NATIONAL UNIVERSITY OF SINGAPORE

PC4240 – SOLID STATE PHYSICS-II

(Semester II: AY2009-10)

Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

1. This examination paper contains **FOUR** questions and comprises **THREE** printed pages.
2. Answer any **THREE** questions.
3. Answers to the questions are to be written in the answer books.
4. This is a CLOSED BOOK examination.

1. (a) A thin metallic slab is subjected to a magnetic field B along the z-direction and an oscillating plane-polarized electric field in the x-y plane [$E = E_0 e^{i\omega t}$ and $v = v_0 e^{i\omega t}$ where v is the velocity of oscillating electrons and ω is the angular frequency of the incident wave]. The power absorbed from the electric field is proportional to the real part of the conductivity $\sigma(\omega)$.

(a) Using the equation of motion for an electron in crossed electric and magnetic fields, show that

$$\sigma(\omega) = \sigma_0 \left[\frac{1 + i\omega\tau}{1 + (\omega_c^2 - \omega^2) + 2i\omega\tau} \right]$$

where σ_0 is the dc conductivity ($\omega = 0$) and τ is the relaxation time of electrons and ω_c is the cyclotron resonance frequency.

(b) Explain how the above cyclotron resonance experiment is useful to determine the effective masses of electrons and holes in a semiconductor.

2. (a) Why does a superconducting ring trap a magnetic field when it is cooled in the presence of a magnetic field below its critical temperature (T_C) and then the magnetic field is removed ?

(b) The wave function for a superconductor can be written as $\psi = \sqrt{n} e^{i\theta(r)}$ where $n = \psi^* \psi$ is the concentration of the Cooper pairs and $\theta(r)$ is the phase.

Show that the flux (Φ) through the superconducting ring is quantized and is given by $\Phi = (2\pi\hbar c/q)s$ where q is the charge of a Cooper pair and s is an integer.

(c) What is a Josephson junction? Show that current (J) across the Josephson junction in absence of a dc voltage is given by $J = J_0 \sin\delta$ where $\delta = \theta_2 - \theta_1$ is the phase difference of a Cooper pair across the junction.

3. Starting from the Hamiltonian for an atom or an ion in the presence of a magnetic field (H), show that the diamagnetic susceptibility of a solid of volume V composed of N ions with all electronic shells filled is given by $\chi = -\frac{N}{V}\frac{Ze^2}{6m} < r^2 >$ where Z is the total number of electrons in the ion and $< r^2 >$ is the mean square ionic radius.

4. Consider an atom with two interacting spin-1/2 electrons. The ground state of such an atom can be a singlet with S = 0 or a triplet with S = 1. Let the energy difference between the single and triplet state be Δ. If $\Delta > 0$, the ground state is a singlet and $\Delta < 0$, the ground state is a triplet.

   (a) Find the expression for the susceptibility χ.

   (b) Sketch χ versus $k_B T/|\Delta|$ for the case $\Delta > 0$ and $\Delta < 0$ where k_B is the Boltzmann constant.

   (c) Show that energy per unit area to create a 180 deg domain wall in a ferromagnet is given by $\sigma_w = 2\pi\sqrt{(KJS^2/a)}$ where K is the anisotropy constant, J is the exchange integral, S is the spin quantum number and a is the lattice constant.

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(R. M)