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Glasgow College, UESTC

Physics II —Semester 1, 2018 - 2019

Final Exam Solution

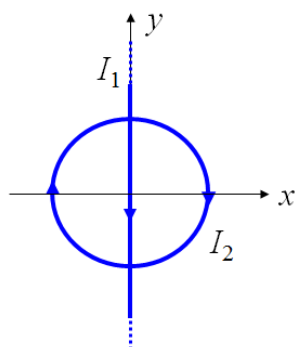
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Question 1 Multiple-choice Questions (3×6=18 points)

Choose the **ONE alternative** that best complete the statement or answer the questions.

(B) 1. Infinitely long current I_1 and circular current I_2 are insulated, and they lie on the same plane. What is the direction of magnetic force acting on current I_2?
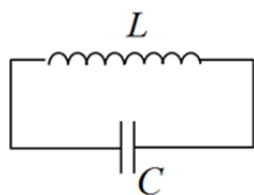

A) + x direction;

B) − x direction;

C) + y direction;

D) − y direction.

(A) 2. There are some equations and statements about the electrostatic field E_0 and induced electric field E_i. Which of them is correct?

A) $\oint \vec{E}_i \cdot d\vec{S} = 0$.

B) $\oint \vec{E}_0 \cdot d\vec{S} = Q_{in}$.

C) Both of these two types of field are conservative.

D) Both of these two types of field are produced by electric charges.

(D) 3. In an LC circuit, the current changes as $I = I_0 \cos \omega t$. What is the energy stored in the Capacitor?
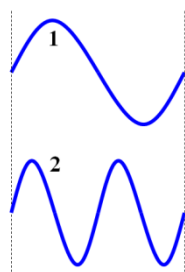

A) $U = \frac{1}{2} C I_0^2 \cos^2 \omega t$;

B) $U = \frac{1}{2} C I_0^2 \sin^2 \omega t$;

C) $U = \frac{1}{2} L I_0^2 \cos^2 \omega t$;

D) $U = \frac{1}{2} L I_0^2 \sin^2 \omega t$.

(A) 4. There are some statements about the Photoelectric Effect. Which of them is NOT correct?

A) The stopping voltage increases if the intensity of incoming light increases.

B) The stopping voltage increases if the frequency of incoming light increases.

C) An electron absorbs a photon so that it can escape from the metal surface.

D) If the frequency of incoming light is lower than the cutoff frequency, there is no photocurrent.

(C) 5. The following figure shows the de Broglie wave of particle 1 and particle 2. Then what is the relationship about their momentums?

A) $p_1 = 2p_2$;   B) $p_1 = 4p_2$;   C) $p_2 = 2p_1$;   D) $p_2 = 4p_1$.

(B) 6. According to the rules of quantum numbers of electrons inside atom, which of the following electron configuration is possible?
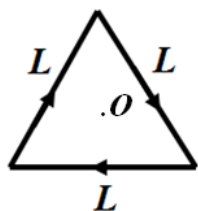
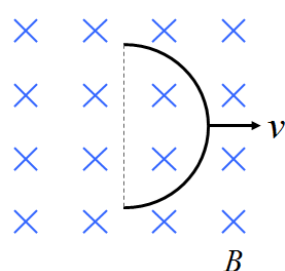A) $1s^2 2s^3 2p^3$;   B) $1s^2 2s^2 2p^5 3s^2$;   C) $1s^2 2s^2 2p^6 2d^2$;   D) $2s^2 2p^8 3s^2$.

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Question 2 Fill-in Questions (4×4=16 points)

1. Consider an equilateral triangle wire (length L for each side) with current I, how much is the magnetic field produced at its center o?

$$B = \underline{\hspace{1cm} \dfrac{9\mu_0 I}{2\pi L} \hspace{1cm}}.$$

2. A semicircular wire (radius R) is moving with speed v in the plane it lays, the moving direction is perpendicular to the diameter line (dashed line in the figure). If there is a magnetic field B as shown in figure, how much is the EMF in the wire? ε = _____ $2BRv$ _____.

3. Write out the Maxwell's equations corresponding to the description.

a. Electric field can be produced by changing magnetic field: _____ $\oint \vec{E} \cdot d\vec{l} = -\dfrac{d\Phi_B}{dt}$ _____

b. Magnetic field can be produced by different ways: _____ $\oint \vec{B} \cdot d\vec{l} = \mu_0 I + \mu_0\varepsilon_0 \dfrac{d\Phi_E}{dt}$ _____

4. An electron in the second shell may have a group of quantum numbers like $(n=2, l=0, m_l=0, m_s=\frac{1}{2})$. List 3 other possible groups of quantum numbers for it.

_____ $(n=2, l=0, m_l=0, m_s=-\frac{1}{2})$ _____

_____ $(n=2, l=1, m_l=0, m_s=\frac{1}{2})$ _____

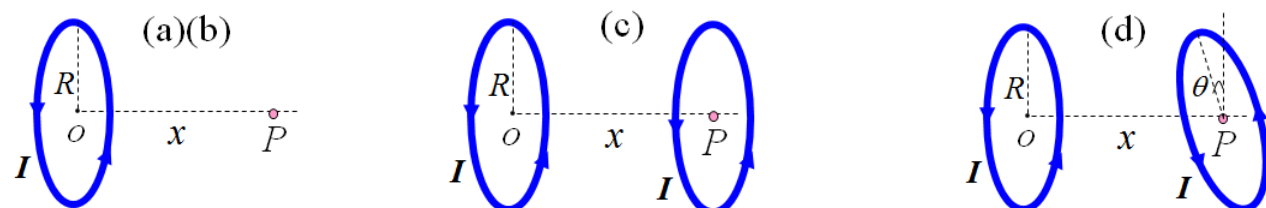_____ $(n=2, l=1, m_l=1, m_s=\frac{1}{2})$ or $(2,1,-1,\frac{1}{2}), (2,1,0,-\frac{1}{2}), (2,1,1,-\frac{1}{2}),\ (2,1,-1,-\frac{1}{2})$ _____

Score

Question 3 (20 points)

Consider a circular loop (radius *R*) with a current *I*.

(a) Calculate the magnetic field produced at point P (distance *x* from the center o) on its axis.

(b) How much is the magnetic moment *μ*?

(c) If another identical loop is place on point P, what is the mutual inductance *M* between these two loops? (Suppose *x* >> *R*, and two loops are coaxially placed)

(d) If the second loop rotates about P for a small angle *θ* and then it is released from rest, describe its motion. (Only consider the action of magnetic force, the mass of loop is *m*)
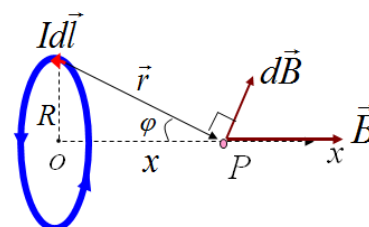

Solution: (a) From the symmetry, magnetic field has only axial component. (2 point)

Choose an infinitesimal current, we can obtain an integral for the total field:

$$B = \int \frac{\mu_0 I dl}{4\pi r^2} \sin\varphi \text{ (2 points)}$$

$$= \frac{\mu_0 I \sin\varphi}{4\pi r^2} \cdot 2\pi R = \frac{\mu_0 I R^2}{2r^3} = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}} \text{ (2 points)}$$

(b) Magnetic moment is defined as $\mu = IS$ **(2 points)**

So $\mu = \pi R^2 I$ **(2 points)**

(c) If *x* >> *R*, $B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}} \approx \frac{\mu_0 I R^2}{2x^3}$ **, it can be treated as a constant nearby point P.**

The mutual inductance $M = \frac{\Phi_B}{I}$ **(2 points)**

$$= \frac{B \cdot \pi R^2}{I} = \frac{\mu_0 \pi R^4}{2x^3} \text{ (2 points)}$$

(d) There will be a magnetic torque acting on the second loop, and it will move as a simple harmonic motion. (2 points)

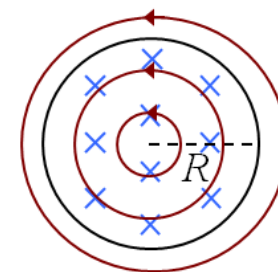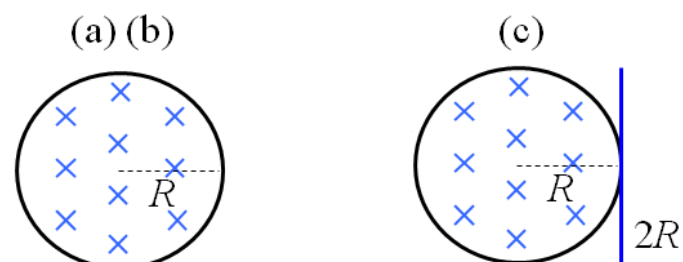$$\tau = \mu B \sin\theta \approx \frac{\mu_0 \pi R^4 I^2}{2x^3}\theta \quad \text{(2 points)}$$

The period is $T = 2\pi\sqrt{\frac{mx^3}{2\mu_0 \pi R^2 I^2}}$ **(2 points)**

Score

Question 4 (16 points)

Uniform magnetic field exists only in a cylindrical space with radius R, and it changes as dB/dt = C > 0, where C is a constant.

(a) Calculate the induced electric field inside the cylindrical space.

(b) Calculate the induced electric field outside the cylindrical space.

(c) If a straight wire (length 2R) lays tangent to the solenoid at its center. What is the EMF in the wire?

$(a)\,(b)$ (c)

Solution: (a) Analyze the symmetry, we know the magnetic field lines are concentric circles. (2 points)

Use the general form of Faraday's law: $\oint \vec{E}_i \cdot d\vec{l} = E_i \cdot 2\pi r = -\dfrac{d\Phi_B}{dt} = -C \cdot S$ **(2 points)**

So for the induced electric field inside: $r < R:\ E_i = -\dfrac{C \cdot \pi r^2}{2\pi r} = -\dfrac{C}{2}r$ **(3 points)**

(b) For the induced electric field outside: $r > R:\ E_i = -\dfrac{C \cdot \pi R^2}{2\pi r} = -\dfrac{CR^2}{2r}$ **(3 points)**

(c) Consider an imaginary closed circuit with two extra wires 1 and 2.

Because these two wires are along the radial direction, they are perpendicular to the induced electric field.

So $\varepsilon_1 = \int \vec{E}_i \cdot d\vec{l} = 0 = \varepsilon_2$ **(3 points)**

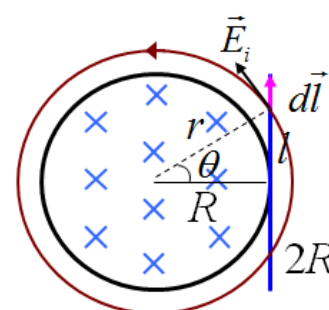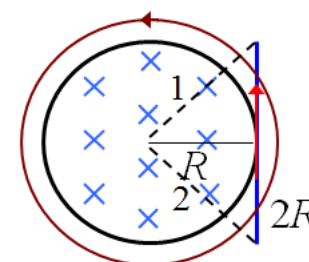**Thus the EMF in the real wire is equivalent to the closed circuit:**

$\varepsilon = \varepsilon_\Delta = -\dfrac{d\Phi_B}{dt} = -\dfrac{d}{dt}(\dfrac{\pi R^2 B}{4}) = -\dfrac{\pi R^2 C}{4}$ **(3 points)**

【**Alternative Solution**】

Choose an infinitesimal and write integral:

$\varepsilon = \int_L \vec{E}_i \cdot d\vec{l} = \int -\dfrac{CR^2}{2r}\cos\theta dl$ **(3 points)**

$= \int_{-\pi/4}^{\pi/4} -\dfrac{CR^2}{2}d\theta = -\dfrac{\pi R^2 C}{4}$ **(3 points)**

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Question 5 (20 points)

Radiation from the Sun reaches the Earth at a rate about 1350W/m^2.

(a) Assume it is a single electromagnetic wave, calculate the maximum electric field caused by this wave.

(b) Light is transmitted as photons, so if 100J sunshine is received by some device, how much photons are there? Assume that all the photons in sunshine have the same wavelength 550nm.

(c) Sometimes radiation may hurt human being. Visible light is also some kind of radiation, does it easily hurt human?

(d) What kinds of radiation are more dangerous to human being, and how do they cause the damage?

($h = 6.63 \times 10^{-34} J \cdot s, \ c = 3.00 \times 10^8 m / s, \ \varepsilon_0 = 8.85 \times 10^{-12} C^2 / N \cdot m^2, \ e = 1.60 \times 10^{-19} C$)

Solution: (a) Energy transmitting rate is intensity:

$$\overline{S} = \frac{1}{2} \frac{E_{max} B_{max}}{\mu_0} = \frac{1}{2} \varepsilon_0 c E_{max}^2 \quad \textbf{(3 points)}$$

So $E_{max} = \sqrt{\frac{2\overline{S}}{\varepsilon_0 c}} = 1.01 \times 10^3 V / m$ **(2 points)**

(b) A photon with wavelength 550nm has energy $E = \frac{hc}{\lambda} = 3.62 \times 10^{-19} J = 2.26 eV$ **(3 points)**

So In 100J sunshine, the number of photon is $N = \frac{100J}{3.62 \times 10^{-19} J} = 2.77 \times 10^{20}$ **(2 points)**

(c) The energy range of visible photon is about $1.64 eV \sim 3.27 eV$ **(2 points)**

Compare to the ionization energy of Hydrogen atom, this is too small to cause chemical reactions which may hurt human being. (2 points)

(d) Ultraviolet rays, X-rays or γ-rays, the photons have greater energy than visible light. So that the radiation may motivate harmful chemical reactions, destroy DNA structure or other important structures, cause skin cancer or other diseases.

In addition, microwave radiation can motivate forced vibration of polar molecules (e.g. water molecules), the temperature increase may cause some damage. And low frequency electromagnetic waves may cause some resonance and disturb the physiological activities.

(6 points)

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Question 6 (10 points)

The wave function of a microscopic particle can be expressed as $\Psi = \begin{cases} Cx(1-x), & 0 \le x \le 1 \\ 0, & x < 0 \text{ or } x > 1 \end{cases}$, where C is a constant to be determined.

(a) Where does the particle have maximum probability density?

(b) What is the constant C?

(c) What is the probability to find the particle in region $0 < x < \dfrac{1}{3}$? (The probability distribution is given by $|\psi|^2$)

Solution: (a) The probability distribution is given by $|\psi|^2 = |C|^2 x^2 (1-x)^2$.

So let $x = \dfrac{1}{2}$, there is a maximum probability density. (2 points)

(b) Normalization condition: $\int_{-\infty}^{\infty} |\psi|^2 \, dx = \int_0^1 C^2 x^2 (1-x)^2 dx = 1$ (2 points)

so $C = \sqrt{30}$ (2 points)

(c) The probability to find the particle in region $0 < x < \dfrac{1}{3}$:

$$p = \int_0^{\frac{1}{3}} C^2 x^2 (1-x)^2 dx \quad \textbf{(2 points)}$$

$$= 30 \left(\frac{x^3}{3} - \frac{x^4}{2} + \frac{x^5}{5} \right) \Bigg|_0^{\frac{1}{3}} = \frac{17}{81} \quad \textbf{(2 points)}$$