Insight Publications

INSIGHT

Trial Exam Paper

2006

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

Questions 1 to 3 refer to the following information.

As part of a Year 12 Physics experiment the following apparatus (Figure 1), consisting of two coils, a 6 V battery, a switch S, and a 200 Ω resistor is assembled.

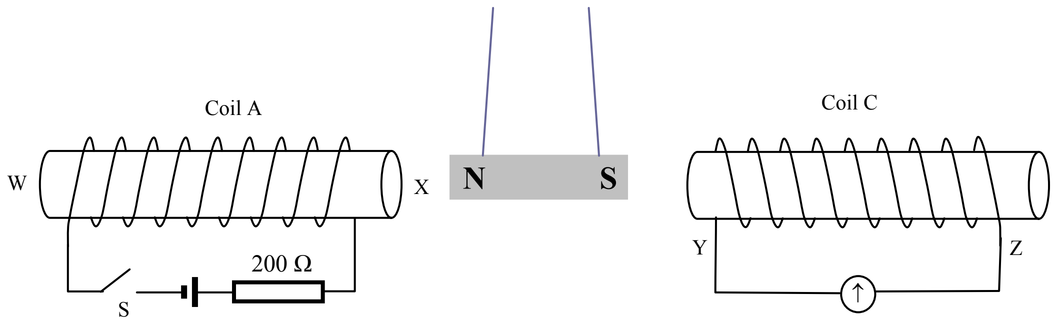


Figure 1

Coil A has a soft iron core inside of it. Nearby, coil C is wound around a thin plastic tube and has a sensitive galvanometer attached to it. Between the two coils a bar magnet is suspended as shown.

Question 1

When the switch S is first closed the magnetic field inside coil A

A. is non-existent because the current is not AC.
B. is in the direction from W to X.
C. is in the direction from X to W.
D. remains unchanged.

B

2 marks

Answer is B

Worked solution

Until the switch is closed there is no magnetic field inside coil A due to the wire.

There is a magnetic field due to the proximity of the bar magnet in the direction of X to W.

Coil A will not produce an opposing field for two reasons. Firstly: the circuit is not complete so no current can flow, and no magnetic field due to current in the coil will be produced. Secondly: assume the circuit were closed, and that the coil could therefore conduct. Even if this were the case, a current would be induced in the coil only when the magnetic field inside it changed.

Question 2

Explain what effect closing switch S would have on the suspended bar magnet and coil C.

Answer

- The current flowing through coil A makes it act like an electromagnet with its north pole at X and its south pole at W.
- This results in the bar magnet being repelled from end X of coil A, towards coil C.
- As the bar magnet moves toward coil C it will increase the size of the magnetic field inside coil C.
- Coil C will try to oppose the increase in flux through it and induce a current to produce an opposing flux.
- The current will flow through the galvanometer in the direction from Z to Y (right to left).

3 marks

Mark allocation

- 1 mark for stating that the bar magnet will be repelled
- 1 mark for stating the increase of the magnetic field
- 1 mark for stating that coil C will try to oppose the increase in flux.
- Drawing on the diagram is also acceptable to show the direction of the current described in the third dot point.

Question 3

When switch S is closed the needle of the galvanometer attached to coil C will

A. move right.

B. move left.

C. move right then return to the neutral position.

D. move left then return to the neutral position.

E. not move.

D

2 marks

Answer is D

Worked solution

Coil C will only induce a magnetic field while the field inside it is changing. As soon as the bar magnet stops moving, the induced magnetic field will cease. Thus the galvanometer will only register a current for a short duration.

Tip

- *The right-hand grip rule is used to determine the direction of the induced current. You must always pay attention to the direction the coil is wound. In this case the magnetic field is getting stronger in the direction from Z to Y, therefore the induced current must produce a magnetic field in the direction from Y to Z. To do this, the current must travel down the exposed turns of the coil, thus travelling through the galvanometer in the direction from Z to Y (right to left).*

Question 4

Sally and Ben are discussing the construction of a DC motor. Sally claims that they need to use a commutator, but Ben thinks that slip rings are the correct component to use. Who is correct and why?

Answer

- Sally is correct.
- For each half cycle (or rotation) of the coil, the current through the coil must change direction to keep the coil rotating in the same direction.
- DC current never changes direction by itself, so the commutator changes the direction of the current by changing which side of the coil is positive every 180^o.

3 marks

Mark allocation

- 1 mark for stating that Penny is correct
- 1 mark for the change in direction of the current
- 1 mark for the commutator changing direction every 180^o

Tip

- *Slip rings cannot change which side of the coil they are attached to and so can only work if the supply voltage is changing (i.e. if the current is AC).*

Question 5

Sally decides to build her design as shown below in Figure 2. Describe what happens when she closes the switch. Justify your answer.

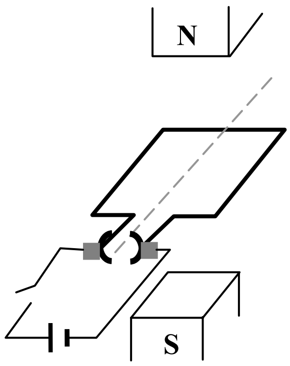
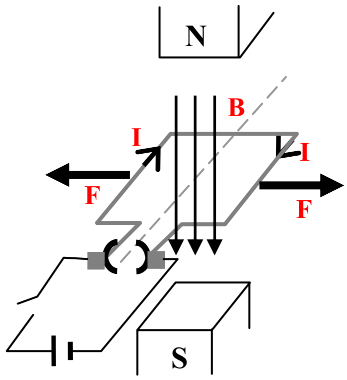


Figure 2

Answer

- Nothing happens. The loop remains stationary.
- The force (**F**) generated according to the right-hand slap rule will be out to the sides of the loop.
- These forces will not provide any torque (turning force) about the axis of rotation.



3 marks

Mark allocation

- 1 mark per line

Ishmael's train set is constructed on a large table in the centre of the room. His train set uses a transformer to convert the mains AC supply from 240 V RMS to 12 V RMS. Ishmael is tired of tripping over the extension lead running from the wall socket to the transformer so he decides to connect the transformer to the wall socket and run two long wires up the wall and across the roof to his train set. The wires are each 5 metres long and have a resistance of 0.001 Ω per metre.

Question 6

The primary coil of the transformer has 1800 turns. How many turns must the secondary coil possess in order to convert from 240 V RMS to 12 V RMS?

Worked solution

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow \frac{240}{12} = \frac{1800}{N_2} \quad \Rightarrow N_2 = \frac{1800 \times 12}{240} = 90 \text{ turns}$$

90 turns

2 marks

Mark allocation

- 1 mark for correct substitution into formula
- 1 mark for correct answer

Question 7

Ishmael finds that his trains are not moving as quickly as before. A possible reason for this is that

A. the transformer is connected with the secondary coil attached to the mains supply.
B. Ishmael has fewer trains than normal on the track at one time.
C. the wires connecting the transformer to the train set are too short.
D. the wires connecting the transformer to the train set are too long.

D

2 marks

Answer is D

Worked solution

The trains are receiving less power than before due to power losses in the lines. The low voltage out of the transformer means the wires are carrying high current. Since $P_{loss} = I^2R$, the longer the wires the greater the resistance, so the greater the power loss. This would not be as noticeable when only a short length of wire is used between the transformer and the train set.

Question 8

Ishmael measures the current out of the secondary coil of the transformer as being 100 A RMS. What is the power of the transformer?

Worked solution

P = VI = 12 × 100 = 1200 W

Or $\frac{N_1}{N_2} = \frac{I_2}{I_1} = 20 \quad \Rightarrow I_1 = \frac{I_2}{20} = \frac{100}{20} = 5\text{A} \Rightarrow \text{P} = \text{VI} = 240 \times 5 = 1200\text{ W}$

1 200 W

2 marks

Mark allocation

- 2 marks for the correct answer

Question 9

Find the peak voltage across the secondary coil of the transformer at this time.

Worked solution

$V_p = \sqrt{2}\ V_{rms} = \sqrt{2} \times 12 = 16.97 = 17\ \text{V}$

V_{rms} = 12 V from original information

17 V

2 marks

Mark allocation

- 2 marks for the correct answer

Question 10

How much power is being lost in the wires?

Worked solution

$P_{loss} = I^2 R_{line}$

$R_{line} = 2 \times 5 \times 0.001 = 0.01\ \Omega$

$P_{loss} = 100^2 \times 0.01 = 100\ \text{W}$

100 W

3 marks

Mark allocation

- 3 marks for correct answer
- 2 marks if only 5 m of wire used (ie P_{loss} is calculated as being 50 W).

Tip

- *Make sure you read the question carefully to check whether the resistance is quoted as a figure per metre, or as one figure for the entire length of wire used.*

The orientation of the rectangular coil in an AC generator is compared with the flux passing through each turn of the coil. The coil has 100 turns. Figure 3 shows the coil orientation whilst Figure 4 shows the magnetic flux through the coil at the same point in time.

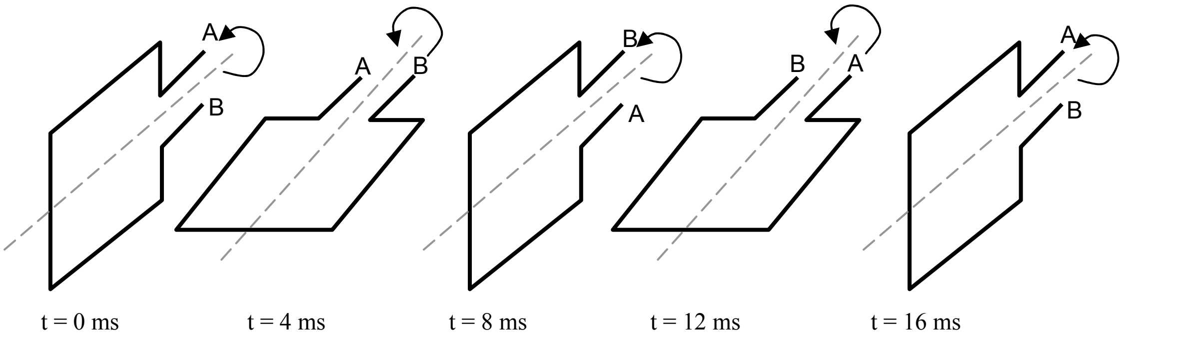


Figure 3

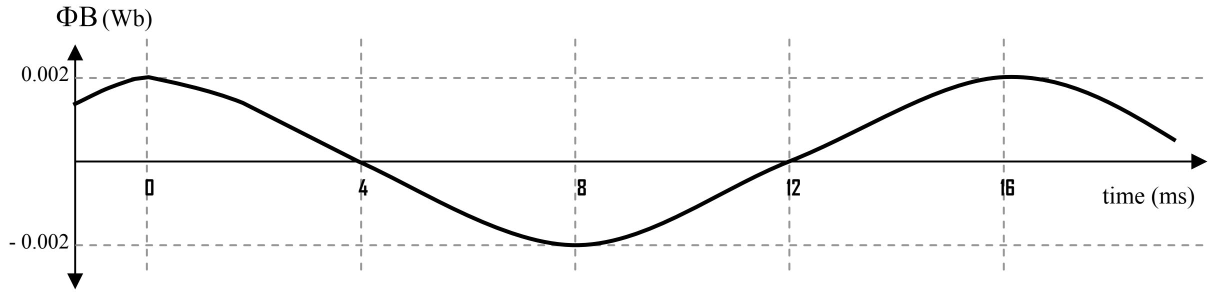


Figure 4

Question 11

From the above information, calculate the average EMF generated.

Worked solution

$$\varepsilon = \frac{-N\Delta\Phi_B}{\Delta t} = \frac{-100\times 0.002}{4\times 10^{-3}} = -50\ \text{V} = 50\ \text{V (negative sign is not important)}$$

50 V

3 marks

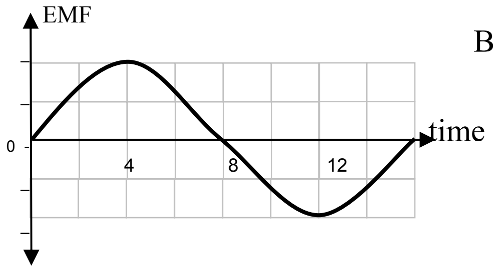
Mark allocation

- 1 mark for using 100 turns
- 1 mark for correct substitution into formula
- 1 mark for correct answer

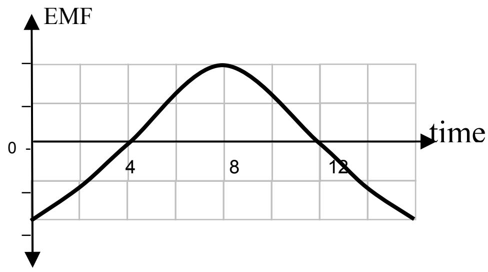
Question 12

Over the same time period, which graph best represents the induced EMF?

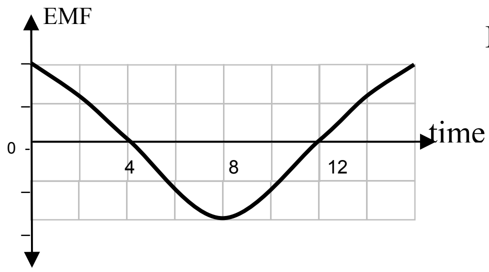
A



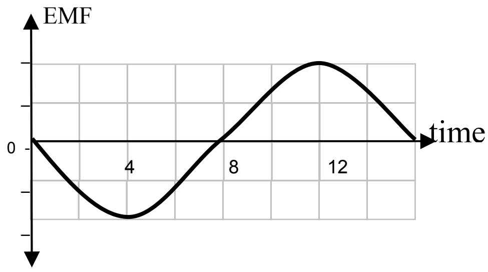
B



C



D



A

2 marks

Answer is A

Worked solution

The EMF waveform can be determined by taking the negative gradient of the slope of the flux–time graph.

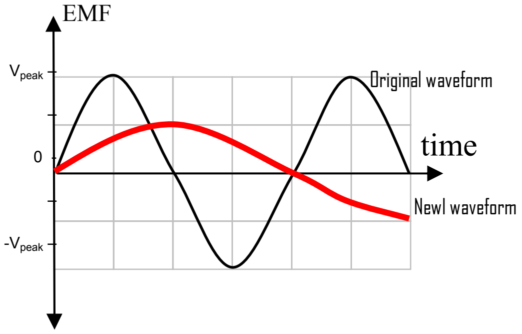
Question 13

Describe how the above EMF waveform would change if the rotational speed of the coils was halved.

Answer

Period would double.

Maximum voltage would halve.



2 marks

Mark allocation

- 1 mark for noting that the period would double
- 1 mark for noting that the maximum voltage would have
- If students choose to draw the diagram, full marks will be awarded.

Question 14

The dimensions of the coil are 40 cm × 20 cm. Find the size of the magnetic field inside the coil.

Worked solution

$$\Phi B = BA \Rightarrow B = \frac{\Phi_B}{A} = \frac{0.002}{0.4 \times 0.2} = 0.025 \text{ T}$$

0.025 T

3 marks

Mark allocation

- 1 mark for converting the area to m^2
- 2 marks for the transformation of equation and correct answer

Tip

- *Remember to convert the dimensions of the coils to metres to get answer in the right units.*

A small bar magnet is suspended by a spring above a solenoid as shown in Figure 5.

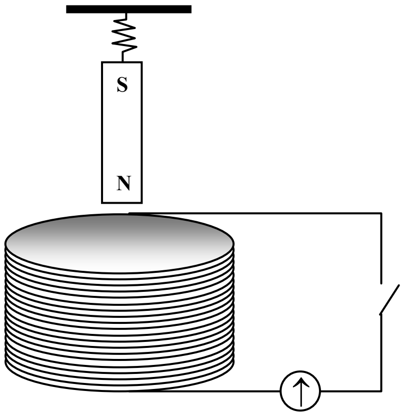


Figure 5

Use the following key to answer questions 15 to 17. (One or more answers may be given.)

KEY:

A. The needle experiences no change.
B. The needle moves to the left.
C. The needle moves to the right.
D. The needle moves left then right.
E. The needle moves right then left.
F. The needle does not deflect.

Initially the magnet is stationary.

Question 15

Use the above key to describe what happens to the needle of the galvanometer when the switch is first closed.

A and F

2 marks

Answers are A and F

Tip

- *Since the magnetic field has not changed inside the coil there will be no induced current.*

Mark Allocation

- 2 marks for both correct answers
- 1 mark for only 1 correct answer
- 1 mark off for any incorrect answer given, down to 0 marks.

Question 16

The spring is now stretched slowly so that the magnet approaches the solenoid. During this time, what happens to the needle?

C

2 marks

Answer is C

Worked solution

The magnetic field (pointing downwards) will increase inside the coil; the coil will try to oppose this change by inducing a current which produces an upwards magnetic field. Using the right-hand grip rule, the current must travel in an anticlockwise direction in the coil, and so the needle deflects to the right.

Question 17

The spring is now released, and the magnet moves up and down repeatedly. Use **one** of the keys A to F to describe the motion of the needle during this time.

D or E

2 marks

Worked solution

As the magnet moves, the magnetic field will vary inside the coil, increasing as the magnet nears the solenoid and decreasing as it moves away. The coil will induce its own field to oppose any change, and thus will produce an upwards magnetic field as the magnet nears the solenoid and a downwards one as it moves away. Hence, the needle will move back and forth, indicating the alternating direction of the current.

Mark allocation

- 2 marks for D or E or both
- 0 marks for any other answer.

AREA OF STUDY 2 – Interactions of light and matter

Use the following key to answers questions 1 and 2.

Light source

A. Laser

B. Sodium vapour lamp

C. Incandescent light globe

D. Blue LED

Question 1

Which of the above light sources produces coherent light?

Worked solution

Only lasers produce wave trains of monochromatic photons at the same time. This is coherence.

A sodium vapour lamp produces defined wavelengths of light, but the photons are not in phase. A blue LED produces a narrow range of wavelengths. An incandescent globe produces a wide spectrum of wavelengths.

A

2 marks

Question 2

Which **one or more** of the above light sources produce photons of discrete wavelengths?

A and B

2 marks

Answers are A and B

Mark allocation

- 1 mark for each correct answer, minus 1 mark down to 0 for each incorrect answer.

Tip

- *Refer to question 1 for an explanation of light source properties.*

Andre is investigating the photoelectric effect by varying the frequency of light incident upon a sodium metal cathode. The apparatus is shown in Figure 1.

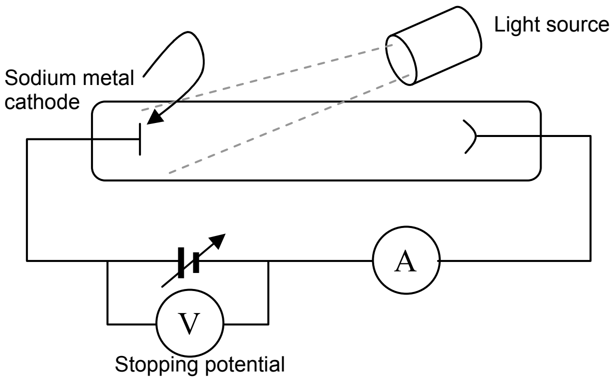


Figure 1

For each frequency, the stopping potential V_s is recorded by Andre.

Trial no.	**Frequency ($\times 10^{14}$ Hz)**	**V_s (V)**
1	3.0	0.0
2	4.0	0.0
3	5.0	0.0
4	6.0	0.2
5	7.0	0.5
6	8.0	1.1
7	9.0	1.4

Question 3

What is the maximum energy a photoelectron can possess as it leaves the cathode if the incident light used has a frequency of 9×10^{14} Hz?

Worked solution

$E_{max\ (photon)} = qV_s$

From the table: at 9×10^{14} Hz,

$V_s = 1.4$ V

$= 1 \times 1.4$

$= 1.4$ eV ($= 2.24 \times 10^{-19}$ J)

1.4 eV

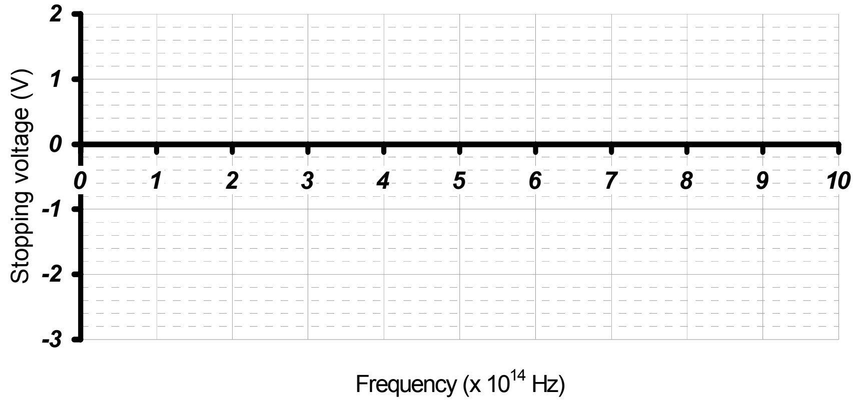
2 marks

Mark allocation

- 1 mark per line of the equation
- Full marks for correct answer in Joules if units are changed in the answer box.

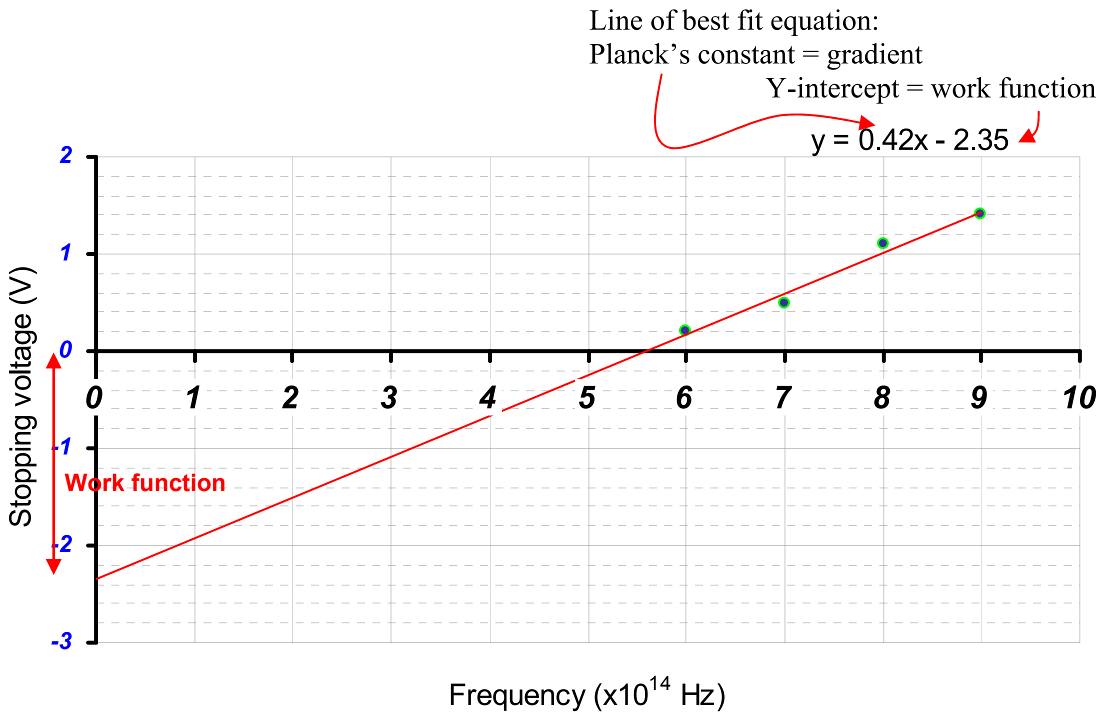
Question 4

Plot Andre's data on the axes provided and hence or otherwise justify the statement that the work function for sodium is 2.4 eV.



Answer

Graph should appear as below:



3 marks

Mark allocation

- 1 mark for correctly plotted points
- 1 mark for straight line graph extended to Y-axis
- 1 mark for explanation that Y-intercept is equal to work function of metal in eV

Tip

- *Plot points carefully. Ignore the zero values when constructing the 'line of best fit'. Zero values indicate only that there is no current flowing. This is because there is no photoelectrons being ejected. Do not confuse the last zero reading with the cut-off frequency – the cut-off frequency may fall below that the last zero reading. In this case from the graph you can see that the cut-off frequency is approximately 5.5 $\times$ 10^{14} Hz. The table is not accurate enough to do calculations from. It is only useful for plotting data points.*

Question 5

From your graph calculate Planck's constant.

Worked solution

Gradient is Planck's constant $h = {}^{\Delta V}/_{\Delta f} \approx 0.42 \times 10^{-14} = 4.2 \times 10^{-15}$ eVs

Answers will vary depending on line of best fit (accept answers from 3.4×10^{-15} up to 5.0×10^{-15}).

3.4 eVs

3 marks

Mark allocation

- 1 mark for selecting 2 points from the graph. They cannot be points from the table.
- 2 marks for calculation. Working must be shown.
- 0 marks if 4.14×10^{-15} is written without any working shown.

Andre now fixes the frequency at 7×10^{14} Hz, and records the current flowing through the circuit for various stopping potentials. He then plots his results to obtain the graph labelled X below in Figure 2.

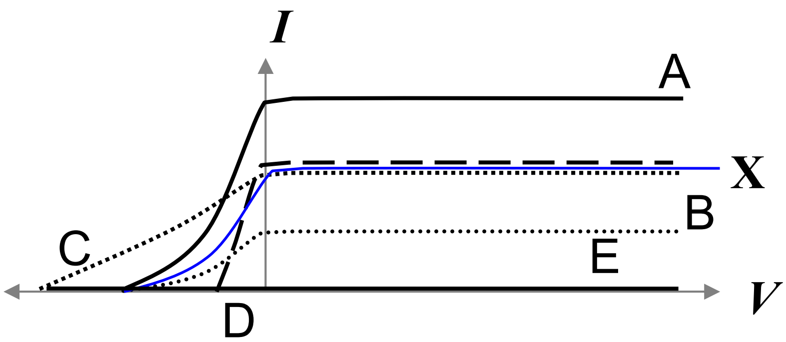


Figure 2

Andre then repeated this experiment with a piece of thick cardboard covering half of the light source.

Question 6

Which **one** of the graphs A to E is most likely to indicate the results of this repeated experiment?

B

2 marks

Answer is B

Worked solution

By halving the light intensity the number of photons striking the cathode is halved therefore only half as many photoelectrons are released and the current is reduced. The photoelectrons will still have the same maximum kinetic energy because the energy of the photons used to release them is determined by the frequency of the photons, which is unchanged.

Tip

- *A change in stopping potential is caused by a change in frequency. A change in current is caused by a change in intensity.*

A laser is used as the light source for a demonstration of Young's 'Double Slit' experiment as shown in Figure 3.

S_1 and S_2 are slits through which the laser light passes, and the dotted lines represent wave fronts. Boxes A to L are parallel sections of the screen onto which the light falls.

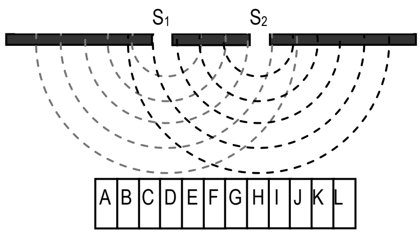


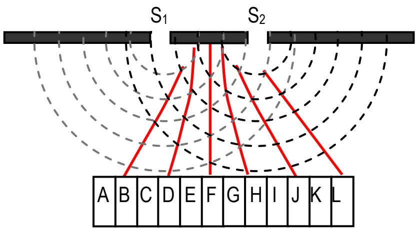
Figure 3

Question 7

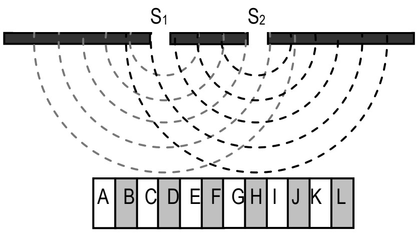
Shade in any of the boxes A to L which represent regions on the screen which will appear bright.

Answer

Correct answer is to shade in regions B, D, F, H, J, L.



Red lines indicate maxima. These appear as bright bands on the screen. Bands should be equally spaced apart.



3 marks

Mark allocation

- 3 marks if all shading is correct
- 2 marks if L is not shaded in but the rest are correctly shaded
- 1 mark if only F is shaded and minus 1 mark for each wrong region shaded down to 0 marks

Question 8

Two students who observe the demonstration are discussing whether the same effect would be observed if the slits were removed and two identical lasers were used instead. Brad thinks the interference pattern will change. Amy thinks the pattern will not. Who is correct and why?

Answer

- Brad is correct
- Even though the lasers are identical, each will not produce photons at exactly the same time – this means that the light will not be in phase from both sources.
- The interference pattern will not be seen, as constructive and destructive interference will not occur.

3 marks

Mark allocation

- 1 mark for stating that Brad is correct
- 1 mark per reason

An electron in an excited energy level of a mercury atom emits a photon of wavelength 175 nm as it changes energy levels, as shown in Figure 4.

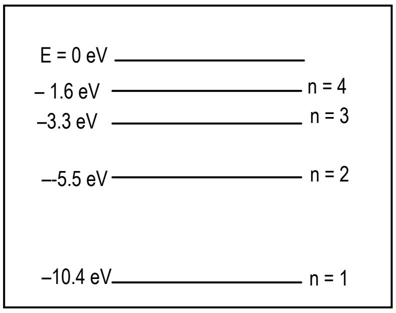


Figure 4

Question 9

What energy level was the electron in before it emitted the photon?

Worked solution

$$E_{\text{photon}} = \frac{hc}{\lambda} = \frac{4.14\times10^{-15}\times3\times10^{8}}{175\times10^{-9}} = 7.1\text{ eV}$$

10.4 – 7.1 = 3.3 (subtract photon energy from energy levels to find an answer that equals one of the levels given.)

So electron was originally in the n = 3 energy level

3 energy level

3 marks

Mark allocation

- 1 mark for the equation
- 1 mark for each line

Tip

- *Use h = 4.14 × 10^{-15} eVs if data is given in eV instead of 6.63 × 10^{-34} J*

Question 10

Which of the following wavelengths is not possible for an emitted photon from this atom?

A. 565 nm

B. 318 nm

C. 253 nm

D. 226 nm

D

Answer is D

Worked solution

Use $\lambda = {}^{hc}/_{\Delta E}$ to find wavelengths, where ΔE is the difference in energy levels.

Answer A corresponds to the n_3 to n_2 transition; answer B to the n_4 to n_2 transition; and answer C to the n_2 to n_1 transition.

Answer D corresponds to 5.5 eV, which is an energy level, rather than a difference between energy levels.

2 marks

END OF SECTION A

SECTION B – Detailed Studies

DETAILED STUDY 1 – Synchrotron and its applications

Use the diagram and key shown in Figure 1 to answer questions 1 to 3.

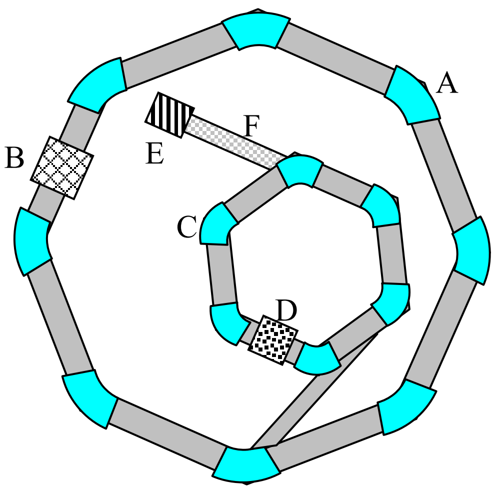


Figure 1

Question 1

At which of the points A to F would a wiggler be found?

B

2 marks

Answer is B

Tips

- *Wigglers are only used in the storage ring of a synchrotron and are placed in the straight sections between bending magnets.*

Question 2

Where are bending magnets located in the above diagram?

A	**C**

2 marks

Answers are A and C

Tip

- *Bending magnets are found in both the storage and booster rings.*

Mark allocation

- 1 mark for each correct answer, minus 1 mark for each incorrect answer down to 0 marks.

Question 3

Indicate at which points from A to F radio frequency (RF) cavities could be located.

B and E

2 marks

Answers are B and E.

Tip

- *RF cavities are used in the electron gun to pulse the electrons produced and in the storage ring to rebunch electrons.*

Mark allocation

- 1 mark for each correct answer, minus 1 mark for each incorrect answer down to 0 marks

Question 4

In a small synchrotron, it is planned to use bending magnets which produce a field strength of 0.5 T to contain the electron beam in a curve of radius 14 m. What momentum must the electrons possess to maintain this radius?

Worked solution

$$r = \frac{p}{qB} \Rightarrow p = Brq$$

$\Rightarrow$ p = $0.5 \times 14 \times 1.6 \times 10^{-19}$

$= 1.12 \times 10^{-18}$ kg m s^{-1}

1.12×10^{-18} kg m s^{-1}

2 marks

Mark Allocation

- .1 mark for correct substitution
- 1 mark for the answer

Question 5

The electrons are initially accelerated from 0 ms^{-1} by an electron gun. The potential difference across the plates of the electron gun is 6000 V. With what energy does each electron leave the electron gun? Give your answer in joules.

Worked solution

$E = Vq = 6000 \times 1.6 \times 10^{-19}$

$= 9.6 \times 10^{-16}$ J

$\mathbf{10^{-6}}$ **J**

2 marks

Mark allocation

- 1 mark for the answer
- 1 mark for conversion to Joules
- If answer given as 6000 eV only 1 mark will be awarded

Question 6

Explain why a linac is constructed using progressively longer drift tubes.

Answer

- The space between the drift tubes is an electric field in which the electrons are accelerated.
- Inside a drift tube there is no electric field and this is where the electrons maintain a constant velocity.
- To keep the electron bunches evenly spaced, the faster bunches must spend the same amount of time inside the drift tubes as the slower bunches. This means the faster electron bunches must travel through longer drift tubes, ensuring that all bunches are accelerated for the same time interval when they exit the drift tubes in synchronisation.

3 marks

Mark allocation

- 1 mark awarded for each line

Tip

- *These questions are looking for an explanation which demonstrates that you understand the function of the equipment and why it operates in this way. It would not be sufficient to write 'Because the electrons speed up' – this would receive 0 marks.*

Question 7

Circle the correct word in bold to make the following sentences correct.

> Conventional X-rays are not as useful as light from a synchrotron of similar wavelength for diagnostic purposes because synchrotron light is **[collimated / pulsed / wide spectrum]**. Conventional X-rays are always **[coherent / incoherent / adherent]** and **[lower / equal / higher]** intensity than synchrotron light.

3 marks

Tips

- *Synchrotron light is always more intense than traditional X-rays and is of much higher intensity. Synchrotron light can also be collimated. These are all useful traits in diagnostic procedures.*

Question 8

A photon of energy 6.5 eV collides with an electron, and 2.3 eV of energy is transferred to the electron. Calculate the initial and final momentum of the photon.

Worked solution

Momentum of photon $p = {}^{h}/_{\lambda} = {}^{hf}/_{c}$

Energy of photon $E = hf \Rightarrow p = {}^{E}/_{c}$

$$p_{\text{initial}} = \frac{E}{c} = \frac{6.5 \times 1.6 \times 10^{-19}}{3 \times 10^{8}} = 3.47 \times 10^{-27}\,\text{kg m s}^{-1}$$

$$p_{\text{final}} = \frac{E}{c} = \frac{4.2 \times 1.6 \times 10^{-19}}{3 \times 10^{8}} = 2.24 \times 10^{-27}\,\text{kg m s}^{-1}$$

$\mathbf{P_{initial} = 3.47 \times 10^{-27}\,kg\ m\ s^{-1}}$	$\mathbf{P_{final} = 2.24 \times 10^{-27}\,kg\ m\ s^{-1}}$

3 marks

Mark allocation

- 1 mark for the energy of photon equation
- 1 mark for each correct answer
- Subtract 1 mark if the answers are not in the correct units.

An unknown crystalline sample is subjected to X-rays of wavelength 150 pm during Bragg diffraction analysis. The graph shown in Figure 2 was faxed to a researcher but unfortunately some data was obscured.

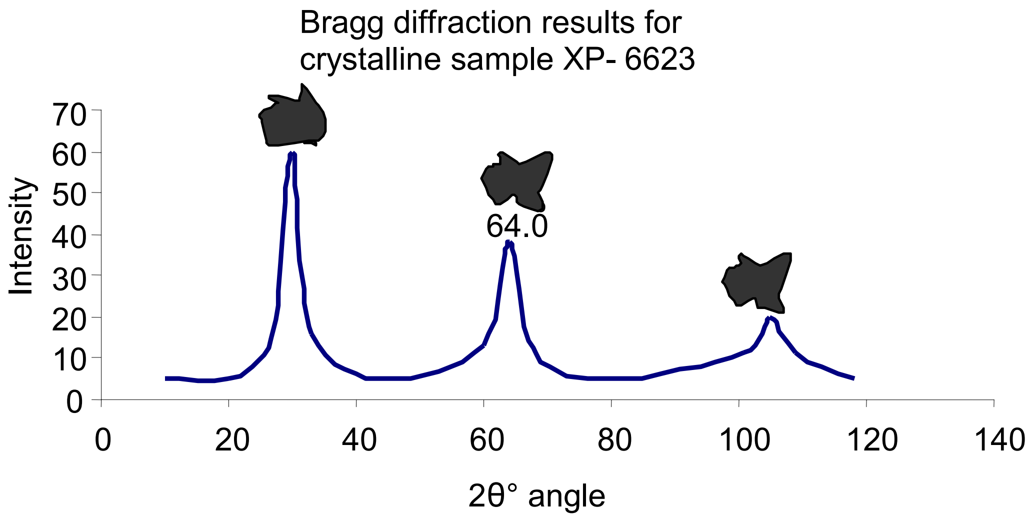


Figure 2

Question 9

Use the above information to find the crystal layer spacing.

Worked solution

$2d \sin \theta = n\lambda \Rightarrow d = \dfrac{n\lambda}{2\sin\theta} = \dfrac{2\times 150\times 10^{-12}}{2\sin 32^o}$ remember to halve the 2θ value from the graph

$= 2.83\times 10^{-10}$ m

2.83×10^{-10} m

3 marks

Mark allocation

- 1 mark for halving 2θ from graph
- 2 marks for transposition and correct answer

Question 10

Calculate the exact values of the first and third peaks which have been obscured on the graph above.

Worked solution

$2d\sin\theta = n\lambda$

$$\sin\theta = \frac{n\lambda}{2d} \Rightarrow \theta = \sin^{-1}\left(\frac{n\lambda}{2d}\right) = \sin^{-1}\left(\frac{n\times(150\times10^{-12})}{2\times(2.83\times10^{-10})}\right)$$

1st peak $\Rightarrow n = 1$

$$\Rightarrow \theta = \sin^{-1}\left(\frac{1\times(150\times10^{-12})}{2\times(2.83\times10^{-10})}\right) = \sin^{-1}(0.265) = 15.36^o$$

$\Rightarrow$ so 1st peak 2θ angle $= 2\times15.36 = 30.72^o$

3rd peak $\Rightarrow n = 3$

$$\Rightarrow \theta = \sin^{-1}\left(\frac{3\times(150\times10^{-12})}{2\times(2.83\times10^{-10})}\right) = \sin^{-1}(0.795) = 52.66^o$$

so 3rd peak 2θ angle $= 2\times52.66 = 105.32^o$

First peak = 30.72°

Third peak = 105.32°

3 marks

Mark allocation

- 1 mark for transposition of formula
- 1 mark for each correct answer (first & third peak angles)
- If angles not doubled minus 1 mark

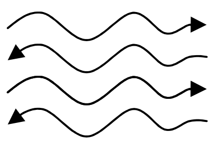
Note consequential error $\theta = \sin^{-1}\left(\frac{n\times(150\times10^{-12})}{2\times(Q.9ans)}\right)$ for both values.

DETAILED STUDY 2 – Photonics

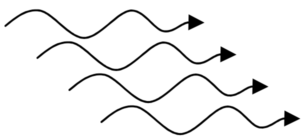
Question 1

Which of the following diagrams best represents light emitted from a laser?

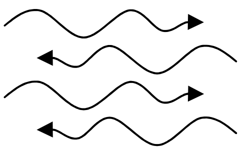
A.



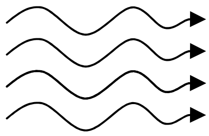
B.



C.



D.



D

2 marks

Answer is D

Tip

- *Laser light is coherent and of a single wavelength, so all wavetrains are emitted at the same time and are identical in length.*

A laser beam is shone into the core of a step index fibre with a core refractive index of 1.45 and a cladding refractive index of 1.30, as shown in Figure 1.

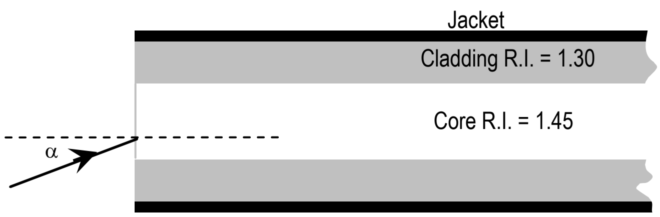


Figure 1

Question 2

What is the minimum angle at which a light ray can strike the core–cladding boundary and not enter the cladding?

Worked solution

This is the critical angle:

$$\sin\theta_c = \frac{n_2}{n_1} = \frac{n_{\text{cladding}}}{n_{\text{core}}} = \frac{1.3}{1.45}$$

$$\Rightarrow \theta_c = \sin^{-1}\frac{1.3}{1.45} = 63.708° = 63°42'30'' = 63°43'$$

63°43’

2 marks

Mark allocation

- 1 mark for recognising this is the critical angle
- 1 mark for correct answer

Question 3

What is the greatest value for angle α that will still allow the light beam to remain inside the core?

Worked solution

This is the acceptance angle:

$$\sin\alpha = \sqrt{n_1^2 - n_2^2}$$

$$\Rightarrow \alpha = \sin^{-1}\sqrt{n_1^2 - n_2^2} = \sin^{-1}\sqrt{1.45^2 - 1.3^2}$$

$$= \sin^{-1} 0.642 = 39.96° = 40°$$

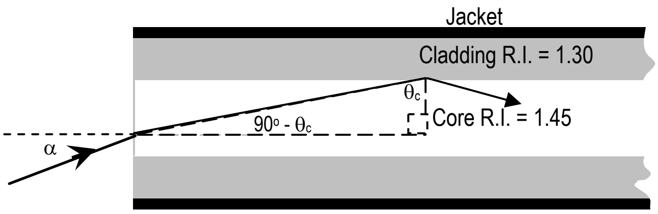
40°

3 marks

Mark allocation

- 3 marks for transposition, substitution and correct answer

Alternative answer with consequential implications is as follows:



Using Snell's law:

$n_{air} \sin \alpha = n_{core} \sin (90^o - \theta_c)$ θ_c value is answer to Question 2

$\Rightarrow \quad 1.00 \times \sin \alpha = 1.45 \sin (90^o - \theta_c)$

$\Rightarrow \quad \sin \alpha = 1.45 \sin (90^o - \theta_c)$

$\Rightarrow \quad \alpha = \sin^{-1} [1.45 \sin (90^o - \theta_c)]$

Mark allocation for using Snell's law

- 1 mark per line

Question 4

LEDs all have a 'band gap'. Describe what the band gap is and what characteristic of the LED it determines.

Answer

- The band gap is the difference in energy between the electrons in the conduction band and the non-conducting electrons in the valency band.
- When an electron in the valency band gains enough energy to jump up to the conduction band, the LED will conduct.
- When an electron drops from the conduction band back to the valency band, it will emit its excess energy as a photon.
- The difference in energy between the conduction and valency bands is called the band gap energy and this is the amount of energy the emitted photons will have.
- The band gap energy determines the characteristic wavelength (colour) of the light emitted from the LED.

4 marks

Mark allocation

- 1 mark per line and the last line is necessary to be awarded full marks

Question 5

A red LED emits light of an average wavelength of 605 nm. While a blue LED emits light of an average wavelength of 470 nm. Find the ratio

$$\frac{\text{Band gap energy of red LED}}{\text{Band gap energy of blue LED}}$$

Worked solution

$$\frac{\text{Band gap energy of red LED}}{\text{Band gap energy of blue LED}} = \frac{\Delta E_{red}}{\Delta E_{blue}} = \frac{\frac{hc}{\lambda_{red}}}{\frac{hc}{\lambda_{blue}}} = \frac{\lambda_{blue}}{\lambda_{red}} = \frac{470}{605} = 0.777$$

Band gap energy $\Delta E = {}^{hc}/_{\lambda}$

2 marks

Mark allocation

- 2 marks for correct substitution and answer

Question 6

Circle the correct physics term in bold to make the following paragraph correct.

An endoscope is a device used by surgeons to view inside the body during keyhole surgery. Light is transmitted through bundles of **[incoherent / coherent / linear]** optic fibres to the operational end of the endoscope. This light undergoes **[reflection / refraction / total internal reflection]** inside the body cavity. Some of this light then passes through a focusing **[mirror / lens / prism]** before entering a set of **[incoherent / coherent / linear]** optic fibres which transmit the light using the principal of **[reflection / refraction / total internal reflection]** to the viewing eyepiece as an accurate **[picture / reflection / image]** of the body cavity.

3 marks

Mark allocation

- Half a mark awarded for each correct term.

Question 7

Modal dispersion causes signal attenuation because

A. shorter wavelengths travel slower inside the optic fibre.
B. some light signals will travel a longer path than others due to the angle at which they enter the optic fibre and so take more time to reach the end.
C. impurities in the fibre slow down some wavelengths more than others.
D. longer wavelengths travel more slowly inside the optic fibre.

B

2 marks

Answer is B

Worked solution

Modal dispersion is due to the difference in path length taken by light of the same wavelength.

Question 8

Modal dispersion is a significant problem in optic fibres classified as

A. single mode.
B. step index multimode.
C. graded index multimode.
D. all of the above.

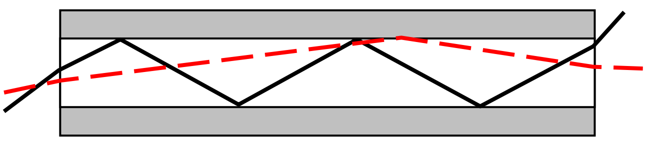
B

2 marks

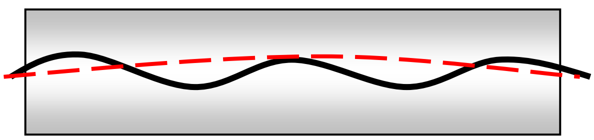
Answer is B

Worked solution

Because of the sharp change in refractive indices between the core and cladding, the light will take a jagged (zigzag) path along the core. Graded index fibres have a gradual change in refractive index from the core outwards and so the light beam is always undergoing minute changes in direction that create a smoothly curved path which is shorter than step index path. Single mode fibres have a very narrow acceptance angle and effectively only allow one light path through the fibre.



Step index fibre. The dotted path is the lower mode. It is shorter and so will arrive faster than the other mode (solid line).



Graded index fibre. Same initial acceptance angle as lines above but due to constant total internal reflection the path is short.

A light signal is to be transmitted down an optic fibre with an attenuation curve as shown in Figure 2.

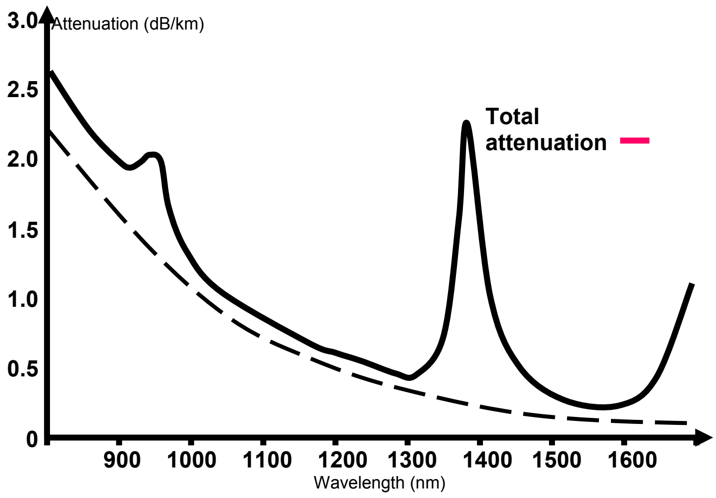


Figure 2

Question 9

Indicate the range of wavelengths which would be best for transmitting data between Melbourne and Sydney along an optic fibre of roughly 1000 km in length.

Answer

Minimum wavelength **1550 nm** Maximum wavelength **1600 nm**

The best wavelength range is where the attenuation is lowest. This would be in the range 1550 to 1600 nm. Accept 1450 nm to 1650 nm.

2 marks

Mark allocation

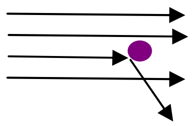
- 1 mark for low end in range
- 1 mark for high end in range

Question 10

The dotted line represents a form of attenuation. Name this type of attenuation and explain why its effect is dependent on the wavelength of the light being transmitted.

Answer

- Rayleigh scattering
- It is caused by the spreading out of light due to collisions between the photons and particles which are smaller than the wavelength of the photons.



- (The particles are impurities or inconsistencies in the glass.)
- The relationship is: attenuation $\propto \frac{1}{\lambda^4}$ so the larger the wavelength the less scattering.

3 marks

Mark allocation

- 1 mark for correct name
- 1 mark for each dot point or suitable diagram and explanation up to maximum of 3 marks

DETAILED STUDY 3 – Sound

Question 1

A microphone uses a thin ribbon of aluminium suspended in a magnetic field to detect vibrations in the air and convert them into electrical signals. This type of microphone is called (one or more answers)

A. velocity.
B. dynamic.
C. ribbon.
D. moving coil.
E. electret-condenser.
F. crystal.

A and C

2 marks

While hiking one day Simone notices she can hear an echo from a cave. Her map indicates the cave is 462 m long. Simone uses the stopwatch function on her watch to record the delay. It takes on average 2.67 seconds for the echo of her 3800 Hz whistle to be heard when she stands at the mouth of the cave.

Question 2

What is the speed of sound inside the cave?

Worked solution

Speed = $^{distance}/_{time}$ distance = 2 × 462 = 924 m

Speed = $^{924}/_{2.67}$ = 346.067 = 346 ms^{-1}

346 ms^{-1}

2 marks

Mark allocation

- 1 mark for the equation
- 1 mark for the correct answer
- Only 1 mark if student used distance = 462 ⇒ speed = 173 ms^{-1}
- 0 marks for 340 ms^{-1}

Question 3

What is the wavelength of the sound as it travels inside the cave?

Worked solution

$$v = f\lambda \Rightarrow \lambda = \frac{v}{f} = \frac{346}{3800} = 0.091\text{ m}$$

consequential answer $v = x \div 3800$, where x is the answer to Question 2.

0.091 m

2 marks

Mark allocation

- 2 marks for transposition and correct answer

Question 4

A siren located at the top of a tower is struck once. At a distance of 35 m from the siren, the sound level is recorded at 75 dB. At what distance from the siren is the sound level only 50 dB?

Worked solution

Sound level $L = 10\log\frac{I}{I_0}$, where $I_0 = 10^{-12}$ Wm^{-2}

$$L_{35} = 75 = 10\log\frac{I_{35}}{10^{-12}} \qquad L_x = 50 = 10\log\frac{I_x}{10^{-12}}$$

At 35 m $\Rightarrow 7.5 = \log\frac{I_{35}}{10^{-12}}$ At new distance x: $\Rightarrow 5 = \log\frac{I_x}{10^{-12}}$

$$\Rightarrow 10^{7.5} \times 10^{-12} = I_{35} \qquad \Rightarrow 10^{5} \times 10^{-12} = I_x$$

$$\Rightarrow I_{35} = 10^{-4.5}\,Wm^{-2} \qquad \Rightarrow I_x = 10^{-7}\,Wm^{-2}$$

Intensity varies inversely with the square of the distance:

$I \propto \frac{1}{r^2} \therefore I = \frac{k}{r} \therefore Ir^2 = k$ or $I_1 r_1^2 = I_2 r_2^2$

$$I_1 r_1^2 = I_2 r_2^2$$
$$\Rightarrow 10^{-4.5} \times 35^2 = 10^{-7} \times r_2^2$$
$$\Rightarrow r_2^2 = \frac{10^{-4.5} \times 35^2}{10^{-7}} = 10^{2.5} \times 35^2 = 316.23 \times 1225 = 387379$$
$$\Rightarrow r_2 = \sqrt{387379} = 622.4\text{ m}$$

622.4 m

4 marks

Mark allocation

- 1 mark for each correct intensity
- 2 marks for transposition and correct answer

Question 5

Ken has a guitar string tuned to resonate at a fundamental frequency of 600 Hz. At which of the frequencies below will this string also resonate? (One or more answers may be given.)

A. 300 Hz
B. 900 Hz
C. 1200 Hz
D. 1800 Hz

C and D

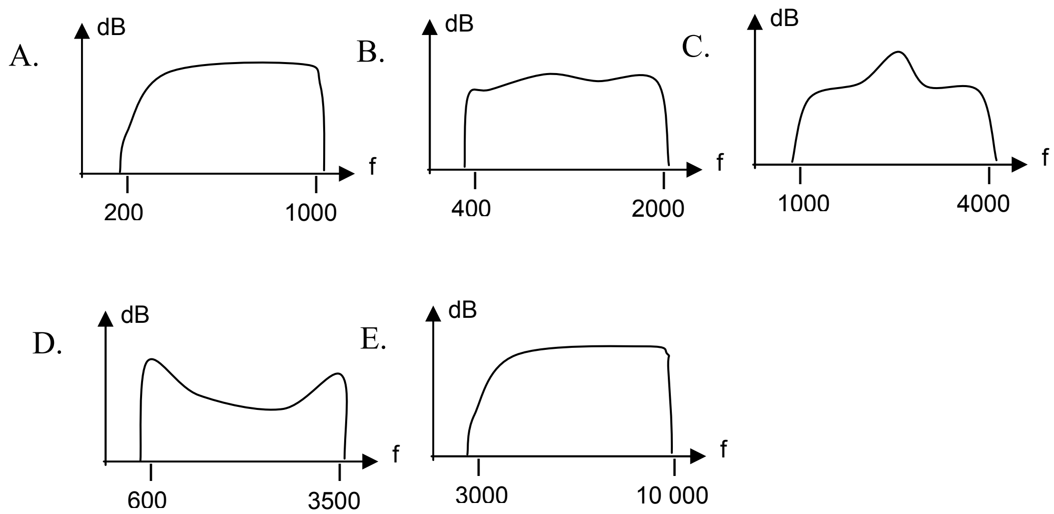
2 marks

Answers are C and D

Tip

- *These are the second ($2f_1$) and third ($3f_1$) harmonics, which must be whole number multiples of the fundamental frequency for a string.*

Ken plans to build his own speaker system for his guitar described in **Question 5**. He has the response curves for five possible drivers to use.



Initially Ken decides to use only driver A as a speaker by connecting it to his amplifier with two wires, but he finds the sound produced is very flat and he is disappointed.

Question 6

State **two** things that Ken could do to improve the sound from his speaker system. You must explain why the sound will improve.

Answer

1. Change the driver from A to B.

Reason: Driver B has a wider range of frequencies than A so more harmonics will be produced giving a richer sound.

2. Use a baffle.

Reason: By mounting the driver on a baffle (large flat board), any destructive interference caused by sound produced from the rear of the driver mixing with sound from the front (which can be out of phase) will no longer be able to occur. An infinite baffle such as a speaker box would work best.

4 marks

Mark allocation

- 1 mark for each option
- 1 mark for each reason

Tips

- *Since the original sound in Question 5 was at 600 Hz we must keep this fact in mind when we answer subsequent questions. This often occurs in exams. That is why driver B is better than the others in this case.*

Question 7

The quality of sound from a single driver speaker is not as good as that from a multiple driver speaker because

A. diffraction effects are less noticeable in the multiple driver speaker.

B. diffraction effects are more noticeable in the multiple driver speaker.

C. refraction effects are less noticeable in the multiple driver speaker.

D. refraction effects are more noticeable in the multiple driver speaker.

B

2 marks

Answer is B

Worked solution

Diffraction depends on the ratio λ/w, where w is the width of the driver and λ is the wavelength of the sound produced. Maximum diffraction occurs when this ratio is close to 1. Therefore a multiple driver speaker will be able to produce much more diffraction. With several different sized drivers, the opportunity for diffraction is increased compared to a single driver, which has only a small range of wavelengths that produce significant diffraction.

Question 8

Circle the correct option from those in bold to complete the following sentence.

A pipe which is closed at one end and is of length **[1.8 / 2.6 / 3.2]** metres will have a **[first / second / third]** harmonic with a wavelength of **[1.8 / 2.4 / 3.2]** metres.

Worked solution

Pipes closed at one end produce only the odd harmonics

1st (fundamental) harmonic has $\lambda_1 = 4L$, where L = pipe length,

$\Rightarrow \quad \lambda_1 = 4 \times 1.8 = 7.2$ m or $4 \times 2.6 = 10.4$ m or $4 \times 3.2 = 12.8$ m

3rd harmonic (first overtone) $\lambda_3 = {}^{4L}/_3$

$\Rightarrow \lambda_3 = 7.2 \div 3 = 2.4$ m or $10.4 \div 3 = 3.47$ m or $12.8 \div 3 = 4.27$ m

3 marks

Mark allocation

- 1 mark for each of the correct answers.
- Subtract 1 mark for any incorrect answers down to a minimum of zero

A police cadet's hearing is tested and the graph in Figure 2 shows the results.

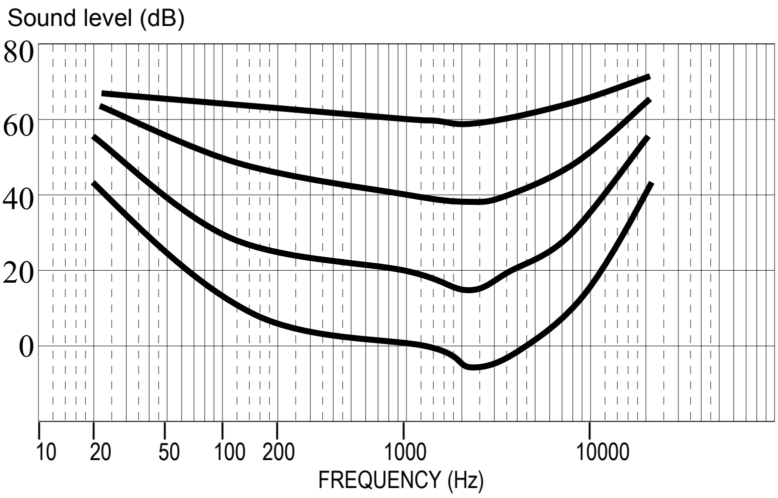
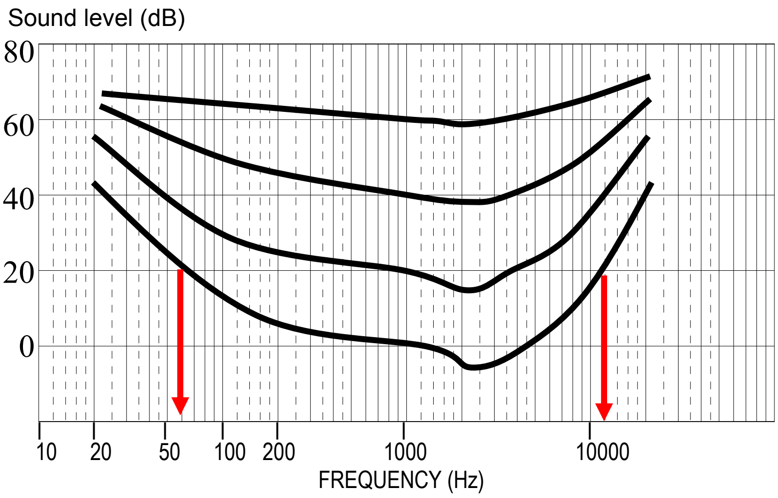


Figure 2

Question 9

What range of frequencies can the police cadet hear below 20 dB?

Worked solution



60 Hz → 12 000 Hz

2 marks

Mark allocation

- 1 mark for each value

Tips

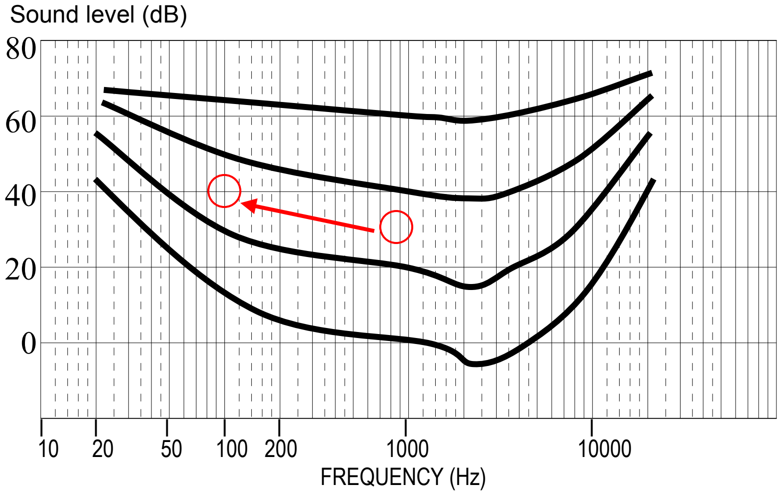
- *Find where the lowest phon line cuts the 20 dB level on the graph – anything below this can be heard.*

Question 10

At what sound level does a 100 Hz sound need to be at to sound as loud as an 800 Hz sound at 40 dB?

Worked solution

To find this answer, locate where 800 Hz is on the 40 dB phon and track the phon back to where 100 Hz is and read from the sound level axis.



± 50 dB

2 marks

Mark allocation

- 2 marks for the correct answer (Accept range from 46 to 53 dB)

END OF SOLUTIONS