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2015학년도 석사과정/석사·박사통합과정 후기모집 면접·구술고사 전공시험

과목명 : 실험 (Experiment) 2015. 5. 1 시행

[1] (20 pts) Consider a temperature sensor component X whose electrical resistance R_T changes depending on its temperature T like $R_T = R_{T0} + \Delta R_{T0} \times (T-T_0)$. Thus, if you measure the resistance value of the component X, you can measure the temperature of the surrounding media.

1) (7 pts) Set up a temperature measurement circuit to measure the temperature of the surroundng media using the component X. You can use all or some of the following components : a constant voltage source E_{const}, a voltmeter V_m, an ammeter A_m, a resistance R, and a capacitor C.

2) (13 pts) When analyzing electrical measurement data, one has to consider the input and output resistances of electrical instruments. Draw an equivalent circuit diagram for your temperature measurement circuit including the input and output resistances of the used instruments. Then, write down the equation for the temperature T using the measured voltage V (or current I) from the voltmeter (or ammeter). Note that the output resistance of the voltage source is R_E, the input resistance of the voltmeter is R_V, and the input resistance of the ammeter is R_A.

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과목명 : 역학 및 전자기 (50분, 총 40점) 2015. 5. 1 시행

[1] Assume that there exists a heavy particle with magnetic charge q. The following magnetic field

$$\vec{B} = \frac{q}{4\pi}\frac{\vec{r}}{r^3}$$

is formed around this particle. ($\vec{r}$ the position measured from the magnetic charge.) An electron with mass m and electric charge −e moves around it. The mass of the magnetic charge is much larger than m, so you can ignore its motion.

(a) (15 points) Show whether the orbital angular momentum

$$\vec{L} = m\vec{r}\times\vec{v}$$

of the electron around the magnetic charge is conserved. ($\vec{r}$ is the position of the electron from the magnetic charge.) Also, show whether

$$\vec{J} = m\vec{r}\times\vec{v} + \frac{eq}{4\pi}\frac{\vec{r}}{r}$$

is conserved. You may use the formula

$$\vec{A}\times(\vec{B}\times\vec{C}) = \vec{B}(\vec{A}\cdot\vec{C}) - \vec{C}(\vec{A}\cdot\vec{B})$$

if necessary.

(b) (10 points) Consider the electric field produced by the electron, and the magnetic field produced by the magnetic charge, as shown in Figure 1. The momentum density produced by the electromagnetic fields is given by

$$\vec{P} = \frac{1}{c^2\mu_0}\vec{E}\times\vec{B} \quad .$$

The angular momentum of these fields around the magnetic charge is given by the integral of the angular momentum density $\vec{r}\,'\times\vec{P}$ over spatial coordinate $\vec{r}\,'$ (measured from the magnetic charge). Without doing explicit evaluation, show that this angular momentum is proportional to

$$eq\frac{\vec{r}}{r} \quad .$$

With this result, interpret the conserved quantity that you found in problem (a). (ϵ_0 , μ_0: vacuum permitivity and permeability, c: light speed)

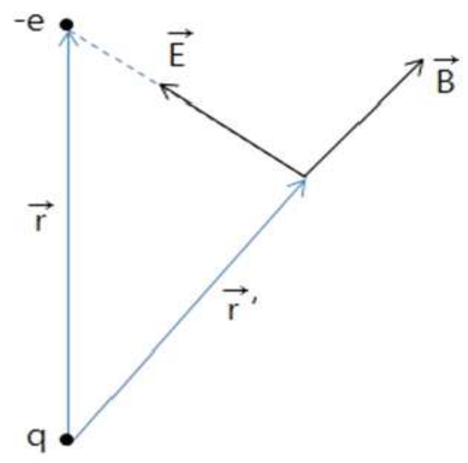

Figure 1

(c) (15 points) Now consider a heavy particle carrying magnetic charge q, and also an electric charge Ze (with $Z > 0$). An electron with mass m and electric charge −e moves around it. The mass of the heavy particle is much larger than m. Show that uniform circular motions are allowed around an axis which passes through the heavy particle, in which the position $\vec{r}$ of the particle m from the heavy particle makes an angle θ with the rotation axis. See Figure 2. With given θ, compute the speed and the radius of the circular motion.

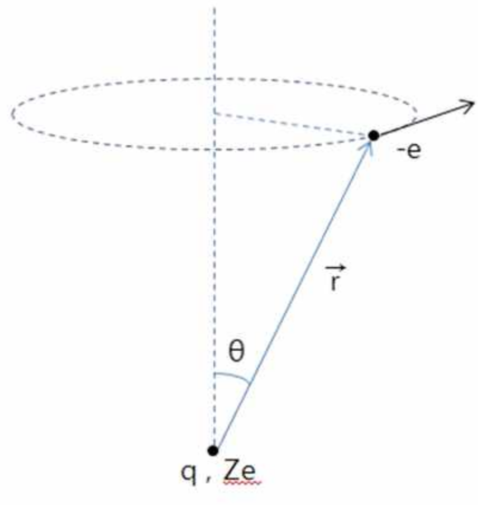

Figure 2

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1. Consider a Hamiltonian $H(t) = H_0 + V(t)$ which is composed of a time-independent Hamiltonian H_0 and time-dependent perturbation $V(t)$. Assume that we know the energy eigenvalues ε_n and corresponding eigenstates $|\psi_n\rangle$ of H_0 defined by $H_0|\psi_n\rangle = \varepsilon_n|\psi_n\rangle$.

(a) (5 pts) Suppose that the wave function in the presence of $V(t)$ is of the following form:

$$|\psi(t)\rangle = \sum_n c_n(t) e^{-\frac{i}{\hbar}\varepsilon_n t}|\psi_n\rangle.$$

Find the differential equation that $c_n(t)$ satisfies.

(b) (10 pts) Suppose that at $t=0$ the system is in the ground state with $n=1$. At $t=0$ a time-independent perturbation V_0 was introduced for t_0 and turned off:

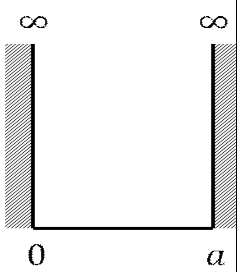
$$V(t) = \begin{cases} V_0 & \text{if } 0 < t < t_0, \\ 0 & \text{oterwise.} \end{cases}$$

At $t > t_0$, show that the transition probability from the ground state to an excited state with $n > 1$ up to first order in $V(t)$ is given by

$$P_{1\to n} \approx \frac{4|V_{n1}|^2}{\hbar^2 \omega_{n1}^2} \sin^2(\omega_{n1} t_0)$$

where $V_{nm} = \langle \psi_n | V_0 | \psi_m \rangle$ and $\hbar\omega_{nm} = \varepsilon_n - \varepsilon_m$.

(c) (10 pts) Consider an electron of mass m_e in a one-dimensional box with the size of $a = 10a_{\mathrm{B}}$ where a_{B} is the Bohr radius. For $V_0 = a\mathrm{Ry}\,\delta(x - a/2)$ and $t_0 = 10^{-2}\hbar/\mathrm{Ry}$, estimate $P_{1\to n}$ for $n = 2,3,4$. Explain the vanishing condition for $P_{1\to n}$ from the form of the wave functions.



Note that $\mathrm{Ry} = \frac{\hbar^2}{2m_e a_{\mathrm{B}}^2} = \frac{e^2}{2a_{\mathrm{B}}} \approx 13.6\ \mathrm{eV}$.

2. Consider an ideal gas consisting of N identical particles of mass m within a three-dimensional container of volume V. Treat particles classically but taking into account the indistinguishability of the particles.

(a) (8 pts) Show that the partition function is given by $Z = \frac{Z_1^N}{N!}$ where $Z_1 = \frac{V}{\lambda_T^3}$, $\lambda_T = \sqrt{\frac{2\pi\hbar^2\beta}{m}}$, $\beta = \frac{1}{k_{\mathrm{B}}T}$ and k_{B} is the Boltzmann constant. Obtain the mean pressure P, the mean energy E and the heat capacity at constant volume C_V.

(b) (7 pts) The entropy S (which is a macroscopic quantity) is related with the partition function Z (which contains microscopic information about the system) as $S = k_{\mathrm{B}}(\ln Z + \beta E)$. Imagine that a partition is introduced to divide the ideal gas into two equal parts. Let's denote the entropy of one of the divided part as S'. Show that the entropy is an extensive quantity such that $S = 2S'$. Explain that the indistinguishability of the particles is essential to prove the extensive nature of the entropy. Note that $\ln N! \approx N\ln N - N$ for $N \gg 1$.