Problems

Q.1

Explain using annotated sketches, what is meant by (a) diamagnetism, (b) paramagnetism, (c) ferromagnetism, (d) anti-ferromagnetism and (e) ferrimagnetism.

If you had a solid specimen with unknown magnetic properties, what experiments would you carry out to determine to which of these five classes the material belonged?

Q.2

In nuclear magnetic resonance (NMR) experiments, a sample is placed in a large magnetic field, wrapped in a coil of wire. It is important that the magnetic field should be very homogeneous around the sample.

(a) Using sketches of the magnetic field applied to an object with $\chi > 0$, $\chi < 0$ and $\chi = 0$, explain why would it be beneficial for the wire that is used to make the coil to have zero magnetic susceptibility?

(b) Copper has a density of 8960 kg/m^3, an atomic weight of 63.55 amu and a Fermi energy of 7 eV. Copper metal consists of Cu^+ ions ([Ar]3d^{10}), each donating a 'free' electron to the solid. Assuming a mean orbital radius of 0.32 Å, and considering *two* relevant contributions to magnetic susceptibility, calculate whether you would expect copper metal to be net diamagnetic or paramagnetic, and estimate the susceptibility.

(c) How might a copper wire be treated in order to give zero total magnetic susceptibility?

(d) Assuming Rh^{3+} (rhodium) ions have electronic configuration [Kr]4d^6, estimate the magnetic moment of each rhodium ion. Estimate the percentage concentration of Rh^{3+} that would be needed as impurities within copper in order to yield zero total magnetic susceptibility, stating your assumptions.

(e) What would happen to this material if the wire was operated at low temperatures?

Q.3

List and briefly describe *three* different energies which must be considered when explaining the formation of magnetic domains within ferromagnetic materials. Which of these energies is instrumental in prohibiting the following theoretical magnetic structures in a ferromagnetic material:

a) atomic magnetic moments pointing in random directions
b) all atomic moments pointing in the same direction
c) magnetisation direction changing gradually throughout the material
d) magnetisation changing abruptly at the domain boundaries

Describe the way in which the domain structure changes when a magnetic field is applied, distinguishing between reversible and irreversible changes.

Q.4

The table below shows a measurement of the susceptibility of two materials, A and B, in the range 800–1000 K. How might these measurements have been carried out?

Temp. (K)	χ (A)	χ (B)	Temp. (K)	χ (A)	χ (B)
800	0.0054	0.00087	925	0.0020	0.00068
825	0.0040	0.00082	950	0.0018	0.00065
850	0.0032	0.00078	975	0.0016	0.00063
875	0.0027	0.00075	1000	0.0014	0.00060
900	0.0023	0.00071			

Deduce the Curie temperature of each material, and thus the exchange energy J. Both materials are composed of ions with spin $S = 1/2$, separated by 0.3 nm. The thickness of the domain wall in each is measured to be 20 nm for A and 200 nm for B. Stating your assumptions, estimate the anisotropy energy of both materials, and state which one of these you would term magnetically *hard*, and which one *soft*?

Q.5

Describe and justify the relative importance of the parameters: *saturation magnetisation* (B_s), *remnant field* (B_r), *coercive field* (B_c) and magnetic permeability (μ_r) for materials in the following applications:

(a) electromagnetic cores
(b) transformer cores
(c) permanent magnets
(d) information storage in hard disk drives

Give example values for the important parameter(s) in each case, and state any other properties that are important in choosing materials for these applications.