NATIONAL UNIVERSITY OF SINGAPORE

PC4240 – SOLID STATE PHYSICS-II

(Semester II: AY2008-09, 29 April 09)

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) What are the differences between Hall resistance and magnetoresistance ? Show that the Hall coefficient for a semiconductor is given by

$$R_H = \frac{1}{e}\frac{p-nb^2}{(p+nb)^2}$$

where $b = (\mu_e/\mu_h)$ is the ratio of the mobility of the electron to hole, p and n are concentrations of holes and electrons.

(b) A sample of Si has been doped with unknown amounts of B to obtain p-type Si. The sample has rectangular dimensions of length = 10 cm, width = 2 cm and thickness =1mm. A constant current of 100 mA is passed through the sample along its length. When it is placed in a magnetic field of 0.16 T acting along its width, a Hall voltage of 30 μV is measured along its thickness. The atomic concentration of Si is 5 x10 ^{28} m^{-3}. The hole drift mobility is 140 cm^{2}V^{2}s^{-1}.

(i) Calculate the concentration of B atoms.
(ii) Calculate the resistivity of the sample.
(iii) Calculate the voltage drop along the sample.

2. (a) The transition metal scandium (Sc) has a single electron in the 3d subshell.

(i) Calculate the values of total angular momentum J and the Landé's splitting factor, g, and use these values to determine the lowest energy of a dipole moment in a field of 0.5 T.

(ii) Determine the relative probability of the atomic dipoles occupying the highest and lowest energy levels at temperatures of 1 K and 300 K.

(b) The valence electron concentration per unit volume of metallic Sodium is 2.65 x10^{28} m^{-3} and its Fermi energy is 3.22 eV. Derive the expression for the Pauli paramagnetic susceptibility of Sodium and find its diamagnetic contribution if the measured susceptibility is χ_p = 7.2 x10^{-6} (in SI unit).

(c) A magnetic field H of 10 T is applied to a solid of 1cm^3 containing N = 10^{20}, S = ½ magnetic ions. Derive the magnetic contribution to the specific heat C_V and to the entropy S. Then estimate the order of magnitude C_V at T = 1 K and T = 300 K.

3. (a) In the mean-field approximation, the spontaneous magnetization within a domain is given by $M_s = M_0 \tanh(\mu_0 \mu \lambda M_s / k_B T)$ where λ is the Weiss constant and M_0 is the magnetization at T = 0 K.

Show that at just below T_C, $M_s \propto \sqrt{T_C - T}$.

(b) Show that according to the theory of spin-wave excitation, the decay of magnetization at low temperatures is described by $\Delta M/M_0 = AT^{3/2}$ where A is a constant and $\Delta M = M_0 - M(T)$.

(c) The spontaneous magnetization of a spherical single particle of Ni of radius r and volume V is $M_s = 5.1 \times 10^5$ A m^{-1}. The energy required to form a Bloch wall is $\sigma_W = 0.7 \times 10^{-3}$ J m^{-2}. Find the critical radius for a single domain particle which will be such that the reduction in magnetostatic energy obtained by division into domains is less than the energy needed to form a wall.

4. (a) Explain the working principle of adiabatic demagnetization to reach milli kelvin temperatures. Draw clear illustrations.

(b) How will you distinguish a superconductor from a perfect conductor ?

(c) Assuming that the Heisenberg interactions can be introduced simply as an effective field that is proportional to the spontaneous magnetization within a domain, derive an expression for the magnetization of a domain as a function of magnetic field H, magnetic moment per atom μ and temperature T starting from the classical Langevin equation for paramagnetism.

If $\mu = 2 \times 10^{-23}$ Am^2, N = 9×10^{28} m^{-3} and $T = 300$ K, find the value of the mean field parameter (i.e., the Weiss constant λ) which is needed in order to cause spontaneous magnetization.

---End of the paper---

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