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과목명 : 실험 (20분, 총20점) 2015. 10. 23 시행

1. In Fig. 1, a circuit for a current measurement is shown and in Fig. 2, a schematic experimental setup is shown. In this experiment, one is trying to measure a sample which changes its resistance R_D according to the current flowing through it. As shown in Fig. 3, the sample's resistance varies from 100 MΩ (10^8Ω) to 0Ω below the absolute current value of |I| = 10 pA (10^{-11}A). A variable voltage source with a range of －10 mV to 10mV will be used and resistor R_E will be used to produce current (In other words, we will use the voltage source and a resistor as a current source). Ammeter used in this experiment can be regarded to be perfectly accurate and with negligible resistance.

(a) To observe the resistance change of this sample, one must be able to apply current of 10pA or less. The variable voltage source can increase the voltage by 0.1mV, and wire's resistance is less than 1Ω. Determine a proper value (range) of R_E to observe this sample's resistance change around |V|=1~2mV. (6 pts)

(b) Draw a schematic I-V curve (plot) expected from this experiment's result. V is the applied voltage from the variable voltage source. (8 pts)

(c) Due to small voltage and small current involved in this experiment, noise should be minimized. Describe possible noise sources and also suggest possible solutions to reduce noise level. (Hint : Noise can be electrical, thermal, or vibrational etc.). (6 pts)

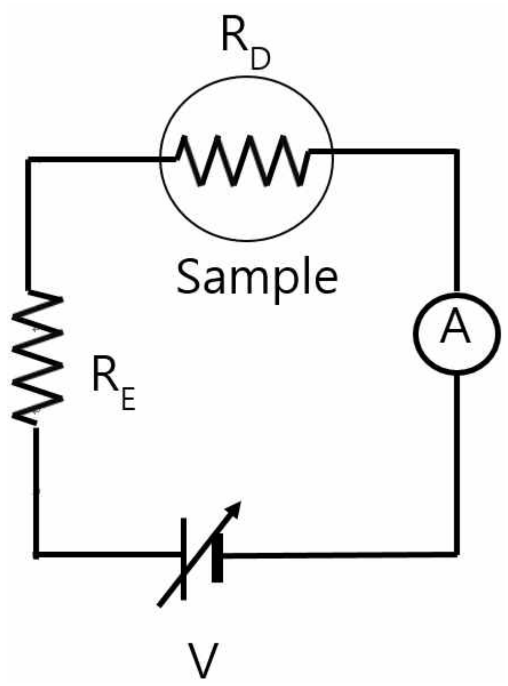

Fig. 1

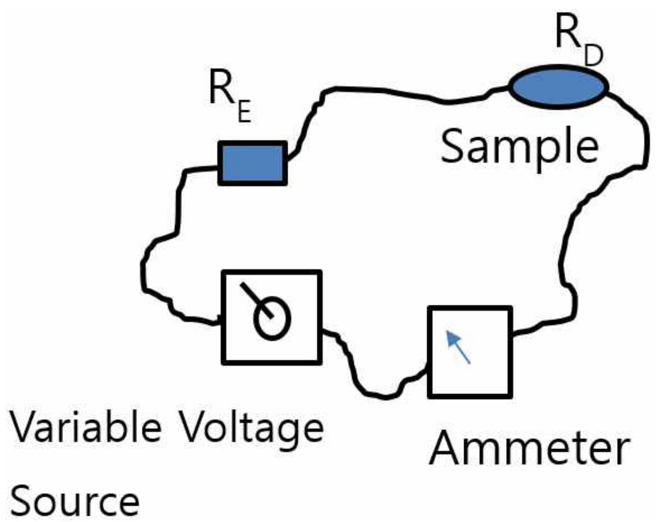

Fig. 2

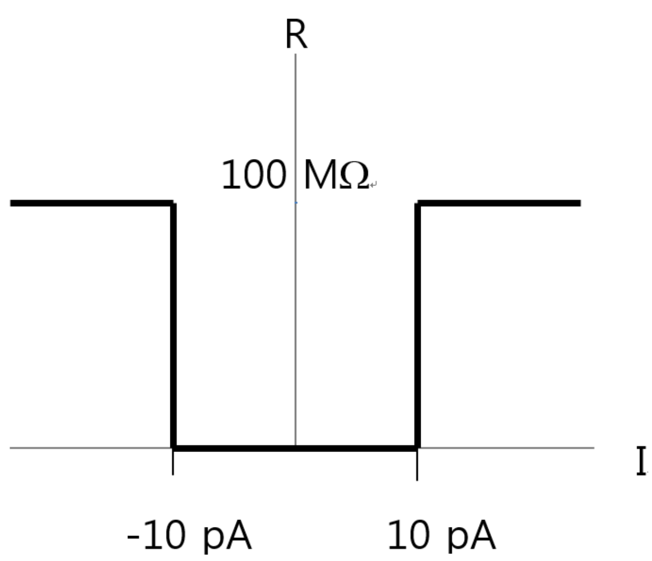

Fig. 3

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과목명 : 양자 및 통계 (50분, 총40점) 2015. 10. 23 시행

1. A spin-1/2 particle is placed in a time-dependent magnetic field

$$\vec{B} = B_0 \cos(\omega t)\hat{k}$$

where B_0 and ω are positive real constants, $\hat{k}$ is the unit vector along the z-axis, and t is time. The Hamiltonian is given by $-\vec{\mu} \cdot \vec{B}$ where $\vec{\mu} = \gamma \vec{S}$ is the magnetic dipole moment with spin $\vec{S}$ and positive gyromagnetic ratio γ. Note that the Pauli matrices are given by

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}.$$

(a) (10 pts) The particle was initially in the spin-up state with respect to the x-axis. Show that the time-dependent state vector $\chi(t)$ at time t is

$$\chi(t) = \frac{1}{\sqrt{2}} \begin{pmatrix} \exp[i \frac{\gamma B_0}{2\omega} \sin(\omega t)] \\ \exp[-i \frac{\gamma B_0}{2\omega} \sin(\omega t)] \end{pmatrix}$$

(b) (7 pts) Find the expectation value when the z-component of the spin is measured at time t.

(c) (8 pts) What is the minimum value of B_0 which will allow a probability of 1 for measuring the x-component of the spin to be “down”?

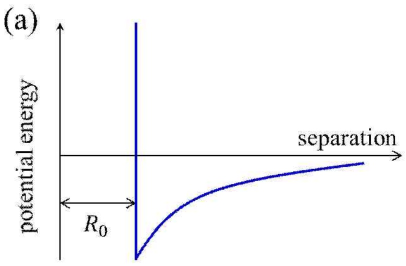
2. The equation of state for an ideal gas is given by

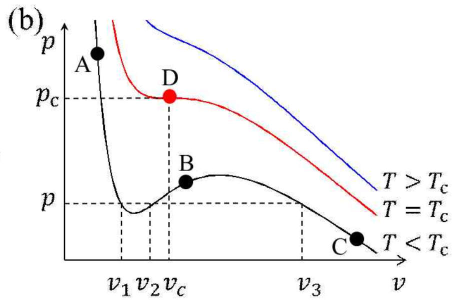
$$pv = k_B T$$

where p is the pressure, v is the volume per particle, T is the temperature and k_B is the Boltzmann constant. For a gas of interacting molecules, the equation of state can be modified as

$$\left(p + \frac{a}{v^2}\right)(v - b) = k_B T$$

where a and b are constants. Typically the intermolecular potential at small separation is repulsive due to the Coulomb repulsion of the overlapping electronic clouds, whereas at large separation it is attractive, as approximately shown in Fig. (a).





(a) (5 pts) Comparing with the ideal gas ($a = 0$ and $b = 0$), discuss (i) whether a is positive or negative and (ii) the physical meaning of $\frac{1}{v^2}$ dependence in $p + \frac{a}{v^2}$ term. What is the characteristic value of b in $v - b$ term?

(b) (5 pts) Figure (b) shows the p-v diagram for several temperatures. The compressibility is defined by $\kappa = -\frac{1}{v}\left(\frac{\partial v}{\partial p}\right)_T$, which describes the relative volume change with respect to a pressure change. From the sign and relative size of the compressibility, explain whether the point A is gas, liquid or unstable phase. Similarly discuss the points B and C.

(c) (5 pts) For a given p and $T < T_c$, generally there are three solutions in v (such as v_1, v_2, v_3 as seen in Fig. (b)). As T increases to a critical temperature T_c, they merge to v_c, thus the equation of state near the critical point D must be the following form:

$$(v - v_c)^3 = 0.$$

Express p_c, v_c and $k_B T_c$ in terms of a and b, and find $\frac{p_c v_c}{k_B T_c}$.

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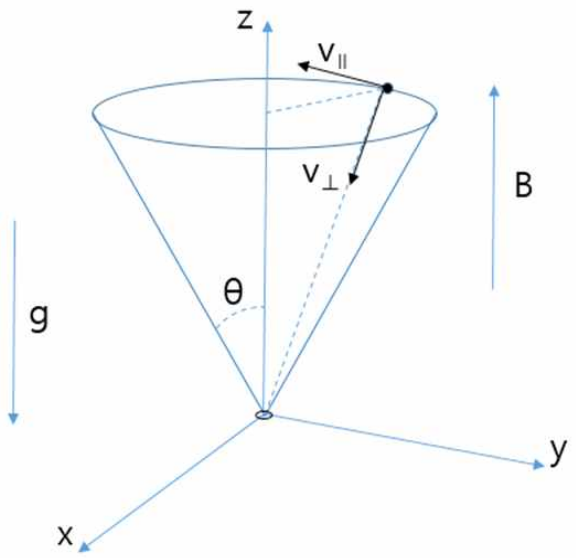
과목명 : 역학 및 전자기 (50분, 총40점) 2015. 10. 23 시행

1. Consider a conical surface which makes an angle θ with the vertical axis, as shown in the Figure. A particle with mass m and charge q>0 can move without friction on the surface. The gravity acts downwards with gravitational acceleration g, and a



uniform magnetic field B>0 is also applied along the z axis. At the bottom tip of the cone is a small hole on the surface, which the particle may fall into.

(a) Show that the following “angular momentum”

$$J_z = L_z + \frac{qB}{2}\rho^2 = m\left(x\dot{y} - y\dot{x}\right) + \frac{qB}{2}\rho^2$$

is conserved, where dots denote time derivatives and $\rho \equiv \sqrt{x^2+y^2}$. [Hint: Calculate the following quantity, $\frac{dL_z}{dt} = \hat{z}\cdot\frac{d\vec{L}}{dt}$, where $\vec{L}$ is the orbital angular momentum of the particle.] Also, by decomposing the particle velocity into $\vec{v}_{\perp}$ and $\vec{v}_{\parallel}$ as shown in the Figure, show that one can write

$$J_z = m\rho v_{\parallel} + \frac{qB}{2}\rho^2 \quad .$$

Here $\vec{v}_{\parallel}$ is on the xy plane tangential to the circle of the cone, and $\vec{v}_{\perp}$ is on the surface of the cone pointing to the bottom tip. ($v_{\parallel}$ is positive / negative for counter-clockwise / clock-wise rotations, respectively, when looked down from the positive side of the z axis.) (10 pts)

(b) The particle starts its motion on the surface at the height z=h, at rest. Show that the particle cannot pass through the hole at z=0 (or equivalently $\rho = 0$). [Hint: Use the conservation of J_z , and also the energy conservation if necessary.] (7 pts)

(c) Now suppose that the particle starts from z=h with the following components of the initial velocity: $v_{\perp}$ = 0 and $v_{\parallel}$ = u. Show that the particle can NOT pass through the hole UNLESS

$$u = u_{*} \equiv -\frac{qBh}{2m}\tan\theta \ .$$

(8 pts)

(d) Assuming the initial condition of problem (c), with $u = u_{*}$, show that z decreases monotonically towards z=0, thereby proving that the particle can actually pass through the hole. [Hint: Consider the expression for $v_{\perp}$ as a function of z, which one can obtain using conservation laws. Then check if $v_{\perp}$ can change sign.] (15 pts)