UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2000/2001 Academic Session

February/March 2001

ZCT 542/4 - Solid State Theory II

Time : 3 jam

Please check that the examination paper consists of **EIGHT** printed pages before you commence this examination.

Answer any FOUR questions. Candidates may choose to answer all questions in the Malay Language. If candidates choose to answer in the English Language, it is compulsory to answer at least one question in the Malay Language.

1. (a) Using the dielectric tensor as an example, explain what is meant by a second-rank tensor.

(10/100)

(b) Define the representation quadric (RQ) for a symmetric second-rank tensor.

(10/100)

(c) Using the principle that the RQ should be invariant for symmetry operations of the unit cell, prove that the RQ of a cubic crystal is a sphere.

(15/100)

(d) State with proofs the form of the RQ for tetragonal and orthorhombic crystals.

(25/100)

(e) An electromagnetic wave propagates along the c axis of an orthorhombic crystal. What are the wave velocities for waves that are plane-polarized along (i) the a axis, (ii) the b axis?

(10/100)

(f) Give a brief account of electromagnetic wave propagation in a general direction in an orthorhombic crystal.

(30/100)

[In the tetragonal unit cell all the angles are 90^0 and the side lengths are $a = b \neq c$. In the orthorhombic unit cell all the angles are 90^0 but *a*, *b* and *c* are all different]

2. (a) Draw a sketch to show a 180^0 Bloch domain wall in a ferromagnet. Explain the terms *exchange energy* and *anisotropy energy* and explain qualitatively how the balance between them determines the width of the Bloch wall.

(20/100)

(b) If $\mathbf{S}_1$ and $\mathbf{S}_2$ are the mean spin values on adjacent planes in your sketch the exchange energy may be written $-J\,\mathbf{S}_1 \cdot \mathbf{S}_2$. Assuming that the width is N layers and N >> 1 so that the angle ϕ between adjacent layers is small,show that on the assumption that ϕ has the same value throughout the wall the exchange energy of a line of spins in the wall is $W_{ex} = \pi^2 JS^2/2N$ and hence that the exchange energy per unit area is $w_{ex} = \pi^2 JS^2/2Na^2$ where a is the lattice constant. Explain why a simple approximate expression for the anisotropy energy is w_{anis} = KNa where K is a constant. Minimise the total wall energy $w = w_{ex} + w_{anis}$ and hence derive expressions for (a) the wall width N and (b) the minimum value of w.

(40/100)

(c) Sketch hysteresis loops to illustrate the difference between *soft* and *hard* magnetic materials and mention one application of each class.

(20/100)

(d) Explain the general form of the hysteresis loops in terms of pinning of domain walls and hence give a brief discussion of materials design for soft and hard behaviour.

(20/100)

3. (a) Consider a magnetic system with nearest-neighbour exchange forces only. Draw sketches to show (i) ferromagnetic, (ii) antiferromagnetic and (iii) ferrimagnetic ordering on a simple square lattice. How does the sign of the exchange determine the ordering?

(25/100)

(b) Sketch the temperature dependence of the static magnetic susceptibility in the paramagnetic phase ($T > T_C$) of (i) a ferromagnet and (ii) an antiferromagnet. Explain the physical reason for the difference between the two sketches.

(25/100)

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(c) The exchange coupling between two thin films of Fe separated by a thin film of Cr may be of either sign depending on the Cr thickness. Describe an experiment that illustrates this effect.

(25/100)

(d) Describe and explain the phenomenon of giant magnetoresistance in a Fe/Cr/Fe sandwich.

(25/100)

4. (a) Describe the nature of the phase transition to ferroelectricity for a simple one-dimensional two-sublattice model.

(10/100)

(b) Assuming that the transition is second-order, draw sketches to show the temperature dependence of (a) the specific heat, (b) the dielectric constant and (c) the spontaneous polarization P_S.

(20/100)

(c) The Landau free energy describing such a phase transition is

$$F = \alpha P^2 + \frac{1}{2}\beta P^4 \qquad \text{with} \quad \alpha = \alpha_0 (T - T_C)$$

and α_0, β both positive. Explain with the aid of suitable sketches how the form of F corresponds to your description of the transition. Derive from F the expression for the temperature dependence of P_S.

(30/100)

(d) Write a brief account of the applications of ferroelectric materials.

(40/100)

5. (a) Describe the Meissner effect in a Type I superconductor like Sn. Sketch magnetization curves to distinguish between Type I and Type II superconductors.

(25/100)

(b) Superconductivity is described as a macroscopic quantum phenomenon. Give an account of the flux quantization experiments in both conventional and high-T_C materials that support this statement.

(25/100)

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(c) Use the idea of macroscopic quantization to describe the mixed state of Type II superconductors and explain the distinction between reversible and irreversible materials.

(25/100)

(d) Why are irreversible materials used in solenoid windings? Explain why solenoid wires are protected against flux-jump instabilities by a copper sheath and explain how the protection works.

(25/100)

6. (a) Define the director in a liquid crystal.

(10/100)

(b) Describe in terms of director properties nematic, cholesteric, smectic A and smectic C liquid crystals.

(50/100)

(c) Light is incident along the helical axis in a cholesteric liquid crystal and a strong reflection band is observed over a narrow wavelength interval. Explain this result in terms of propagation of light along the helix within the liquid crystal.

(20/100)

(d) Explain why the wavelength interval of the strong reflection is generally temperature dependent. How is this temperature dependence used in applications?

(20/100)

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