PHYSICS

Unit 4 – Written examination 2

2007 Trial Examination

SOLUTIONS

Area of Study 1- Electric Power

Question 1

Answer: A

Explanation:

The magnetic field is directed from left to right through the inside of the solenoid, so a point P it will be directed to the right.

Question 2

Use Lorentz Force calculation:

$F = BIL$

$1.4 \times 10^{-3} = 0.05 \times I \times 0.04$ F = BIL

$I = 0.7A$

Directed into-the-page. For direction, use RH Slap rule – current must be into the page.

Question 3

Y to X. For clockwise rotation, we require the force on side XY to be directed upwards. With the magnetic field left to right, this necessitates a current from Y to X.

Question 4

The **brushes** of the DC motor are fixed permanently to the DC supply and slide across the commutator as the coil spins. Every 180°, **when the coil is in a vertical position**, the split in the **commutator** is aligned with the brushes, temporarily cutting the supply of current (and hence the force). Momentum carries the coil past vertical and the current is restored, but now in the opposite direction, thus maintaining torque and rotation in the same direction.

Question 5

A small clockwise rotation will lead to an increase in magnetic flux from left to right, which induces an opposing field through the coil from right to left. This induced field is accompanies by an induced current from X to Y, as required (use RH grip rule to confirm).

Question 6

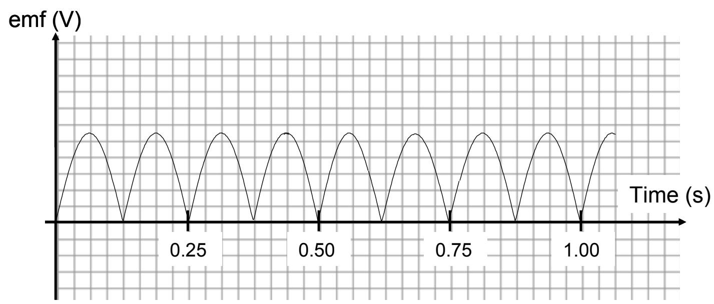
Use Faraday's equation: emf : $\varepsilon = -N\dfrac{\Delta\phi}{\Delta t}$

Consider one quarter turn: $\Delta\phi = 0 - BA = -BA = -0.2A, \Delta t = \dfrac{0.25}{4} = 0.0625$ seconds

So, emf : $0.3 = -25\dfrac{-0.2A}{0.0625} \quad \rightarrow \quad A = 0.00375 = 3.75\times10^{-3}\,m^2$

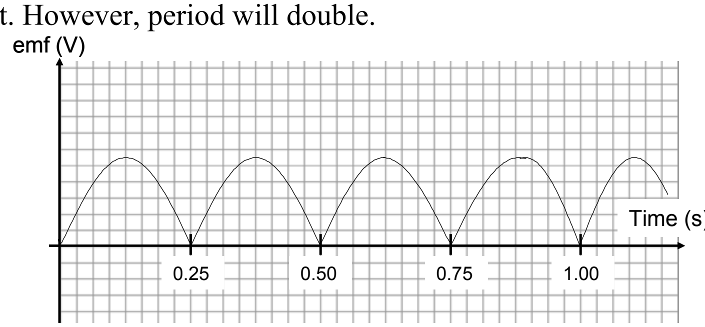
Question 7

Be careful to show DC output due to commutator (compared with usual slip rings)



Question 8

Increase in field strength and increase in period will cancel out, thus magnitude of emf will be constant. However, period will double.



Question 9

Kelvin is correct as a generator involves a rotating coil within a magnetic field. An alternator involves a rotating magnet (often a solenoid) inside a stationary coil. Slip rings simply change the device from DC to AC output.

Question 10

ACW current implies an induced magnetic field upwards through the loop (RH grip rule). This must be opposing a change downwards, which results from the removal of the loop from an upwardly directed magnetic field. Field lines a directed from North to South, so X must be a **South** pole.

Question 11

40 V. 5V per division, 8 divisions for $V_{peak\text{-}peak}$

Question 12

$$V_{RMS} = \frac{V_{p-p}}{2\sqrt{2}} = \frac{40}{2\sqrt{2}} = 14.1V$$

Question 13

Use the voltage-turns ratios:

$$\frac{V_{prim}}{V_{\sec}} = \frac{n_{prim}}{n_{\sec}}$$

$$\frac{40}{4} = \frac{150}{n_{\sec}}$$

$n_{\sec} = 15$ turns

Question 14

An ideal transformer is one where $Power_{in} = Power_{out}$, i.e. no power is lost between the primary and secondary sides. A laminar iron core significantly reduces the extent of induced eddy currents and associated heat losses in the core, so power losses are minimized and thus the transformer can be considered ideal.

Question 15

Using the turns ratio of the transformer:

$$I_{shack} = 5 \times I_{cables}$$

$$I_{cables} = 3A$$

Question 16

First, using the turns ratio of the transformer:

$$V_{prim\,side\,of\,transformer} = 5 \times V_{shack\,side\,of\,transformer}$$

$$V_{prim} = 5 \times 236 = 1180V$$

So, from generator to transformer, $V_{drop\,in\,cables} - 1200 - 1180 = 20V$

Now with, $I_{cables} = 3A, V_{drop} = 20V$

$$R_{cables} = \frac{V}{I} = 6.7\Omega$$

Question 17

If current in the shack is decreased, current in the cables will also decrease.
Reduced cable current leads to reduced voltage drop ($V_{drop} = I_{cables}R_{cables}$)

$V_{prim\,side\,of\,transformer} = 1200 - V_{drop,}$ which will now be $> 1180V >$ 1180 V.

$V_{shack} = \dfrac{V_{prim}}{5}$, which will be > 236 V

Area of Study 2 – Interactions of light and matter

Question 1

$$E_{photon} = hf = \frac{hc}{\lambda}$$
$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{450 \times 10^{-9}}$$
$$= 4.42 \times 10^{-19} J$$

Question 2

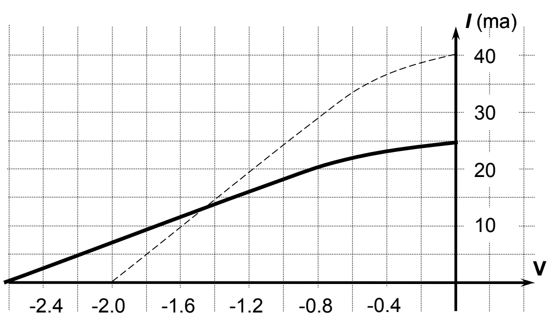
$$E_{k \ \max} = 2.0 \ (x\text{-intercept of graph})$$
$$hf_{blue} = \frac{4.42 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.76eV$$
$$E_{k \ \max} = hf - W$$
$$W = hf - E_k = 0.76eV$$

Question 3

A, E. Moving the slider towards A reduces the size of the applied stopping voltage (i.e. Collector plate is less negative). Hence, Increased photocurrent – more electrons reach the collector. Increase in kinetic energy of electrons reaching the collector plate – less work is done to slow them down after they leave the metal source.

Question 4

Shorter wavelength = higher frequency, so according to E = hf, the ejected electrons will require a larger stopping voltage.
Reduced intensity = fewer photons per second, so fewer electrons will be ejected, and thus less photocurrent will be observed.
No information about size of change, so only sketch required:



Question 5

P is on the 3rd nodal line, so:
Path Difference = 2.5 λ

$1.7 \times 10^{-6} = 2.5\lambda$

$\lambda = 6.8 \times 10^{-7} m$

$680 nm$

Question 6

A, D, F. Spacing on interference pattern is proportional to wavelength and distance to screen, and inversely proportional to slit separation.

Question 7

For similar diffraction pattern, $\lambda_{x-ray} = \lambda_{electron}$

$\lambda_{x-ray} = 0.15 nm$

$\lambda_{electron} = \frac{h}{mv}$ (de Broglie wavelength)

$0.15 \times 10^{-9} = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times v}$

$v = 4.86 \times 10^{6} ms^{-1}$

$v = 4.9 \times 10^{6} ms^{-1}$

Question 8

B, C. Diffraction $\alpha = \frac{\lambda}{w}$. So, with a reduction in w (crystal lattice spacing), we require a reduction in λ in order to achieve the same pattern as Figure 6. B would reduce λ of electrons as their speed would increase and hence $\frac{h}{mv}$ would decrease. C would reduce λ of X-Rays according to the wave equation

Question 9

At the very least, the electrons in the gaseous atoms must absorb sufficient energy via an electron collision to then emit a photon of $\lambda = 480 nm$. This corresponds to an energy of

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

$= \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{480 \times 10^{-9}} = 2.59 eV$

$= 2.6 eV$

Practically, you would require more energetic electrons to ensure they transfer sufficient energy via collisions with gaseous atoms.

Question 10

B, E. 4.9 eV would be absorbed from $n = 1$ to $n = 2$.
11.2 eV would be absorbed – ionizing the mercury.

Question 11

When modeled as waves, electrons will only maintain stable energy levels as a standing wave
For a given atomic "circumference", there are only certain wavelengths that will constructively reinforce to form standing waves.

These discrete wavelengths correspond to specific energy levels via the relationship $E = \frac{hc}{\lambda}$.

Detailed Study 1 – Synchrotron and its applications

Question 1

Electron Linac: D
Storage Ring: J
Booster Ring: E

Question 2

Undulators consist of closely varying magnetic fields that are designed to produce narrow, bright radiation of a specific frequency. **Wigglers** are similar, but are designed instead to produce a wide, powerful beam of shorter wavelength radiation.

Question 3

Spectrum: Synchrotron radiation can be produced over a much wider, continuous range of frequencies, unlike a torch globe, which is restricted to a much narrower band ie visible light.	The continuous X-Ray frequencies are particularly useful in imaging processes and any frequency can be "tuned" or selected for a specific task.
Brightness: The intensity of synchrotron radiation is many orders of magnitude greater than other sources, including torch globes.	Very small amounts of radiation can illuminate and analyse microscopic materials with a much greater effect.
Divergence: Synchrotron radiation has a much narrower cone angle than light from a torch globe.	The radiation can be highly directed and focused on precise areas of a sample.

Question 4

Assuming conservation of momentum: $\Delta p_{photon} = \Delta p_{electron}$

$$\Delta p = \frac{h}{\lambda_{before}} - \frac{h}{\lambda_{after}}$$

$= 1.36 \times 10^{-24}$

Unit of $kgms^{-1}$, Ns or other alternatives

Question 5

Kinetic Energy = $qV = 10000 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-15}\,J$

Question 6

$$v_{electron} = \sqrt{\frac{2KE}{m}} = 5.93\times10^{5}\ ms^{-1}$$

$$r = \frac{mv}{qB} = \frac{9.1\times10^{-31}\times5.93\times10^{5}}{1.6\times10^{-19}\times0.02} = 1.69\times10^{-4}m = 1.7\times10^{-4}m$$

Out-of-page. Magnetic force acts on moving charge as per RH slap rule.

- B directed down page
- I is effectively right to left (moving, negative charge)

Question 7

Tuneable refers to the fact that the synchrotron is designed so that a **monochrometer** (device that only allows radiation of one frequency to pass) can select specific frequencies from a **beamline** (path of radiation from the storage ring to the target) for use in a particular task.

Question 8

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

$$\lambda = \frac{4.14\times10^{-15}\times3\times10^{8}}{9.5\times10^{3}} = 1.3\times10^{-10}m \text{ as required}$$

Question 9

Bragg diffraction: $n\lambda = 2d\sin\theta$

$n = 1$, $\lambda = 0.13\ nm$ (from Question 8), $\theta = 18^{o}$ (from Figure 4)

$d = 2.1\times10^{-10}m$

Question 10

The three peaks at 18, 38 and 69^{o} correspond to $n = 1, 2, 3$

However, if $n = 4$ is tried in the diffraction equation, it collapses – indicating that there is no solution and hence only 3 possible angles.

If $n = 4$: $\theta = \sin^{-1}\left(\frac{4\lambda}{2d}\right) = \sin^{-1}(1.23)$ … no solution.

Detailed Study 2 – Photonics

Question 1

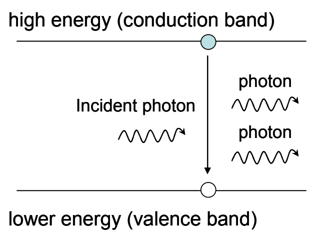
$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{6.63\times10^{-34}\times3\times10^{8}}{3.4\times10^{-19}} = 5.85\times10^{-7}\,m$$

$585\,nm$

Question 2

Stimulated Emission is the process whereby a photon with the same energy as the band gap can stimulate an electron to fall from the conduction band to the valence band, releasing another identical photon. In lasers, this process is essential to amplify the source – generating many identical photons from one initial random emission.



Question 3

Single-mode step-index: A (not affected by modal dispersion as only 1 mode)
Multimode step-index: C (significantly affected by modal dispersion due to addition distance covered by higher modes)
Multimode graded-index: B (partially affected by modal dispersion due to mitigated distance affects.

Question 4

Modal dispersion: Spreading out of pulses resulting from the different transit lengths of different modes (pathway) along a fibre.
Material dispersion: Spreading out due to speed variation of different wavelengths.
In multi-modal fibres, modal dispersion is so significant that material dispersion is not considered an important factor.

Question 5

$$\sin\theta_c = \frac{n_{clad}}{n_{core}}$$

$$\sin 82.1 = \frac{1.49}{n_{core}}$$

$$n_{core} = 1.50$$

Question 6

$NA = \sqrt{n_{core}{}^2 - n_{clad}{}^2} = \sqrt{1.50^2 - 1.49^2} = 0.21$ **(note if use approximate value for ncore of 1.50 NA= 0.17)**

Question 7

Reading off graph: For 1.0 μm, Loss is 0.9 *dB /km*
So, for 3 *km*, total loss is 2.7 *dB*

Question 8

Rayleigh scattering involves the scattering of light from small imperfections in the core of an optical fibre.
Absorption is the process where impurities such as hydroxyl ions or SiO_2 molecules absorb optical energy and transform it into heat.
Rayleigh scattering is most significant at shorter wavelengths (including here at 1.0 μm).

Question 9

Coherent bundles are able to guide light in predictable, ordered patterns – essential for cameras.
Incoherent bundles simply provide a path for a light source, without any concern for order or image creation.

Question 10

Optical based sensing systems have many advantages over copper based circuits:
- They are more resistant to high/low temperature and pressure variation
- They can be fabricated into composite materials such as carbon fibre
- They are smaller and less massive (dead weight saving)
- They are not affected by electromagnetic radiation (e.g. radio signals)

Detailed Study 3- Sound

Question 1

$v = f\lambda$

$\lambda = \frac{v}{f} = v \times T = 330 \times 0.004 = 1.32m$

Question 2

96 dB = $10^{\left(\frac{96}{10} - 12\right)} = 3.98 \times 10^{-3}$ Wm^{-2} (Alex)
Using inverse square law:

$I_{Joel} = \frac{3.98 \times 10^{-3} \times 12^2}{8^2} = 8.96 \times 10^{-3} Wm^{-2}$

$L_{Joel} = 10 \log\left(\frac{8.96 \times 10^{-3}}{1 \times 10^{-12}}\right) = 99.52$ dB= 100 dB

Question 3

Third harmonic: $f_3 = 3 \times \frac{v}{2L}$

$v = \frac{3330 \times 2 \times 0.15}{3} = 333 ms^{-1}$

Question 4

If 3rd harmonic is 3330 Hz, then fundamental is 1110 Hz. Thus B and D (2nd Harmonic) are possible.

Question 5

As sound travels ~ 3 times faster in Helium compared to air, the frequency of the harmonics which will resonate in Alex's vocal chords will be increased. Her voice will be higher pitched.

E.g.: $f_3 = 3 \times \frac{v}{2L} = 3 \times \frac{1005}{0.3} = 10050 Hz$

Question 6

Microphone B offers the flattest, most even response in the required range. It is flat from ~ 300 – 9000 Hz.

Question 7

A, C and D are all FALSE:
A: Increased pressure **reduces** resistance.
C: Diaphragm is charged positive on **one side only.**
D: **Thin** and **less** rigid ribbons respond better to signals.

Question 8

50 dB at 1000Hz is on the 50 phon.
70 dB crosses this phon at 40 Hz and ~ 10,000 Hz.

Question 9

The key here is to identify diffraction as the primary reason for the variation (although some reference to phon curves would be valid too – Alex's ear would be naturally more sensitive to 3000 Hz signal)

Using Alex's head as the "obstacle" around which diffraction occurs:

For the 250 Hz signal: $\frac{\lambda}{w} = \frac{\left(\frac{340}{250}\right)}{0.25} = 5.4$, indicating significant diffraction

For the 3000 Hz signal: $\frac{\lambda}{w} = \frac{\left(\frac{3000}{250}\right)}{0.25} = 0.45$, indicating minimal diffraction

More diffraction would make it much harder to locate a sound source as the intensity of the sound reaching both ears would be similar. Thus the 3000 Hz signals would be easier to locate.

Question 10

An airtight box acts as an infinite **baffle**, minimizing the destructive **interference** caused by positive and negative pressure regions interacting at the edge of a moving speaker cone.
A diagram showing a cone without baffle, with regions of positive and negative pressure would be essential
A simple sketch of a box around the cone would be enough to indicate the enclosure.