GLASGOW COLLEGE UESTC

Final Exam Solution

Physics II (Course Code)

Q1 Multiple choice

Choose the ONE alternative that best completes the statement or answer the question.

1. (B) A conducting rod in a uniform magnetic field rotates about its end as shown in the figure. How much is the induced EMF? [3]

(A) $\varepsilon = BL^2\omega$

(B) $\varepsilon = \frac{1}{2}BL^2\omega$

(C) $\varepsilon = \frac{1}{3}BL^2\omega$

(D) $\varepsilon = 0$

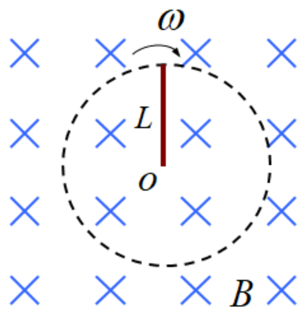

Figure Q1-1.

2. (C) In an LC circuit, the current changes as $I = I_0 \sin \omega t$. What is the energy stored in the Capacitor? [3]

(A) $U = \frac{1}{2}CI_0^2 \cos^2 \omega t$

(B) $U = \frac{1}{2}CI_0^2 \sin^2 \omega t$

(C) $U = \frac{1}{2}LI_0^2 \cos^2 \omega t$

(D) $U = \frac{1}{2}LI_0^2 \sin^2 \omega t$

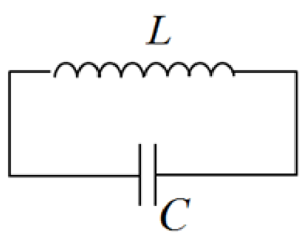

Figure Q1-2.

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3. (B) There are some statements about an electromagnetic wave. Which of them is CORRECT? [3]

(A) The electric field and magnetic field caused by the wave is always parallel to each other.

(B) The electric field and magnetic field at the same point oscillates in phase.

(C) The energy is transported along the direction of electric field.

(D) The wave speed is independent of the medium in which it travels.

4. (C) Someone measures the volume of a cube at rest to be V_0. He then measures the volume V of the same cube, when it passes him at speed v=0.980c in a direction parallel to one side of the cube. How much is V_0 / V? [3]

(A) 0.04 (B) 0.20

(C) 5.0 (D) 25.3

5. (A) Two spaceships leave Earth in the same direction, with a speed of **0.50c** and **0.80c** relative to the Earth respectively. What is the speed v of spaceship 2 relative to spaceship 1? [3]

(A) 0.50c (B) 0.80c

(C) 0.93c (D) 1.30c

6. (A) Photons may be emitted when a hydrogen atom initially at the 4th excited state jumps to other energy level. What is the maximum possible wavelength λ of the photons? [3]

(A) $4.05\times10^{-6}\,m$

(B) $1.88\times10^{-6}\,m$

(C) $3.27\times10^{-7}\,m$

(D) $9.50\times10^{-8}\,m$

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7. (D) The following figure shows the de Broglie wave of two nonrelativistic electrons. Then what is the relationship about their kinetic energy? [3]

(A) $E_{k1} = 2E_{k2}$

(B) $E_{k1} = E_{k2}$

(C) $E_{k2} = 2E_{k1}$

(D) $E_{k2} = 4E_{k1}$

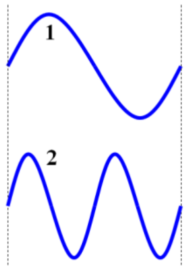

Figure Q1-7.

8. (D) A particle trapped in an infinitely deep square potential well of length L, has a wave functions $\psi(x) = \sqrt{\frac{2}{L}} \sin(\frac{2\pi}{L} x)$. What is the probability to find the particle in region $0 < x < \frac{L}{3}$? [2]

(A) 0.264

(B) 0.303

(C) 0.333

(D) 0.402

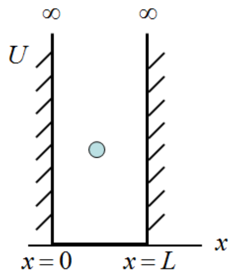

Figure Q1-8.

9. (C) Considering all possible values of quantum numbers (n, l, m_l, m_s), What is the maximum number of electrons in the shell for n=3 ? [2]

(A) 2

(B) 8

(C) 18

(D) 32

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Q2 A straight wire lies on a conducting rail in nonuniform magnetic field $B = bx$ (b is a constant) as figure. The wire moves along x axis with constant speed v, passing origin O when $t = 0$.

(a) Determine the magnetic flux Φ_B through the triangular loop at moment t. [7]

(b) Determine the induced EMF ε in the triangular loop. [6]

(c) If the magnetic field changes as $B = bx\sin t$, what is the induced EMF ε? [6]

(d) Write out the definition formula of self-inductance L, how does L of the triangular loop change when the wire moves? [6]

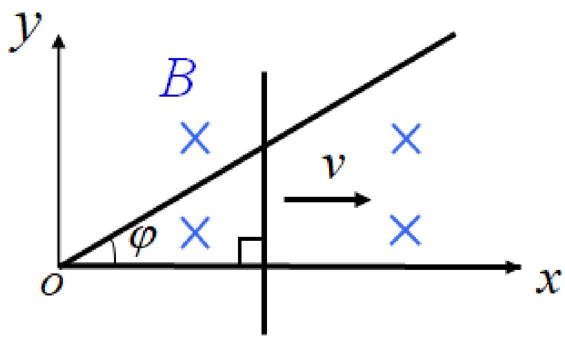

Figure Q2.

SOLUTION: (a) Choose a narrow slide dx as an infinitesimal, the magnetic flux is:

$$d\Phi_B = B \cdot x \tan\varphi \cdot dx \qquad [3]$$

So the total flux is $\Phi_B = \int_0^{vt} B \cdot x \tan\varphi \cdot dx$ [2]

$$= \int_0^{vt} b \tan\varphi \cdot x^2 dx = \frac{bv^3 \tan\varphi}{3} t^3 \qquad [2]$$

(b) By Faraday's law, the induced EMF is

$$\varepsilon = -\frac{d\Phi_B}{dt} \qquad [3]$$

$$= -bv^3 t^2 \tan\varphi \qquad [2]$$

Minus sign means the direction of ε is counterclockwise. [1]

(c) Now the flux is

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$$\Phi_B = \frac{bv^3 \tan\varphi}{3} t^3 \sin t \qquad [3]$$

So the induced EMF is

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

$$= -bv^3 \tan\varphi \cdot t^2 \sin t + \frac{bv^3 \tan\varphi}{3} t^3 \cos t \qquad [3]$$

Where the positive direction is clockwise.

(d) Self-inductance: $L = \frac{\Phi_B}{I}$, where I is the current in the loop, and Φ_B is the magnetic flux through the loop due to the current. [3]

When the wire moves and I keeps constant, the magnetic flux increases. So the Self-inductance increases. [3]

Q3 Wireless power transmission technology can transfer energy by electromagnetic waves. Suppose the electromagnetic wave has a frequency of 6.0MHz, and it transfers 5.0W average power through an effective area 30cm^2.

(a) Write out the Maxwell's equations, and use them to explain the production of electromagnetic waves. [8]

(b) What is the maximum value of electric field $E_{\max}$ and magnetic field $B_{\max}$ due to the electromagnetic wave? [7]

(c) How many photons pass through the 30cm^2 area in 1 second? [5]

(d) If this electromagnetic wave shines onto a metallic surface, can we observe the Photoelectric Effect, why? [5]

SOLUTION: (a) Maxwell's equation:

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$$\oint\!\!\!\oint \vec{E}\cdot d\vec{S} = \frac{Q}{\varepsilon_0} \qquad \nabla\cdot\vec{E} = \frac{\rho}{\varepsilon_0}$$

$$\oint\!\!\!\oint \vec{B}\cdot d\vec{S} = 0 \qquad \nabla\cdot\vec{B} = 0$$

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d\Phi_B}{dt} \quad \text{or} \quad \nabla\times\vec{E} = -\frac{\partial\vec{B}}{\partial t} \qquad [6]$$

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I + \mu_0\varepsilon_0\frac{d\Phi_E}{dt} \qquad \nabla\times\vec{B} = \mu_0\vec{j} + \mu_0\varepsilon_0\frac{\partial\vec{E}}{\partial t}$$

From the 3rd and 4th equation we see changing electric field and magnetic field can excite each other, and the combination of 4 equations becomes a wave equation, which is electromagnetic wave. [2]

(b) The energy transporting rate:

$$\overline{S} = \frac{\overline{P}}{A} = \frac{1}{2}\frac{E_{\max}B_{\max}}{\mu_0} = \frac{1}{2}\varepsilon_0 c E_{\max}^2 \qquad [3]$$

So the maximum value of electric field:

$$E_{\max} = \sqrt{\frac{2\overline{P}}{\varepsilon_0 c A}} = 1.12\times10^3\,V/m \qquad [2]$$

The maximum value of magnetic field:

$$B_{\max} = \frac{E_{\max}}{c} = 3.73\times10^{-6}\,T \qquad [2]$$

(c) Energy of a photon:

$$E = hf = 3.98\times10^{-27}\,J = 2.48\times10^{-8}\,eV \qquad [3]$$

So, the number of photons per 1s is

$$n = \frac{\overline{P}}{E} = 1.26\times10^{27}\,s^{-1} \qquad [2]$$

(d) From the result in (c), we cannot see the photoelectric effect. [2]

When an electron absorbs ONE photon and obtain energy greater than the work function W_0, it can get out of the surface, and that is so-called photoelectric effect. Typically, the work function W_0 is around the energy of a visible photon. Because the energy of a photon is too low in this question, the electrons cannot get out. [3]

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Q4 In a Compton scattering experiment, an X-ray photon collides with a resting electron, the wavelength of photon changes from 0.01nm to 0.011nm after the collision.

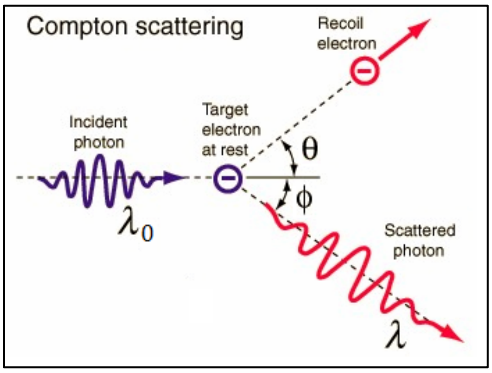
(a) Draw a figure to show the collision process, and determine the kinetic energy ΔE_k transferred from the photon to the electron. [5]

(b) About the electron after collision, how much is the total energy E, speed v and momentum p? [10]

(c) What is the de Broglie wavelength λ of electron? [5]

(d) If the relative uncertainty in momentum of the electron is 0.1%, what is the minimum uncertainty in position Δx, by Heisenberg uncertainty principle? [5]

SOLUTION: (a) The collision process is shown as figure. [2]



Energy transferred: $\Delta E_k = \frac{hc}{\lambda_0} - \frac{hc}{\lambda} = 1.81 \times 10^{-15} J = 1.13 \times 10^4 eV$ [3]

(b) The rest energy of electron is $E_0 = m_e c^2 = 5.12 \times 10^5 eV$

So the total energy is $E = E_0 + E_k = 5.23 \times 10^5 eV$ [3]

The relativity factor satisfies:

$$E = \gamma E_0 \Rightarrow \gamma = \frac{E}{E_0} = 1.022$$ [2]

The speed of electron can be obtained:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \Rightarrow v = \frac{c}{\gamma}\sqrt{\gamma^2 - 1} = 0.207c$$ [3]

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Momentum: $p = \gamma m_e v = 5.78 \times 10^{-23} kg \cdot m / s$ [2]

(c) de Brolie wavelength: $\lambda = \frac{h}{p}$ [3]

$$= 1.15 \times 10^{-11} m$$ [2]

(d) The uncertainty in momentum is $\Delta p = p \times 0.1\%$

Heisenberg uncertainty principle:

$$\Delta x \geq \frac{\hbar}{\Delta p}$$ [3]

$$= \frac{6.626 \times 10^{-34} / 2\pi}{5.78 \times 10^{-23} \times 0.1\%} = 1.82 \times 10^{-8} m$$ [2]

【Also valid: $\Delta x \Delta p \geq \frac{\hbar}{2} \Rightarrow \Delta x \geq 9.1 \times 10^{-9} m$】

End of question paper