

### Level 3 Condensed Matter Physics- Part I

#### Weekly problem 4

##### (1) How much work has been done?

Starting with an expression relating the work done by the torque,  $\tau$ , when an object turns through a small angle  $d\theta$ , show that the potential energy of a magnetic dipole  $\mu$  in a magnetic field is  $E = -\mu \cdot \mathbf{B}$  [3 marks]

##### (2) Energy differences due to magnetism

An atom in a solid has a magnetic moment of  $2\mu_B$  and it is in the presence of a magnetic field of flux density 1 T. Calculate the highest and lowest potential energy states of the atom. How does the difference between these two energy states compare to the thermal energy of the solid at room temperature? [3 marks]

##### (3) Diamagnetism in Bismuth

(a) Bismuth ( $Z = 83$ , atomic mass = 208.98 u) is a diamagnetic material with a density of  $9.75 \times 10^3 \text{ kg m}^{-3}$ . Calculate the magnetic susceptibility of this element given that the root mean square atomic radius of bismuth is 0.16 nm. [2 marks]

(b) A magnetic field of strength  $3 \times 10^3 \text{ A m}^{-1}$  is applied to a sample of bismuth of mass 1 gram. Calculate the magnetic moment induced in the sample by the applied field. [2 marks]

Magnetic constant:  $\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$

Bohr magneton:  $\mu_B = 9.27 \times 10^{-24} \text{ A m}^2$

Boltzmann constant:  $k_B = 1.38 \times 10^{-23} \text{ J K}^{-1}$

Unified atomic mass unit:  $u = 1.66 \times 10^{-27} \text{ kg}$