SOLID STATE PHYSICS 1

- April 2004 -

Do not forget to write your full name and student number on <u>each</u> sheet.
Please use <u>separate</u> sheets for each of the four problems.

I.   The following questions should be answered very briefly (1-2 sentences)
a) What is a Fermi surface?
b) What happens when a type 1 superconductor is immerged into a homogeneous magnetic field ($H<H_c$; $T<T_c$)?
c) What is the necessary and sufficient condition to have optical branches in the phonon dispersion curves?
d) What is the difference between a hexagonal close packed structure and a face centred cubic structure?
e) Which properties of a crystal are influenced by the presence of point defects?
f) What is a piezoelectric material?
g) What is the Curie law (formula and description)?
h) What is a p-n junction?
i) Write down the conservation laws for collision between neutron and phonon. What is an umklapp process?
j) What is a Frenkel exciton?

II.   Consider a 3 dimensional metal with $n = N/V$ free electrons per volume unit (N is the total number of free electrons and V is the volume of the crystal). We will consider free electron theory and the temperature is T=0.

a) Calculate the Fermi energy ε_F expressed by n, $\hbar$ and m_e (the electron mass)

b) Show that the total energy E of the electrons is given by $E = 3/5\ N\varepsilon_F$.

PLEASE TURN !!!

III.   a) Apply Hund's rule to find the angular momentum quantum number, the spin quantum number and the total angular + spin momentum quantum number for

(i) Sm^{2+} in the configuration $4f^6$
(ii) Nd^{3+} in the configuration $4f^3$
(iii) Ni^{2+} in the configuration $3d^8$
Write down the ground state term in spectroscopic notation for all these cases.

b) Describe in words the definition and the most important properties of

(i)   Landau diamagnetism
(ii)   Pauli paramagnetism
(iii)   Ferro-magnetism
(iv)   Antiferro-magnetism

c) The elements in the first two columns of the periodic system (Li-Fr, Be-Ra) are all paramagnetic metals. Fe and its neighbouring elements are either ferro- or antiferromagnetic. Discuss.

IV.   Consider a linear chain consisting of identical atoms with mass M, connected by identical springs with spring constant C (see figure). Assume that each atom interacts with its nearest-neighbour atom only, and that this interaction is linear in the relative displacement along the chain.

M

C

a.   Give the equation of motion of the atoms as a function of their displacement along the chain.
b.   Calculate the phonon dispersion relation, and make a sketch of this.
c.   Give an expression for the sound velocity along the chain.
d.   Describe the physical meaning of the Debye temperature. Give an expression for the Debye temperature in the linear chain.

e. Derive an expression for the total phonon energy at low temperatures within the Debye approximation, and show that the heat capacity at low temperatures is linear in the temperature.

note:

$$\int_0^\infty \frac{x}{e^x - 1} dx = \frac{\pi^2}{6}.$$