PHYSICS

Unit 4 – Written examination 2

2009 Trial Examination

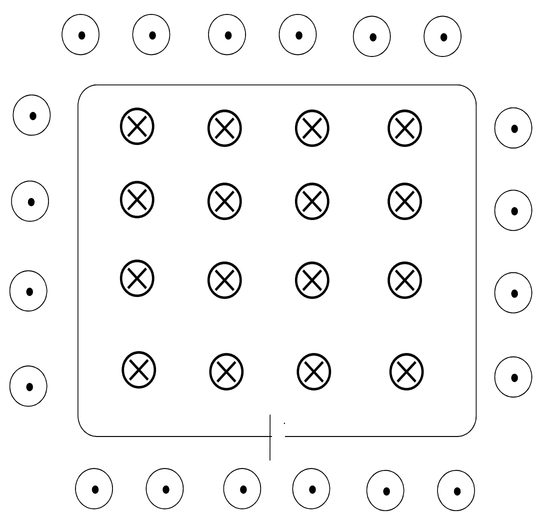
SOLUTIONS

SECTION A – Core

Area of Study 1- Electric Power

Question 1

Answer:



Field is directed into the page within the loop and out of the page external of the loop.

Question 2

Answer: 2.0×10^{-3} N, East

Explanation: Use $F = BIL = 2 \times 10^{-2} \times 2.5 \times 0.04$. Direction is found using RH slap rule.

Question 3

Answer: 0 N

Explanation: Field is parallel to the direction of the current, so no force results.

Question 4

Answer: A = South, B = North

Explanation: Use RH slap rule to determine the required field direction (right to left). Field lines must run from North to South.

Question 5

Answer: A commutator is required to ensure continuous rotation of the coil. It achieves this by changing the direction of the current every 180^o, which in turn changes the direction of the force on the sides of the coil and allows it to rotate continuously.

Question 6

Answer: 0 Wb

Explanation: The coil is parallel to the field, so the area threaded by B is zero. Thus $\Phi = BA = 0$.

Question 7

Answer: $7.5 \text{ x } 10^{-5}$ Wb

Explanation: $\Phi = BA = 3 \times 10^{-2} \times 0.05^2 = 7.5 \times 10^{-5}$ Wb

Question 8

Answer: 3 mV

Explanation:

$$\text{emf} = n\frac{\Delta\phi}{\Delta t} \text{ (magnitude only)}$$

$$= 20\frac{7.5\times10^{-5}}{0.5} = 0.003 \text{ V}$$

Question 9

Answer: **Y to X**

Explanation (one of several options): Consider a small positive charge in the coil, positioned between X and Y. As the coil rotates anticlockwise, the charge will move downwards and be pushed from Y to X under the influence of the magnetic field. This is the induced current.

Question 10

Answer:

Action	Resulting Plot	Explanation
Commutator replaced with slip rings	**A**	Slip rings give an AC output
Coil rotated at half original speed	**C**	Half amplitude and double period due to change in Δ**t** in emf equation
Number of loops in coil increased	**D**	Double amplitude due to change in **n** in emf equation

Question 11

Answer: Anti-clockwise

Explanation: Switching off the power supply causes a change in flux as the magnetic field from the solenoid is now eliminated. The change in flux is to the right, so the coil responds with a change in flux to the left and an induced current (using RH grip rule) which is anti-clockwise when viewed from A.

Question 12

Answer: 21.2 kV

Explanation: $V_{peak} = \sqrt{2} \times V_{RMS} = \sqrt{2} \times 15000 = 21213$ V = 21.2kV

Question 13

Answer: 5.7×10^3 A

Explanation: $I_{peak\text{-}peak} = 2\sqrt{2} \times I_{RMS} = 2\sqrt{2} \times \dfrac{30\times10^6}{15\times10^3} = 5657$ A

Question 14

Answer: 10 MW

Explanation: $P_{loss} = IR^2 = 2000^2 \times 2.5 = 10 \times 10^6$ W

Note: Current of 2000 A in lines is calculated using the transformer ratio of 10:1 at the town end.

Question 15

Answer: 1 kV

Explanation: $V_{Loss} = IR = 2000 \times 2.5 = 5000$ V (across transmission lines)
$V_{prim} = 1.5 \times 10^4 - 5 \times 10^3 = 10$ kV (at primary side of town transformer)
$V_{sec} = \dfrac{10000}{10} = 1.0 \times 10^3$ V (at secondary side of transformer and town)

Question 16

Answer: In order for the transformer to operate correctly, we require a constantly changing flux on the primary side, which will then induce a current in the secondary side. The changing flux comes as a result of the alternating current, which creates a constantly changing magnetic field in the primary coil. So, if the current were smooth DC, there would be a constant magnetic field, no change in flux and no induced current.

Question 17

Answer: Decrease

Explanation: An increased current in the transmission lines will lead to greater voltage drop and thus less voltage available after the step down transformer.

$$I_{Line} = \frac{2.5\times10^4}{10} = 2.5 \times 10^3 \text{ A}$$

$V_{Loss} = IR = 2.5 \times 10^3 \times 2.5 = 6.25 \times 10^3$ V (across transmission lines)

$V_{prim} = 1.5 \times 10^4 - 6.25 \times 10^3 = 8.75 \times 10^3$ (at primary side of town transformer)

$V_{sec} = \frac{8.75\times10^3}{10} = 875$ V (at secondary side of transformer and town)

Area of Study 2 – Light and Matter

Question 1

Answer: 1400 nm

Explanation: 3rd node from the centre has Path Difference of 2.5λ
$2.5 \times 560 = 1400$ nm

Question 2

Answer: Increasing the gap between the slits will cause the interference pattern to become narrower, whilst remaining distinct in terms of alternating nodes and antinodes.

Question 3

Answer: Insignificant diffraction.

Explanation: Using the ratio: $\frac{\lambda}{w} = \frac{560\times10^{-9}}{1.5\times10^{-3}} = 3.7\times10^{-4}$. The ratio is clearly much less than one, so the level of diffraction will be insignificant.

Question 4

Answer: 2.76 eV

Explanation: $E = hf = 4.14 \times 10^{-15} \times \frac{3\times10^8}{450\times10^{-9}} = 2.76$ eV

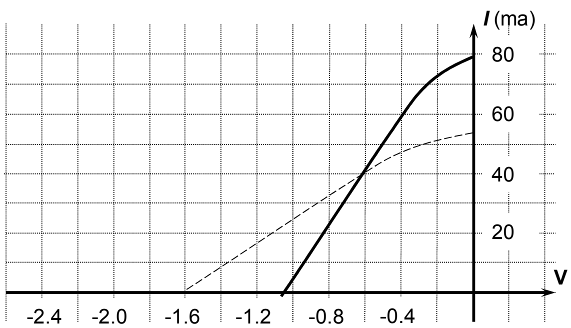
Question 5

Answer: 5.22×10^{14} Hz

Explanation: $Vq = hf - W$
$0.6 = 2.76 - hf_o$
$f_o = 5.22 \times 10^{14}$ Hz

Question 6

Answer: Refer to solid line in the diagram below.



Explanation: Lower frequency leads to a lower stopping voltage, brighter source leads to higher photocurrent.

Question 7

Answer: The photoelectric effect demonstrates that as the frequency of a light increases, the stopping voltage increases.

- The particle model explains that light with a higher frequency emits photons with greater energy and thus imparts more energy to ejected electrons. Therefore, the voltage required to stop such electrons increases.
- The wave model predicts that as the lights frequency increases, more electrons are being emitted per unit of time so the photoelectric current should increase.

As the intensity of light increases, the photoelectric current increases.

- The particle model explains that increasing the intensity of light means increasing the number of photons emitted per unit of time. Therefore, the number of emitted electrons per unit of time reaching the collector terminal should increase and the photoelectric current increases.
- The wave model predicts that as the intensity of light increases, more energy is carried through the wave and imparted to the electrons at the metal's surface. Thus more energy is required to stop the electrons and a greater stopping voltage is required.

In addition, only the particle model and work function can explain the idea of a threshold frequency and no delay in emission. The wave model would suggest that, even at very low frequencies below the observed threshold frequency, energy from a light source would eventually be able to eject and electron from a metal surface.

Thus, the photoelectric effect confirms light's model as a particle.

Question 8

Answer: 2.75×10^{-12} m

Explanation: $E = \frac{hc}{\lambda}$ (energy of photon)

$$451 \times 10^3 = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{\lambda}$$

$$\lambda = 2.75 \times 10^{-12} \text{ m}$$

Question 9

Answer: 2.4×10^{-22} kg ms^{-1}

Explanation: Given similar diffraction patterns, we can assume that wavelength of the electron and X-Ray are the same.

$$\lambda_{electron} = \frac{h}{mv}$$

$$mv = \frac{h}{\lambda}$$

$$mv = \frac{6.63 \times 10^{-34}}{2.75 \times 10^{-12}} = 2.4 \times 10^{-22} \text{ kg ms}^{-1}$$

Question 10

Answer: 1.41×10^{-18} J

Explanation: Energy gap is 10.4 – 1.6 = 8.8 eV
8.8 eV = 1.41×10^{-18} J

Question 11

Answer: 690 nm

Explanation: Smallest energy gap is from n = 3 to n = 2, which is 1.8 eV

$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E}$$

$$\lambda = \frac{4.14 \times 10^{-15} \times 3 \times 10^8}{1.8} = 690 \times 10^{-7} \text{ m}$$

Question 12

Answer: Electrons can be considered as particles in terms of the way they transition between energy levels in an atom. However, they must also be considered to have wavelike properties as they can only exist in discrete energy levels around the nucleus. These energy levels correspond to standing waves, where only certain wavelengths are feasible for a stable level.

Detailed Study 1 – Synchrotron and applications

Question 1

Answer: **B**

Explanation: By definition, synchrotron radiation is produced when the direction of motion of an electron changes since the changing electric field produces a changing magnetic field.

Question 2

Answer: **D**

Explanation: Other answers are incorrect as the radiation has very low divergence, is very intense and has a short wavelength.

Question 3

Answer: **B**

Explanation: $E = Vq = 139 \times 10^{3} \times 1.6 \times 10^{-19} = 2.22 \times 10^{-14}$ J
$E = 0.5mv^{2}$
$2.22 \times 10^{-14} = 0.5 \times 9.1\times 10^{-31} \times v^{2}$
$v = 2.2 \times 10^{8}$ ms^{-1}

Question 4

Answer: **A**

Explanation: Use RH slap rule for moving charge. Current is directed out of the page, field left to right.

Question 5

Answer: **A**

Explanation: $F = evB = \frac{mv^2}{r}$

$$B = \frac{mv}{re}$$

$$B = \frac{9.1\times10^{-31}\times8\times10^{6}}{3\times10^{-4}\times1.6\times10^{-19}} = 1.5\times10^{-1}\text{ T}$$

Question 6

Answer: **B**

Explanation: F = evB
$F = 1.6 \times 10^{-19} \times 8 \times 10^{6} \times 0.15$
$F = 1.9 \times 10^{-13}$ N

Question 7

Answer: **C**

Explanation: Actual speed is close to 59% of light speed. Additional acceleration is then provided by the linac.

Question 8

Answer: **C**

Explanation: A is electron gun, B is linac, D is storage ring.

Question 9

Answer: **B**

Explanation: A is incorrect (straight, not curved). Insertion devices are magnetic devices (so D is incorrect) which cause acceleration perpendicular to motion (so C is incorrect)

Question 10

Answer: **D**

Explanation: Momentum is conserved, but not kinetic energy (So A is incorrect). The interaction is inelastic (So C is incorrect). Scattered photons will have a lower energy and thus lower frequency (So B is incorrect)

Question 11

Answer: **B**

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

$$\sin\theta = \frac{n\lambda}{2d} = \frac{1\times 0.2\times 10^{-9}}{2\times 3.4\times 10^{-10}}$$

$\theta = 17^{\circ}$

Question 12

Answer: **D**

Explanation:

$$\sin\theta = \frac{n\times 0.2\times 10^{-9}}{2\times 3.4\times 10^{-10}} = 0.294n$$

$\sin\theta \le 1 \therefore 0.294n \le 1$

This is only possible for n = 1, 2, or 3

Question 13

Answer: **B**

Explanation: A is incorrect as lasers can be coherent. C is incorrect as synchrotron radiation is coherent. D is incorrect as the photoelectric effect relies on particle-like behaviour.

Detailed Study 2 – Photonics

Question 1

Answer: **B**

Explanation: A is incorrect as the electrons move from a conduction band. C is incorrect as the photon energy depends on colour, not brightness. D is incorrect as blue has a larger energy gap.

Question 2

Answer: **A**

Explanation:

$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{490\times10^{-9}}$$

$$= 4.1 \times 10^{-19}\text{ J}$$

Question 3

Answer: **C**

Explanation: A is incorrect as the photons are in phase. B is incorrect as all photons have the same wavelength. D is incorrect as there is no destructive interference.

Question 4

Answer: **D**

Explanation:

$$n_{\text{cladding}} \sin 90^{\circ} = n_{\text{core}} \sin i_{\text{crit}}$$

$$n_{\text{cladding}} = 1.51 \sin 80.1^{\circ}$$

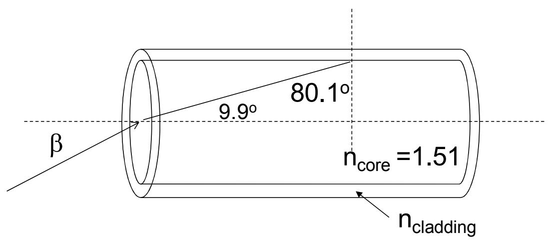
$$n_{\text{cladding}} = 1.49$$

Question 5

Answer: **A**

Explanation: Use Snell's law for initial refraction into core.

$$n_1 \sin i = n_2 \sin r$$
$$1.00 \sin\beta = 1.51 \sin 9.9^{o}$$
$$\beta = 15^{o}$$



Question 6

Answer: **D**

Explanation: A is incorrect as Rayleigh scattering is more evident at higher frequencies. B is incorrect as this is absorption due to resonance. C is incorrect as this is the total effect when absorption due to impurities is factored in.

Question 7

Answer: **C**

Explanation: This is the point of lowest attenuation.

Question 8

Answer: **A**

Explanation: B is incorrect as it accounts for the other peaks. C is incorrect as Rayleigh scattering is greater at shorter wavelengths. D is incorrect as it is the wrong concept.

Question 9

Answer: **B**

Explanation: Modal dispersion is the most significant factor for long distance applications. Single-mode fibres best reduce this.

Question 10

Answer: **C**

Explanation: Refractive index and speed change with the wavelength of light and longer wavelengths travel faster. So red will be slower than infrared.

Question 11

Answer: **C**

Explanation: Only the imaging bundle needs to be coherent, otherwise the image will be jumbled. Illuminating light bundles can be jumbled without affecting the operation of the system.

Question 12

Answer: **A**

Explanation: Step-index, multimode, large diameter fibre has the greatest propensity for modal loss.

Question 13

Answer: **D**

Explanation: Light from a candle is produced by collisions of thermal electrons. The resulting photons are not in phase (incoherent) and varied in energy (broad spectrum) and wavelength (polychromatic).

Detailed Study 3 - Sound

Question 1

Answer: **B**

Explanation: The dust particle moves with the longitudinal sound wave, oscillating towards and away around a mean position.

Question 2

Answer: **B**

Explanation: Distance between compressions is one wavelength
Use $v = f\lambda$
$340 = 170 \times \lambda$
$\lambda = 2.0$ m

Question 3

Answer: **C**

Explanation: $I = 10^{\frac{L}{10}-12}$
$I = 5.0 \times 10^{-3}\ \text{Wm}^{-2}$

Question 4

Answer: **B**

Explanation: Decrease of 6 dB means a decrease in intensity by a factor of 4. Using the inverse square law, this corresponds to a doubling of distance from 4 m to 8 m. Or use the inverse square law $I_1 r_1^2 = I_2 r_2^2$, converting dB to Wm^{-2}.

Question 5

Answer: **D**

Explanation: A is incorrect as there is constructive interference, not destructive. C is incorrect as the waves reflect off the ends, not the sides. C is incorrect as the standing wave is created within the tube, rather than entering.

Question 6

Answer: **D**

Explanation: $f_3 = \frac{3v}{2L}$

$$510 = \frac{3 \times 340}{2 \times L}$$

$L = 1$ m

$$\lambda = \frac{v}{f} = \frac{340}{510} = 0.67 \text{ m}$$

Question 7

Answer: **D**

Explanation: Both dynamic and ribbon microphones rely on the movement of current carrying components within a magnetic field.

Question 8

Answer: **A**

Explanation: B is incorrect as the current must be AC for both forward and backward movement. C is incorrect as crystals are not used. D is not true as resonance is not relevant for the speaker here.

Question 9

Answer: **B**

Explanation: A is incorrect as diffraction is not relevant here. C is incorrect as the wall cannot ensure the sound waves are in phase. D is incorrect as the wall cannot improve the range of the speaker.

Question 10

Answer: **D**

Explanation: 40 Hz at 70 dB places the observer on the 50 phon. 800 Hz at 50dB is also on this phon curve and will thus seem as loud as 40 Hz 70 dB.

Question 11

Answer: **B**

Explanation: High fidelity requires a flat response across the intended range of frequencies. In this case, the response curve is flat through the mid-range frequencies.

Question 12

Answer: **C**

Explanation: The key to this question is diffraction. The 165 Hz sound will diffract readily $\left(\frac{\lambda}{w} = 4.1\right)$, so Annabel and Barry will observe very similar intensities. In contrast, the 3500 Hz signal will not diffract significantly $\left(\frac{\lambda}{w} = 0.2\right)$, so Annabel will observe a much higher intensity.

Question 13

Answer: **D**

Explanation: As per Question 12. $w = 0.5$ for each.