MSE 2002, Spring 2009
Homework Assignment 5, Due at start of class, Thursday, April 30

Solve the following problems:
20.1, 20.10, 20.15, 20.24
19.1 (solve for alumina only), 19.10, 19.18, 19.26 (a and b only)
21.1, 21.7, 21.13, 21.18, and 21.20

20.1

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

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

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

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

$$B_0 = \mu_0 H$$

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

(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 χ_m = 3.13×10^{-4} (Table 20.2), then

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

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

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

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:

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

20.15

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.

20.24

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.

19.1 (solve for alumina only)

19.1 The energy, E, required to raise the temperature of a given mass of material, m, is the product of the specific heat, the mass of material, and the temperature change, ΔT, as

$$E = c_p m \Delta T$$

The ΔT in this problem is equal to 150°C – 20°C = 130°C (= 130 K), while the mass is 5 kg, and the specific heats are presented in Table 19.1. Thus,

$$E(\text{aluminum}) = (900 \text{ J/kg-K})(5 \text{ kg})(130 \text{ K}) = 5.85 \times 10^5 \text{ J}$$

$$E(\text{brass}) = (375 \text{ J/kg-K})(5 \text{ kg})(130 \text{ K}) = 2.44 \times 10^5 \text{ J}$$

$$E(\text{alumina}) = (775 \text{ J/kg-K})(5 \text{ kg})(130 \text{ K}) = 5.04 \times 10^5 \text{ J}$$

$$E(\text{polypropylene}) = (1925 \text{ J/kg-K})(5 \text{ kg})(130 \text{ K}) = 1.25 \times 10^6 \text{ J}$$

19.10

19.10 The phenomenon of thermal expansion using the potential energy-versus-interatomic spacing curve is explained in Section 19.3.

19.18

19.18 Metals are typically better thermal conductors than are ceramic materials because, for metals, most of the heat is transported by free electrons (of which there are relatively large numbers). In ceramic materials, the primary mode of thermal conduction is via phonons, and phonons are more easily scattered than are free electrons.

19.26 (a and b only)

19.26 (a) We are asked to compute the magnitude of the stress within a brass rod that is heated while its ends are maintained rigid. To do this we employ Equation 19.8, using a value of 97 GPa for the modulus of elasticity of brass (Table 6.1), and a value of 20.0 x 10^{-6} $(°C)^{-1}$ for α_l (Table 19.1). Therefore

$$\sigma = E\alpha_l(T_0 - T_f)$$

$$= (97 \text{ x } 10^3 \text{ MPa})\left[20.0 \text{ x } 10^{-6} (°C)^{-1}\right](15°C - 85°C)$$

$$= -136 \text{ MPa} \quad (-20{,}000 \text{ psi})$$

The stress will be compressive since its sign is negative.

(b) The stress will be the same [–136 MPa (–20,000 psi)], since stress is independent of bar length.

21.1

21.1 In order to compute the frequency of a photon of green light, we must use Equation 21.2 as

$$\nu = \frac{c}{\lambda} = \frac{3 \text{ x } 10^8 \text{ m/s}}{5 \text{ x } 10^{-7} \text{ m}} = 6 \text{ x } 10^{14} \text{ s}^{-1}$$

Now, for the energy computation, we employ Equation 21.3 as follows:

$$E = \frac{hc}{\lambda} = \frac{(6.63 \text{ x } 10^{-34} \text{ J-s})(3 \text{ x } 10^8 \text{ m/s})}{5 \text{ x } 10^{-7} \text{ m}}$$

$$= 3.98 \text{ x } 10^{-19} \text{ J} \quad (2.48 \text{ eV})$$

21.7

21.7 We want to compute the velocity of light in diamond given that $\varepsilon_r = 5.5$ and $\chi_m = -2.17 \times 10^{-5}$. The velocity is determined using Equation 21.8; but first, we must calculate the values of ε and μ for diamond. According to Equation 18.27

$$\varepsilon = \varepsilon_r \varepsilon_0 = (5.5)(8.85 \times 10^{-12} \text{ F/m}) = 4.87 \times 10^{-11} \text{ F/m}$$

Now, combining Equations 20.4 and 20.7

$$\mu = \mu_0 \mu_r = \mu_0 (\chi_m + 1)$$

$$= (1.257 \times 10^{-6} \text{ H/m})(1 - 2.17 \times 10^{-5}) = 1.257 \times 10^{-6} \text{ H/m}$$

And, finally, from Equation 21.8

$$v = \frac{1}{\sqrt{\varepsilon\mu}}$$

$$= \frac{1}{\sqrt{(4.87 \times 10^{-11} \text{ F/m})(1.257 \times 10^{-6} \text{ H/m})}}$$

$$= 1.28 \times 10^{8} \text{ m/s}$$

21.13

21.13 This problem calls for a calculation of the reflectivity between two quartz grains having different orientations and indices of refraction (1.544 and 1.553) in the direction of light propagation, when the light is at normal incidence to the grain boundary. We must employ Equation 21.12 since the beam is normal to the grain boundary. Thus,

$$R = \frac{(n_2 - n_1)^2}{(n_2 + n_1)^2}$$

$$= \frac{(1.553 - 1.544)^2}{(1.553 + 1.544)^2} = 8.45 \times 10^{-6}$$

21.18

21.18 We are asked to compute the thickness of material to yield a transmissivity of 0.70 given that T is 0.80 when l = 15 mm, n = 1.5, and for normally incident radiation. The first requirement is that we calculate the value of β for this material using Equations 21.13 and 21.19. The value of R is determined using Equation 21.13 as

$$R = \frac{(n_s - 1)^2}{(n_s + 1)^2}$$

$$= \frac{(1.5 - 1)^2}{(1.5 + 1)^2} = 4.0 \text{ x } 10^{-2}$$

Now, it is necessary to compute the value of β using Equation 21.19. Dividing both sides of Equation 21.19 by $I_0(1 - R)^2$ leads to

$$\frac{I_T}{I_0(1 - R)^2} = e^{-\beta l}$$

And taking the natural logarithms of both sides of this expression gives

$$\ln\left[\frac{I_T}{I_0(1 - R)^2}\right] = -\beta l$$

and solving for β we get

$$\beta = -\frac{1}{l}\ln\left[\frac{I_T}{I_0(1 - R)^2}\right]$$

Since the transmissivity is T is equal to I_T/I_0, then the above equation takes the form

$$\beta = -\frac{1}{l}\ln\left[\frac{T}{(1 - R)^2}\right]$$

Using values for l and T provided in the problem statement, as well as the value of R determined above, we solve for β as

$$\beta = -\left(\frac{1}{15 \text{ mm}}\right)\ln\left[\frac{0.80}{(1 - 4.0 \text{ x } 10^{-2})^2}\right] = 9.43 \text{ x } 10^{-3} \text{ mm}^{-1}$$

Now, solving for l when $T = 0.70$ using the rearranged form of Equation 21.19 above

$$l = -\frac{1}{\beta}\ln\left[\frac{T}{(1-R)^2}\right]$$

$$= -\frac{1}{9.43 \text{ x } 10^{-3} \text{ mm}^{-1}}\ln\left[\frac{0.70}{(1-4.0 \text{ x } 10^{-2})^2}\right]$$

$$= 29.2 \text{ mm}$$

21.20

21.20 For a transparent material that appears colorless, any absorption within its interior is the same for all visible wavelengths. On the other hand, if there is any selective absorption of visible light (usually by electron excitations), the material will appear colored, its color being dependent on the frequency distribution of the transmitted light beam.