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Problem 37.23 (RHK)

The coupling responsible for ferromagnetism is not the mutual magnetic interaction energy between two magnetic dipoles. To show this we will calculate (a) *the magnetic field a distance of* 10 nm *away along the dipole axis from an atom with magnetic dipole moment* 1.5×10^{-23} J T^{-1} (*cobalt*), *and* (b) *the minimum energy required to turn a second identical dipole end for an end in this field.*

Solution:

The magnetic field along the axis of a magnetic dipole of moment μ at a distance x from it is given by

$$B=\frac{\mu_0\mu}{2\pi x^3}.$$

It is given that a cobalt atom has magnetic dipole moment 1.5×10^{-23} J T^{-1}. The magnetic field at a distance of 10 nm from it along the dipole axis will therefore be

$$B=\frac{2\times10^{-7}\times1.5\times10^{-23}}{\left(10\times10^{-9}\right)^3}\ \text{T}=3.0\times10^{-6}\ \text{T}=3.0\ \mu\text{T}.$$

With this magnetic field the minimum energy required for turning a second identical dipole end to end will be $2\mu B$.

Substituting the values of μ and B, we find

$$2\mu B = 2\times 1.5\times 10^{-23}\times 3.0\times 10^{-6}\ \text{J} = 9.0\times 10^{-29}\ \text{J}.$$

We will calculate the thermal temperature at which the mean thermal kinetic energy of a cobalt atom will be comparable to $2\mu B$.

$$\frac{3}{2}k_B T = 2\mu B,$$

or

$$T = \frac{4\mu B}{3k_B} = \frac{2\times 9.0\times 10^{-29}}{3\times 1.38\times 10^{-23}}\ \text{J} = 4.3\times 10^{-6}\ \text{K}.$$

As the sample of the ferromagnetic material has to have a temperature of less than 10^{-6} K for the spin-spin alignment, we conclude that the spin-spin coupling is not the mutual magnetic interaction energy of elementary dipoles for ferromagnetism.