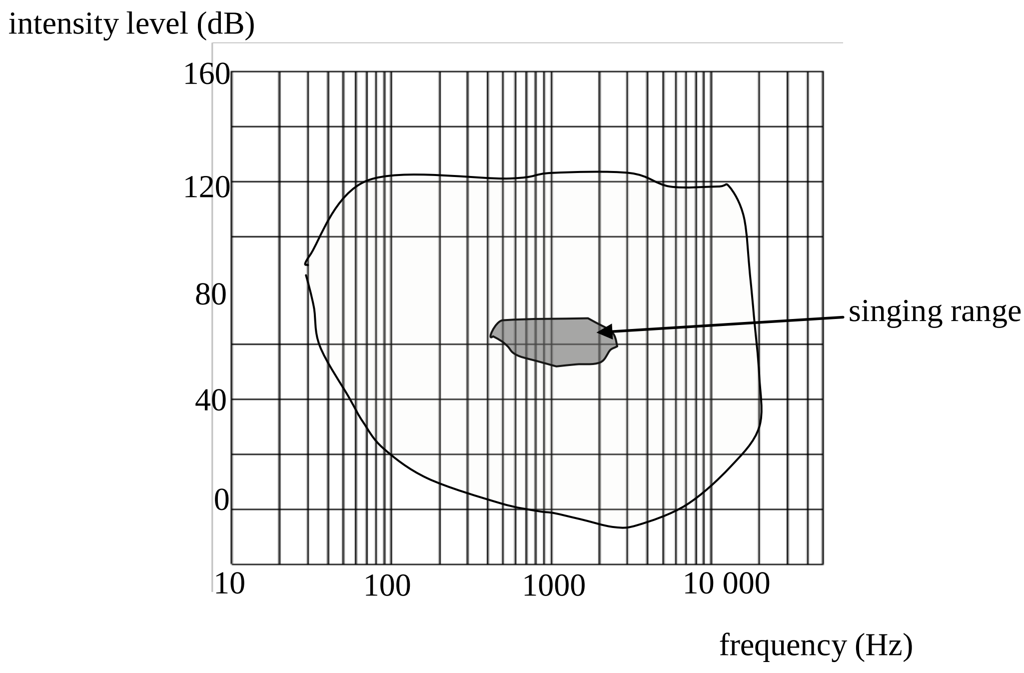


Figure 4

Question 6

The intensity at which Tina would *just* be able to hear at 100 Hz is closest in value to

A. 10^{-7} Wm^{-2}

B. 10^{-8} Wm^{-2}

C. 10^{-9} Wm^{-2}

D. $\mathbf{10^{-10}}$ **Wm^{-2}**

D

Worked solution

From the graph, at 100 Hz, the weakest sound intensity level that Tina can hear is 20 dB. Converting it to intensity values gives

$$L = 10\log\frac{I}{I_0}$$

$$\therefore\ 20 = 10\log\frac{I}{10^{-12}}$$

$$I = 10^{-10}\ \text{Wm}^{-2}$$

Question 7

Tina is interested in recording one of her songs. During an experiment,it is established that her vocal frequencies range from 500 Hz to 3200 Hz. Her recording manager suggests that, for best high-fidelity sound, a combination of two microphones should be used for recording. He argues that amplifiers could be used to bring the intensity of each microphone to the appropriate levels.
The response graphs of four microphones are shown in Figure 5. Which two of the four microphones shown below would be most suitable to record the highest fidelity sound for Tina?

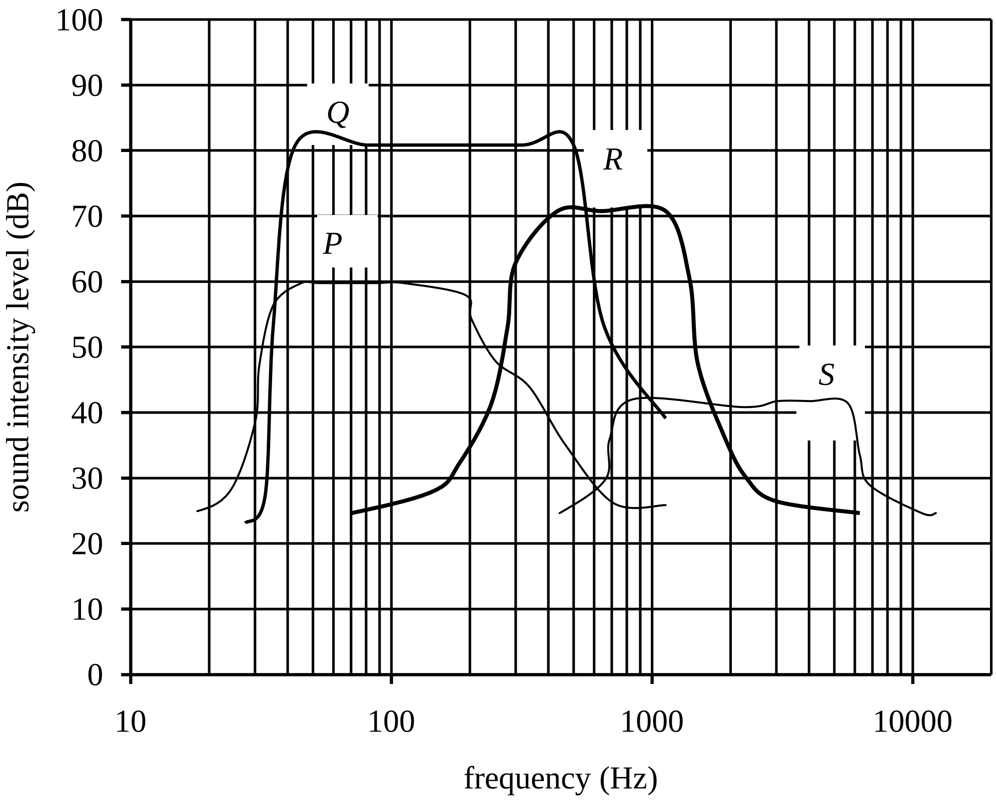


Figure 5

A. *P* and *Q*

B. ***R* and *S***

C. *Q* and *R*

D. *P* and *R*

B

Worked solution

R and *S* have linear regions in the desired frequency range. Hence, correct answer is B.

Tips

- *Remember that the loudness scale is based on an average human having a threshold of hearing as 10^{-12} Wm^{-2} at 1000 Hz.*
- *High-fidelity (hi-fi) sound is achieved with loudspeakers that have linear response and not necessarily loudest sound.*

Use the following information to answer Questions 8 and 9.

The speed of sound can be found using tuning forks and an air column created by water in a tube, as shown in Figure 6. At a certain depth of water, the tuning fork can set up a loud resonating sound in the air column above the water. The total length of the tube is 1.0 m.

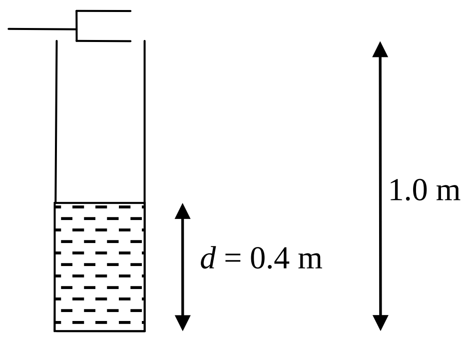


Figure 6

Question 8

Various tuning forks were tried and it was observed that the loudest sound heard is when a tuning fork of 145 Hz is used. At this time, the water in the tube has depth d = 0.4 m. Which of the following is the best estimate for the speed of sound in air under the given conditions?

A. 340 m s^{-1}

B. 345 m s^{-1}

C. **348 m s^{-1}**

D. 351 m s^{-1}

C

Worked solution

The fundamental frequency for an air column closed at one end is

$$f_0 = \frac{v}{4L}$$

$$\therefore\ v = 145 \times 4 \times 0.6 = 348 \text{ m s}^{-1}$$

Question 9

Tuning forks of higher frequencies are next used to find more resonance frequencies at the same depth of water. Which one of the following is most likely to be the next resonant frequency?

A. 290 Hz

B. 350 Hz

C. 362 Hz

D. **435 Hz**

D

Worked solution

Only odd harmonics are possible in a pipe closed at one end. Hence, the next resonant frequency will be $3 \times f_0 = 3 \times 145 = 435$ Hz.

Tips

- *Remember to check whether the pipe in question is open at both ends or closed at one end.*
- *The loudest frequency heard is the fundamental, unless the fundamental has not been sounded.*

Use the following information to answer Questions 10 and 11.

A pipe hangs horizontally from the side of a house and is open at both ends, as shown in Figure 7. Air moves along the inside of the pipe from left to right. In windy weather, the pipe resonates at a certain frequency.

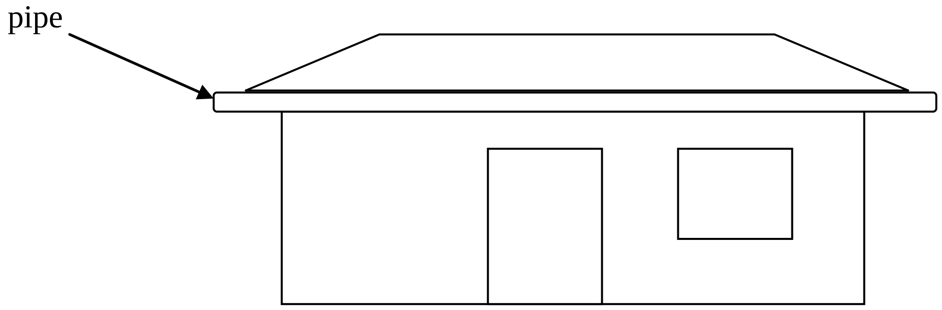


Figure 7

Question 10

Which of the following is the **best** explanation for resonance in this pipe?

A. Standing waves are formed in the air column inside the pipe and the resonant frequency is dependent only on the dimensions of the pipe.

B. The frequency of the sound waves in air equals the natural frequency of the material causing resonance.

C. **Standing waves are formed in the air column inside the pipe at a resonating frequency that is dependent only on the dimensions of the pipe and the speed of sound in the air column.**

D. Constructive and destructive interference patterns in the air column set up a musical note.

C

Worked solution

Option C gives the most detailed explanation of the choices available. The resonating frequency is dependent only on the speed of sound, *v*, and length of pipe, *L*.

Question 11

For the pipe of length 2.2 m, which of the following is closest to the fundamental frequency of the standing wave that would be set up in the pipe? Take the speed of sound to be 350 m s^{-1} inside the pipe.

A. 40 Hz

B. 160 Hz

C. 350 Hz

D. **80 Hz**

D

Worked solution

For a pipe open at both ends, the fundamental frequency is given as

$$f_0 = \frac{v}{2L} = \frac{350}{2 \times 2.2} = 79.5 \text{ Hz}$$

Tip

- *Remember that resonance is a phenomenon based on standing waves.*

.

Question 12

Listed below are four statements about different types of microphones.

Which one of the statements best describes the operation of a crystal microphone?

A. **This type of microphone is based on a piezoelectric material producing a current in response to changes in pressure.**

B. This type of microphone has a capacitor where changes in pressure produce a change in potential difference.

C. Changes in pressure produce movement in a coil mounted over a permanent magnet.

D. Pressure variations cause a thin ribbon of aluminium to oscillate in a magnetic field.

A

Worked solution

A crystal microphone is based on a piezoelectric material's response to sound pressure waves. Hence, correct answer is A.

Question 13

Gemma and Jonah stand outside an exit door to a hall from which a range of frequencies are being produced as part of a concert. Although both are the same distance from the door, Gemma is directly in front of the door and Jonah is to the side. The sounds from the concert are heard by both Gemma and Jonah, but the frequencies seem to be different.

Which of the following statements is the best description of the frequencies heard by Gemma and Jonah?

A. Gemma will receive more of the lower frequencies than the higher frequencies.

B. Jonah and Gemma will both receive the same sound.

C. The intensity of sound received by Jonah will be less but there will be no enhanced frequency.

D. **Jonah will receive more of the lower frequencies than the higher frequencies.**

$\boxed{\text{D}}$

Worked solution

Extent of diffraction is dependent on the wavelength; hence, the lower frequency sounds diffract more and the higher frequencies diffract less. Jonah will receive more of the lower frequencies because they diffract more.

Tip

- *Remember: If low frequency sounds diffract more, then high frequency sounds diffract less and are more directional.*

END OF DETAILED STUDY 2
TURN OVER

Detailed Study 3 – Photonics

Use the following information to answer Questions 1–3.

A red-hot piece of iron, a burning candle, the Sun and an incandescent lamp each give a *continuous* spectrum. The spectra of wavelengths in the visible region produced by these four different light sources are shown in Figure 1. The relative intensities of the spectra are not drawn to scale.

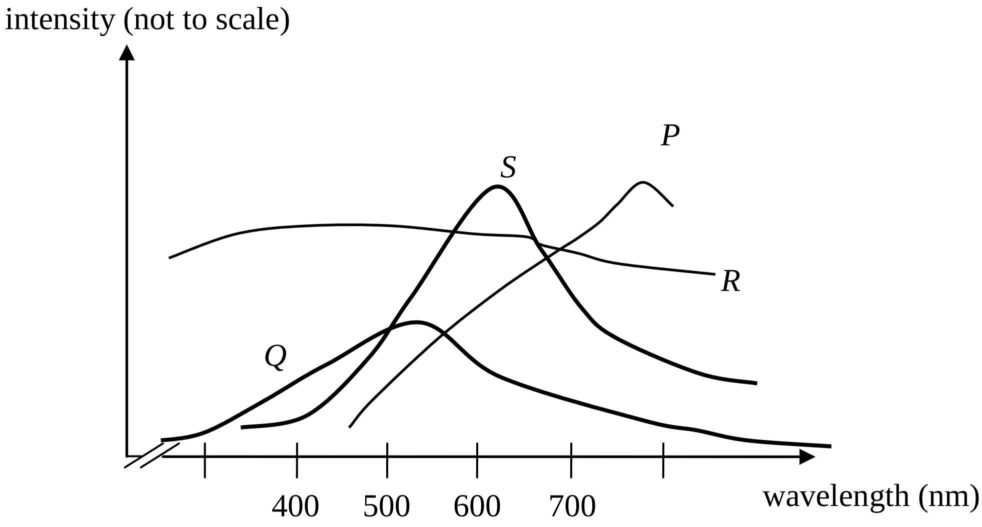


Figure 1

Question 1

Which one of the following statements is the best assignment of light sources to the spectra shown in Figure 1?

A. **Spectrum *P* is by a burning candle, *Q* by an incandescent light bulb, *R* by the Sun and *S* by the red-hot iron.**

B. Spectrum *Q* is by a burning candle, *P* by an incandescent light bulb, *R* by the Sun and *S* by the red-hot iron.

C. Spectrum *R* is by a burning candle, *P* by an incandescent light bulb, *Q* by the Sun and *S* by the red-hot iron.

D. Spectrum *S* is by a burning candle, *P* by an incandescent light bulb, *Q* by the Sun and *R* by the red-hot iron.

A

Worked solution

An incandescent light bulb and the Sun each give a continuous spectrum, but the former has more of the blue whereas the Sun has a much more even spread of intensities across wavelengths. The burning candle has a broad spectrum centred around yellow, whereas that of the red-hot iron is around the red wavelengths. Hence, best answer is A.

Question 2

Which one of the following statements best describes the mechanism by which light is produced in an incandescent lamp?

A. collision of electrons

B. acceleration and deceleration of atoms

C. collisions of atoms

D. **acceleration and deceleration of charged particles**

D

Worked solution

Electromagnetic radiation is produced by the acceleration and deceleration of charged particles. Hence, best answer is D.

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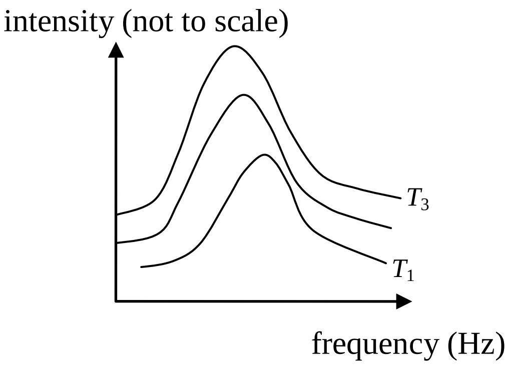
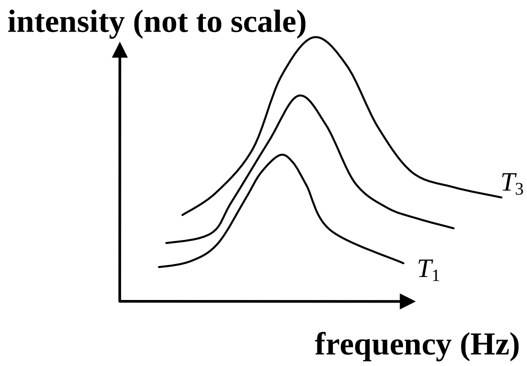
Question 3

As a ball of iron is heated to higher temperatures from an initial temperature of T_1 to a higher temperature of T_3, which one of the graphs in Figure 2 best illustrates the spectra as a function of frequency of light emitted?

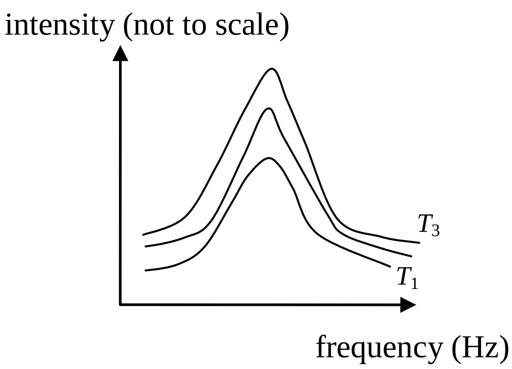
A.



B.



C.



D.

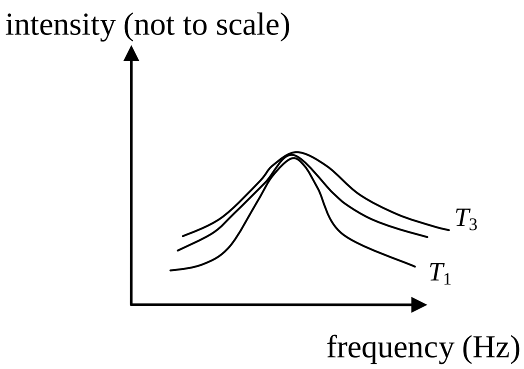


Figure 2

B

Worked solution

With increasing temperature, both intensity and frequency will increase. Hence, best answer is B.

Tips

- *Summarise clearly what mechanism gives the emission spectrum for various light sources.*
- *Remember that red has a higher wavelength than yellow, and yellow has a higher wavelength than blue.*

Use the following information to answer Questions 4 and 5.

The spectra of two different LED light sources are studied by assembling the circuit shown below (Figure 3). The circuit consists of a variable DC power supply, a resistor and the test LED. Each LED's spectrum is measured as the voltage is increased.

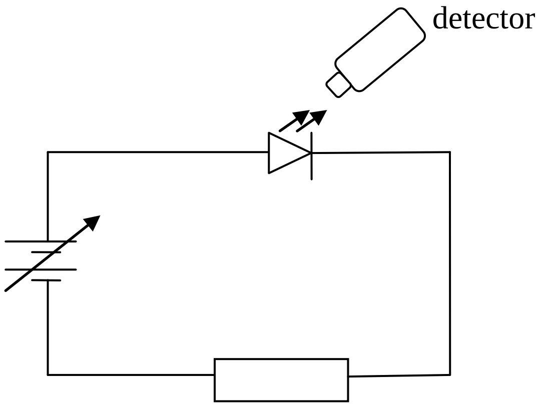


Figure 3

Question 4

The intensity of the spectrum with increasing voltage for a certain LED is shown in Figure 4.

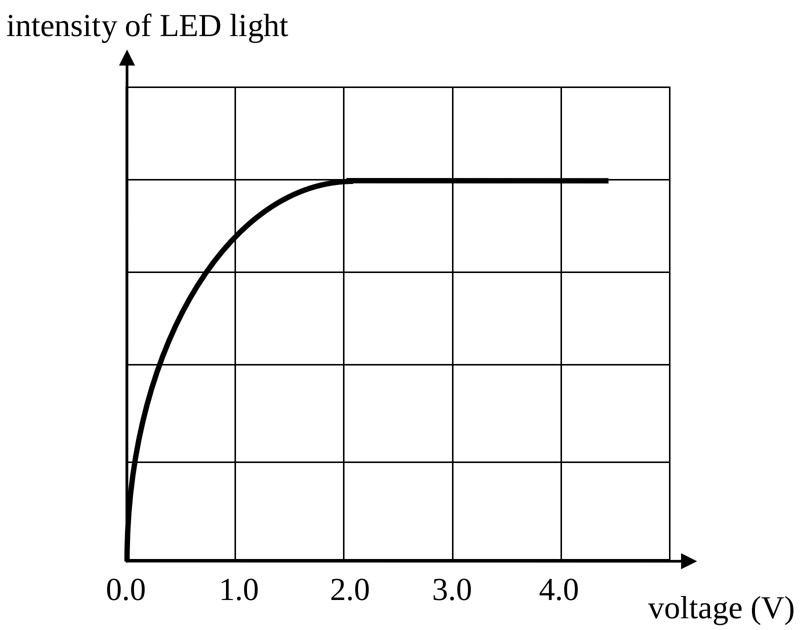


Figure 4

What is the wavelength of the characteristic colour of the LED when it is fully lit?

A. 430 nm

B. 510 nm

C. **620 nm**

D. 750 nm

C

Worked solution

Wavelength, $\lambda = \dfrac{hc}{E_g} = \dfrac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{2.0} = 621\,\text{nm}$

Hence, correct answer is C.

Question 5

The band gap of the material in the LED that emits a wavelength of 510 nm when fully lit is closest to

A. 1.1 eV

B. 3.2 eV

C. **2.4 eV**

D. 4.2 eV

C

Worked solution

Band gap, $E_g = \dfrac{hc}{\lambda} = \dfrac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{510 \times 10^{-9}} = 2.44\text{ eV}$

The band gap could also be read from the graph if the graph had more detail.

Tip

- *Remember to use the correct value for Planck's constant when energy is given in eV.*

Use the following information to answer Questions 6–8.

A laser emits a wavelength of 600 nm and is shone on a fibre optic cable, as shown in Figure 5. The path of the light beam from the source to the core and subsequent reflection at the cladding is also shown. The refractive index of the core is 1.48 and that of the cladding is 1.51.

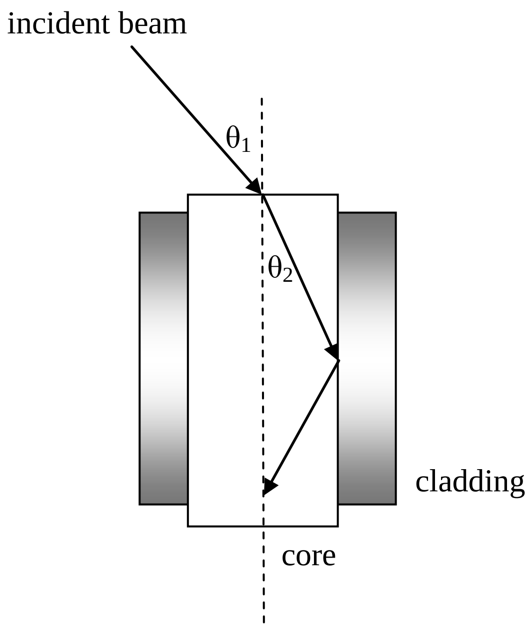


Figure 5

Question 6

When $\theta_1 = 7.50°$, the best value for θ_2 is

A. **5.06°**

B. 4.95°

C. 4.50°

D. 5.15°

A

Worked solution

Using Snell's law, $n = \dfrac{\sin i}{\sin r}$.

Therefore, angle $r = \sin^{-1}\dfrac{\sin 7.5}{1.48} = 5.06°$

Question 7

The best value for the acceptance angle for this cable is about

A. 21°

B. **17°**

C. 14°

D. 10°

B

Worked solution

Acceptance angle, $A_c = \sin^{-1}\sqrt{1.51^2 - 1.48^2} = 17.1°$

Question 8

As the beam travels from the core to the cladding, it reflects. The critical angle from the core to the cladding is closest to

A. 43.68°

B. 51.05°

C. 68.92°

D. **78.56°**

D

Worked solution

Critical angle = $\sin^{-1}\dfrac{1.48}{1.51} = 78.56°$

Tips

- *Since there are subtle differences in the magnitude of refractive fibre optic material properties, such as refractive index and angles, care must be taken when rounding off numbers.*
- *Ensure you understand the differences between acceptance angle, critical angle and incident angle.*

Use the following information to answer Questions 9 and 10.

A single-mode fibre sends data over 10 km. Its transmission characteristic graph is shown (Figure 6).

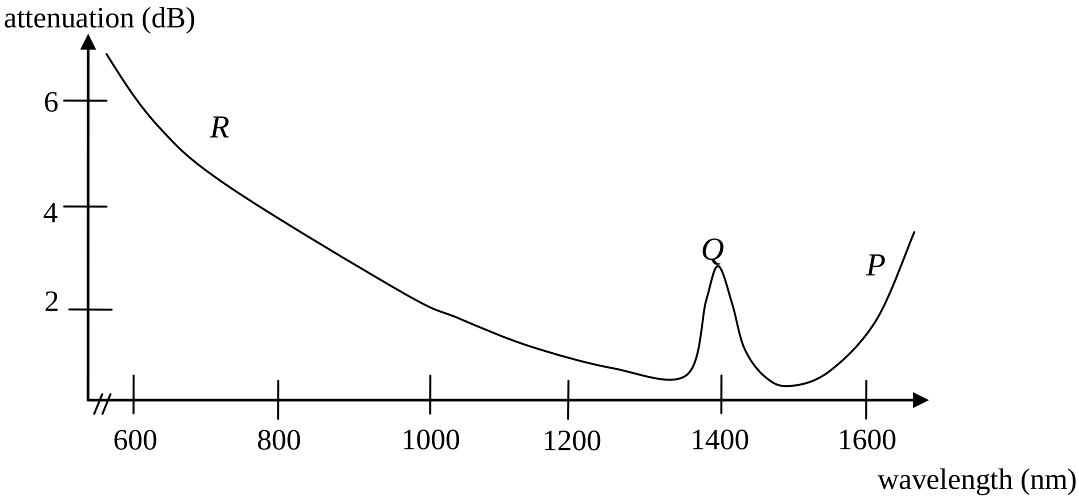


Figure 6

Question 9

The principal cause of attenuation at position *P* is due to

A. Rayleigh scattering.

B. modal dispersion.

C. **absorption by glass.**

D. absorption by OH^-.

C

Worked solution

At high wavelengths, the silica structure of glass absorbs light and causes a broad absorption region. The OH^- ion absorbs strongly around 1400 nm. By contrast, Rayleigh scattering is the scattering at low wavelengths due to the variation in refractive index of the glass.

Question 10

Two lasers are being considered for communication. Laser L_1 has a wavelength of 600 nm and laser L_2 has a wavelength of 1600 nm. Which one of the following statements best describes the attenuation properties of the two fibre optic cable with the lasers?

A. Laser L_1 will have lower attenuation than laser L_2, since laser L_2 has significant losses primarily due to Rayleigh scattering.

B. Laser L_1 will have higher attenuation than laser L_2, since laser L_1 has significant losses primarily due to Rayleigh scattering.

C. Laser L_1 will have higher attenuation than laser L_2 due to both Rayleigh scattering and absorption.

D. Lasers L_1 and L_2 will have about the same attenuation because a very narrow range of wavelengths is used in a laser beam.

B

Worked solution

Rayleigh scattering and absorption will occur in lasers as well; hence, D is incorrect. Inspection of the graph reveals that laser L_1 has a wavelength that results in Rayleigh scattering and the attenuation is much higher than that for L_2.

Tips

- *Pay attention to the details in such questions, such as what kind of fibre is being used.*
- *Remember that Rayleigh scattering is broad whereas absorption by a particular ion will be over a short and specific range of wavelengths.*

Use the following information to answer Questions 11–13.

Shaun and Rishi wish to set up a fibre optic cable over a distance of about 200 km so that they can send large amounts of data across in the most efficient manner. They are having a discussion about which type of cable to use and make a number of statements.

Question 11

Which one of the following statements would lead to the correct choice of fibre optic cable over a long distance?

A. Graded index multimode fibre can carry multiple modes with minimum material dispersion over long distances.

B. Multimode fibres can carry a lot of signal and are very common.

C. **Single-mode fibres have low modal dispersion and can carry large amounts of data using multiplexing.**

D. Multimode fibres have no modal or material dispersion and hence are the preferred choice over long distances.

C

Worked solution

Single-mode fibres are the preferred choice over long distances as they have the lowest attenuation. With time sharing (multiplexing) they can carry large amounts of information. Even with graded index fibres, the attenuation in multimode fibres is significant over long distances, hence restricting their use to local networking and short distances.

Question 12

When an input signal of 25 mW is sent through a 1 km section of the fibre, only 22 mW is received at the receiving end. The attenuation of the signal is closest in magnitude to

A. 3.0 dB

B. 2.5 dB

C. 1.5 dB

D. **0.5 dB**

D

Worked solution

The attenuation of the signal is

$$= -10\log\frac{P_{\text{output}}}{P_{\text{input}}} = -10\log\frac{22\times10^{-3}}{25\times10^{-3}} = 0.56\text{ dB}$$

Question 13

A new fibre optic cable has an attenuation of 0.11 dB per km. During testing of this new fibre optic wire, a signal of 10 mW is received at the end of a 1.50 km sample. The power of the input signal is closest to

A. **14.6 mW**

B. 12.9 mW

C. 11.8 mW

D. 10 mW

A

Worked solution

Attenuation $= -10\log\frac{P_{\text{output}}}{P_{\text{input}}}$.

Therefore, $0.11 \times 1.5 = -10\log\frac{10}{P_{\text{input}}}$ and $P_{\text{input}} = 14.6\,\text{mW}$.

Tips

- *Read carefully whether attenuation is being given in dB or dB/km.*
- *Summarise the principal mechanism for attenuation in each type of fibre.*

END OF SOLUTIONS BOOK