

CHAPTER 20

MAGNETIC PROPERTIES

PROBLEM SOLUTIONS

Basic Concepts

20.1 (a) We may calculate the magnetic field strength generated by this coil using Equation 20.1 as

$$H = \frac{NI}{l}$$

$$= \frac{(400 \text{ turns})(15 \text{ A})}{0.25 \text{ m}} = 24,000 \text{ A} \cdot \text{turns/m}$$

(b) In a vacuum, the flux density is determined from Equation 20.3. Thus,

$$B_0 = \mu_0 H$$

$$= (1.257 \times 10^{-6} \text{ H/m})(24,000 \text{ A} \cdot \text{turns/m}) = 3.0168 \times 10^{-2} \text{ tesla}$$

(c) When a bar of chromium is positioned within the coil, we must use an expression that is a combination of Equations 20.5 and 20.6 in order to compute the flux density given the magnetic susceptibility. Inasmuch as $\chi_m = 3.13 \times 10^{-4}$ (Table 20.2), then

$$B = \mu_0 H + \mu_0 M = \mu_0 H + \mu_0 \chi_m H = \mu_0 H(1 + \chi_m)$$

$$= (1.257 \times 10^{-6} \text{ H/m})(24,000 \text{ A} \cdot \text{turns/m})(1 + 3.13 \times 10^{-4})$$

$$= 3.0177 \times 10^{-2} \text{ tesla}$$

which is essentially the same result as part (b). This is to say that the influence of the chromium bar within the coil makes an imperceptible difference in the magnitude of the B field.

(d) The magnetization is computed from Equation 20.6:

$$M = \chi_m H = (3.13 \times 10^{-4})(24,000 \text{ A} \cdot \text{turns/m}) = 7.51 \text{ A/m}$$

20.4 (a) The two sources of magnetic moments for electrons are the electron's orbital motion around the nucleus, and also, its spin.

(b) Each electron will have a net magnetic moment from spin, and possibly, orbital contributions, which do not cancel for an isolated atom.

(c) All atoms do not have a net magnetic moment. If an atom has completely filled electron shells or subshells, there will be a cancellation of both orbital and spin magnetic moments.

20.10 Ferromagnetic materials may be permanently magnetized (whereas paramagnetic ones may not) because of the ability of net spin magnetic moments of adjacent atoms to align with one another. This mutual magnetic moment alignment in the same direction exists within small volume regions--domains. When a magnetic field is applied, favorably oriented domains grow at the expense of unfavorably oriented ones, by the motion of domain walls. When the magnetic field is removed, there remains a net magnetization by virtue of the resistance to movement of domain walls; even after total removal of the magnetic field, the magnetization of some net domain volume will be aligned near the direction that the external field was oriented.

For paramagnetic materials, there is no magnetic dipole coupling, and, consequently, domains do not form. When a magnetic field is removed, the atomic dipoles assume random orientations, and no magnetic moment remains.

The Influence of Temperature on Magnetic Behavior

20.15 For ferromagnetic materials, the saturation magnetization decreases with increasing temperature because the atomic thermal vibrational motions counteract the coupling forces between the adjacent atomic dipole moments, causing some magnetic dipole misalignment. Ferromagnetic behavior ceases above the Curie temperature because the atomic thermal vibrations are sufficiently violent so as to completely destroy the mutual spin coupling forces.

Domains and Hysteresis

20.16 The phenomenon of magnetic hysteresis and an explanation as to why it occurs for ferromagnetic and ferrimagnetic materials is given in Section 20.7.

20.17 (a) This portion of the problem asks that we compute the flux density in a coil of wire 0.5 m long, having 20 turns, and carrying a current of 1.0 A, and that is situated in a vacuum. Combining Equations 20.1 and 20.3, and solving for B yields

$$B_0 = \mu_0 H = \frac{\mu_0 NI}{l}$$

$$= \frac{(1.257 \times 10^{-6} \text{ H/m})(20 \text{ turns})(1.0 \text{ A})}{0.5 \text{ m}} = 5.03 \times 10^{-5} \text{ tesla}$$

(b) Now we are to compute the flux density with a bar of the iron-silicon alloy, the B - H behavior for which is shown in Figure 20.29. It is necessary to determine the value of H using Equation 20.1 as

$$H = \frac{NI}{l} = \frac{(20 \text{ turns})(1.0 \text{ A})}{0.5 \text{ m}} = 40 \text{ A-turns/m}$$

Using the curve in Figure 20.29, $B = 1.30$ tesla at $H = 40$ A-turns/m.

(c) Finally, we are to assume that a bar of Mo is situated within the coil, and to calculate the current that is necessary to produce the same B field as when the iron-silicon alloy in part (b) was used. Molybdenum is a paramagnetic material having a χ_m of 1.19×10^{-4} (Table 20.2). Combining Equations 20.2, 20.4, and 20.7 we solve for H

$$H = \frac{B}{\mu} = \frac{B}{\mu_0 \mu_r} = \frac{B}{\mu_0 (1 + \chi_m)}$$

And when Mo is positioned within the coil, then, from the above equation

$$H = \frac{1.30 \text{ tesla}}{(1.257 \times 10^{-6} \text{ H/m})(1 + 1.19 \times 10^{-4})} = 1.034 \times 10^6 \text{ A-turns/m}$$

Now, the current may be determined using Equation 20.1:

$$I = \frac{Hl}{N} = \frac{(1.034 \times 10^6 \text{ A-turns/m})(0.5 \text{ m})}{20 \text{ turns}} = 25,850 \text{ A}$$

Soft Magnetic Materials**Hard Magnetic Materials**

20.24 Relative to hysteresis behavior, a hard magnetic material has a high remanence, a high coercivity, a high saturation flux density, high hysteresis energy losses, and a low initial permeability; a soft magnetic material, on the other hand, has a high initial permeability, a low coercivity, and low hysteresis energy losses.

With regard to applications, hard magnetic materials are utilized for permanent magnets; soft magnetic materials are used in devices that are subjected to alternating magnetic fields such as transformer cores, generators, motors, and magnetic amplifier devices.

20.26 (a) The saturation flux density for the nickel-iron, the B - H behavior for which is shown in Figure 20.30, is 1.5 tesla, the maximum B value shown on the plot.

(b) The saturation magnetization is computed from Equation 20.8 as

$$M_s = \frac{B_s}{\mu_0}$$

$$= \frac{1.5 \text{ tesla}}{1.257 \times 10^{-6} \text{ H/m}} = 1.19 \times 10^6 \text{ A/m}$$

(c) The remanence, B_r , is read from this plot as from the hysteresis loop shown in Figure 20.14; its value is about 1.47 tesla.

(d) The coercivity, H_c , is read from this plot as from Figure 20.14; the value is about 17 A/m.

(e) On the basis of Tables 20.5 and 20.6, this is most likely a soft magnetic material. The saturation flux density (1.5 tesla) lies within the range of values cited for soft materials, and the remanence (1.47 tesla) is close to the values given in Table 20.6 for hard magnetic materials. However, the H_c (17 A/m) is significantly lower than for hard magnetic materials. Also, if we estimate the area within the hysteresis curve, we get a value of approximately 100 J/m^3 , which is in line with the hysteresis loss per cycle for soft magnetic materials.

Magnetic Storage

20.27 The manner in which information is stored magnetically is discussed in Section 20.11.

20.31 The Meissner effect is a phenomenon found in superconductors wherein, in the superconducting state, the material is diamagnetic and completely excludes any external magnetic field from its interior. In the normal conducting state complete magnetic flux penetration of the material occurs.