Answer TWO questions.

The numbers in square brackets in the right hand margin indicate the provisional allocation of maximum marks per sub-section of a question.

1\. (a) With reference to the magnetostatic energy of a bulk ferromagnetic material, explain why in zero field the preferred state comprises magnetic domains. [2]

(b) Sketch the domain pattern in a rectangular bar magnet made from a single crystal ferromagnet, under the following conditions: [3]

(i) in zero field.

(ii) in a moderate field applied along the long axis of the bar.

(iii) in a very large field applied along the long axis of the bar.

(c) *"The widths of magnetic domain walls are determined by a balance between the anisotropy and exchange energies of the moments involved."* [4]

Discuss this statement with the aid of a sketch of a domain wall and definitions of the terms 'anisotropy energy' and 'exchange energy'.

(d) What is the Barkhausen effect? What causes it? [3]

(e) The Stoner-Wohlfarth model of rotational hysteresis assumes a polycrystalline assembly of single domain particles, each with an anisotropy energy: [8]

$E_{an} = - K \sin^2\theta.$

Show that the applied field needed to saturate the magnetisation in the assembly is given by:

$H_s = 2K / \mu_o M_s$,

where M_s is the spontaneous magnetisation within a domain.

[Hint: Consider a single particle, and the torque on M_s due to both the anisotropy and the applied field.]

2. (a) Describe the origins of the magnetic moments of atoms. [2]

(b) In the quantum theory of ferromagnetism the magnetisation M (in an applied field H) of a material containing localised electrons is given by: [8]

$$M = N\, g\, \mu_B\, J\, B_J(x)\,, \quad \text{where} \quad x = \mu_o\, g\, \mu_B\, J\, (H + \alpha M) / k_B T\,.$$

i. Define all the symbols used in this expression.

ii. What is the name of the function $B_J(x)$?

iii. Sketch the temperature dependence of the spontaneous magnetisation M_s of the ferromagnet in zero applied field.

iv. How does the expression differ for the case of a paramagnet?

v. Sketch M as a function of H in a paramagnet.

(c) Sketch the Slater-Pauling curve of net magnetic moment per atom as a function of the number of 3d electrons per atom, in the region of the elements Mn, Fe, Co and Ni. [6]

Discuss how the main feature of the Slater-Pauling curve may be understood from the band theory of ferromagnetism.

(d) The paramagnetic susceptibility of most metals is independent of temperature and is weaker than predicted by models based on localised electrons. [4]

Explain qualitatively why this is so, with reference to the effect of an applied field on the spin-up and spin-down sub-bands, and the populations of those sub-bands.

3. (a) Write a brief essay about **<u>one</u>** of the following: [8]

- Magnetism in the Earth's core and in naturally occurring minerals.
- The use of magnets in motors, transformers and loudspeakers.
- Biomagnetism and biomedical applications of magnetism.

(b) What are 'hard' and 'soft' magnetic materials, and what are they used for? [6]

(c) Describe the main aspects of **<u>either</u>** magnetic methods for non-destructive testing **<u>or</u>** magnetic recording using fine particle magnetic media. [6]