ST MARY’S UNIVERSITY

TWICKENHAM, LONDON

BA/BSc Degree Examination students registered for

Level **Six**

Title: **Solid State Physics**

Code: **APH6002**

Semester: **ONE**

Date: **May 17th 2019**

Time: **9:30 – 11:30 AM**

TIME ALLOWED: **TWO** HOURS

Answer **all** questions from Section **A** and **three** questions from Section **B.**

Calculators are permitted.

**Section A (Answer all questions, 25 marks available)**

1. Using Hund’s rules, explain why the angular momentum quantum numbers J, L and S for Ho3+, which has an outer shell of 4f10 electrons, are J = 8, L = 6, and S = 2.

[5 marks]

1. Explain and give two examples of broken symmetry in the context of phase transitions.

[5 marks]

1. Discuss whether a material exhibiting a cubic temperature dependence of the heat capacity at low temperatures is a metal or an insulator.

[5 marks]

1. Find the mean free collision time for Copper using Drude’s model, given that Copper has an outer electron shell of 4s1, an atomic mass of 63.6 g/mol, a density of 8.9 g/cm3 and conductivity of 59.6 x 106 Ω-1 m-1.

[5 marks]

1. What is a Fermi Surface? State and explain the approximate shape of the Fermi surface for free electrons in a three-dimensional monovalent cubic metal?

[5 marks]

**Section B (Answer three questions, 75 marks available)**

1. (a) What is the Debye energy and for what wavelength of phonon does it occur? The Debye energy of a given material is 0.1 eV, calculate the Debye temperature.

[6 marks]

(b) For a single mode, what is the probability of occupancy of a phonon in an energy state of energy E?

[2 marks]

(c) Show that the phonon density of states g(E) dE is proportional to the energy squared.

[8 marks]

(d) Demonstrate that at low temperatures the phonon heat capacity contribution varies as the cube of temperature. State any assumptions that you make. [7 marks]

(e) A material has a unit cell in which the lattice sites are coupled along one dimension only. Comment on how you might expect the result in part (c) to change for this material.

[4 marks]

1. (a) Describe and explain the experimental setup and operation of a free induction nuclear magnetic resonance experiment to extract a nuclear magnetic resonance spectrum.

[6 marks]

(b) Sketch and explain the energy level splitting for a I=1/2 nuclear magnetic moment of a proton in an applied magnetic field. A proton has a g-factor of 5.58569468.

[4 marks]

(c) Calculate the magnetic field required to excite the proton moment between energy states for a nuclear magnetic resonance experiment operating at 60MHz.

[5 marks]

(d) The proton sits in a molecule in which it experiences spin-spin coupling from another proton within a molecule. (i) Enumerate the magnetic states, (ii) identify the transitions, and (iii) sketch and explain the nuclear magnetic resonance spectrum for this pair of atoms. [10 marks]

3. (a) Why does a superconducting material generate no electric field from their current density? Describe what happens to the superconducting state at its critical current density.

[5 marks]

(b) Describe and explain the Meissner effect. Why do superconducting materials have a susceptibility of -1?

[12 marks]

(c) Sketch the observed magnetization (M) against applied field (H) curves for a type 1 and type 2 superconducting materials. What happens in type 2 superconductors that accounts for the difference in M-H behaviour?

[8 marks]

4. (a) Gadolinium is ferromagnetic with a saturation moment of 7 Bohr magnetons and a critical temperature of 20 degrees Celsius. Explain what is meant by a ferromagnetic material and how the alignment differs from (i) paramagnetism, (ii) antiferromagnetic and (ii) a ferromagnetic material.

[8 marks]

(b) Sketch a graph of the expected magnetization changes with temperature in zero and non-zero magnetic fields for Ferromagnetic material with a critical temperature of 20 degrees Celsius and saturation magnetic moment of 7 Bohr magnetons.

[6 marks]

(c) What are magnons and how do they affect the low temperature magnetization?

[3 marks]

(d) Discuss are the factors that influence the formation of magnetic domains and walls.

[8 marks]

**END OF EXAMINATION**