Chapter 16: Magnetic Materials and a Few Devices

16.1 For the magnetic circuit given in Figure 1 containing linear materials (free space surrounds the core), determine the flux, magnetic flux density, and magnetic field everywhere in the core and small gap. Assume the cross-sectional area is equal to *A* everywhere and the relative permeabilities of the core materials are much greater than one. Then, determine the inductance of the *N*-turn coil. Use superposition and "current" and "voltage" division, and do not simplify the expressions.

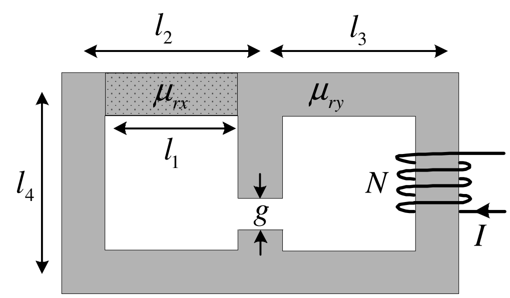


Figure 1

16.2 For the magnetic circuit given in Figure 2 containing linear materials (free space surrounds the core), determine the flux, magnetic flux density, and magnetic field everywhere in the core and small gap. Assume the cross-sectional area is equal to *A* everywhere and the relative permeabilities of the core materials are much greater than one. Use superposition and "current" and "voltage" division, and do not simplify the expressions.

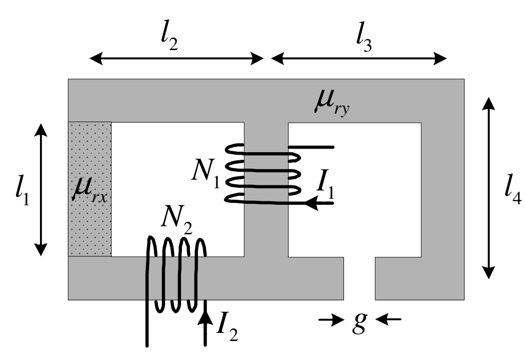


Figure 2

16.3 A current probe placed around air twin-lead line reads 1 mA. When the current probe is placed around only one wire it reads –0.3 mA. If an ideal common-mode choke is placed on this line, determine the new current level in each conductor. Note whether the magnitude of the current increases or decreases in each conductor.

16.4 For two-conductor cables such as twin-lead, carefully explain why the entire cable can be wrapped around a toroid if a common-mode choke is desired rather than physically separating the two conductors and then individually winding them around the toroid.

16.5 Why would Litz wire be used for the winding of a coil with a ferrite core?

16.6 A short piece of speaker wire that is connected to an amplifier is accessible (the remaining portion of the wire is hidden in the wall). Various types of common-mode chokes are used at this location. They have little effect on the interference. Does this imply that the interference is entering the system from another route? Explain. To (help) ensure that it is not entering via the speaker wire, what can be done?

16.7SC Modeling a wire inside a ferrite bead as a parallel *RLC* circuit, determine the geometry factor *K* and the value for the *R*, *L*, and *C* for three different beads by using actual measured impedance characteristics. Plot the magnitude of the impedance of the *RLC* circuit for each bead from 1 to 1,000 MHz and compare to the measured values. [Fair-Rite]

16.8 For the popular 43 ferrite material, a formula seen for the saturation current of a ferrite bead is $I_{sat} = 10R$ where *R* is the outer radius of the bead in cm. Determine the validity and limitations of this formula. [Kimmel, '94]

16.9SC Compare analytically and numerically the idealized inductance equation for a wire inserted in a bead versus the inductance equation for a one-turn toroidal-wound coil.

16.10 Explain how a ferrite bead can be used as a common-mode choke.

16.11 How could a ferrite filter around a shielded cable actually increase the susceptibility of a circuit to ESD?

16.12 For two-hole ferrite bead, where is the bead most likely to saturate first? State all assumptions.

16.13S It is stated that about 10 dB of insertion loss is possible from 1 MHz to 1 GHz for certain ferrite beads. Determine whether this is reasonable. Clearly state all assumptions.

16.14 If the common-mode signals on a line are not sinusoidal, will the common-mode choke still function properly? Explain.

16.15 If all three wires of an electrical power line (the hot, neutral, and ground wires) are wound on one common-mode choke, will it still function as a choke to common-mode signals? Will it affect the desirable signals on the power line? [Nave]

16.16S Explain how one paper towel cardboard roll and several bunches of steel wool could (in theory) be used as a crude RFI reducer for a television set. Assume the interference is conducted. Steel wool consists of long fine fibers of low-cost, low-strength low-carbon steel. Steel wool can be purchased in different grades (different fiber diameters and fineness) and is used in a wide variety of applications ranging from polishing woods to scouring pans. Measure the inductance of one conductor of a typical power cord with and without this steel-wool filter. What frequency(s) is the inductance meter using to determine the inductance? How does this affect the inductance measurement?

16.17 For differential-mode currents, for real loads, and for real characteristic line impedances, it is stated in this chapter that when the load impedance is small compared to the characteristic impedance, then the current is large at the load. Using the transmission line equations show that this statement is true.

16.18 Why are ferrite-loaded antennas typically only used for receiving and not transmitting?

16.19 Sometimes an air gap is introduced into the core of a coil wrapped around a toroid. Does the air-gap decrease or increase the maximum dc current that can be handled by the toroid before saturation? Does the air gap decrease or increase the leakage flux and the inductance of a winding on the toroid?

16.20 Graphically show that the differential permeability can be less than or greater than the relative permeability.

16.21 What is the saturation flux density for copper?

16.22 Derive the expression given in this chapter for the total power dissipated per cycle due to hysteresis losses:

$$P_{d,total} = \frac{8}{3}\nu H_m^3 fV \text{ W/cycle}$$

This assumes that the *B*-*H* curve can be described by the Rayleigh-loop expression:

$$B = \left(\mu_i + 2\nu H_m\right)H \pm \nu\left(H_m^2 - H^2\right)$$

Notice that B is given as a function of H not H as a function of B. Nevertheless, the hysteresis energy loss per unit volume per cycle is the area enclosed by the hysteresis curve.

16.23 An approximation for the demagnetization factor for a general ellipsoid is

$$N_a = \frac{1}{a}\left(\frac{abc}{ab+ac+bc}\right)$$

where a, b, and c are the lengths of the three axes of the ellipsoid. The magnetic field is parallel to the a axis. Determine whether this is a reasonable expression by providing three unique checks of this result with expressions provided in the chapter. [Watson]

16.24 Design, if possible, a 2 mH air-gap toroidal inductor with a total length of less than 5 cm if the dc current is 1.2 A and the ac signal amplitude is 20 mA. Use the Hanna curves given in this chapter.

16.25 Design, if possible, a 2 mH air-gap toroidal inductor with a gap length of greater than 100 mils if the dc current is 1.2 A and the ac signal amplitude is 20 mA. Use the Hanna curves given in this chapter.

16.26 Determine the net torque about the z axis for a circular loop carrying a current of I when in a magnetic field of

$$\vec{H} = H_x \hat{a}_x$$

where H_x is a constant. The loop has a radius of a, is centered about the origin, and is located in the xy plane. Is this torque equal to $\vec{m} \times \mu_o \vec{H}$? Why or why not?

16.27 Determine the net torque about the z axis for a circular loop carrying a current of I when in a magnetic field of

$$\vec{H} = H_\rho \hat{a}_\rho + H_\phi \hat{a}_\phi + H_z \hat{a}_z$$

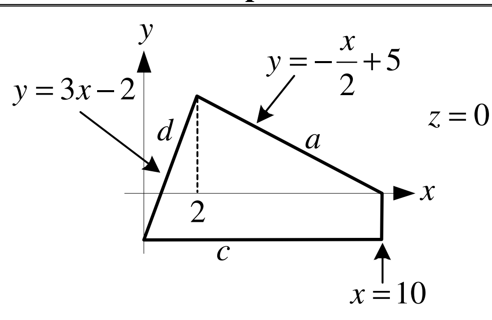
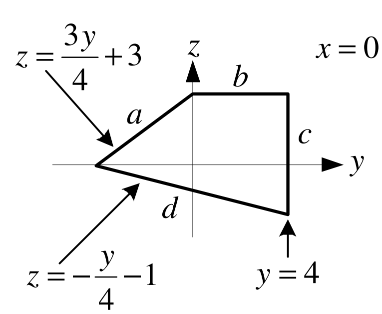
where H_ρ, H_ϕ, and H_z are not a function of position. The loop has a radius of a, is centered about the origin, and is located in the xy plane. Is this torque equal to $\vec{m} \times \mu_o \vec{H}$? Why or why not?

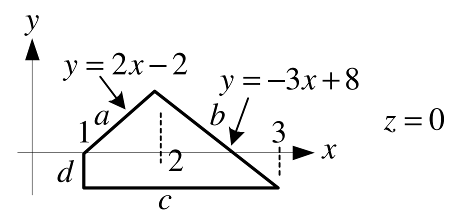
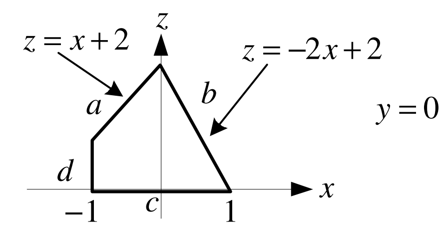
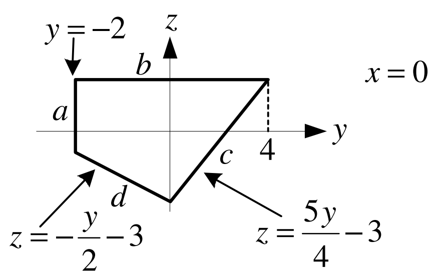
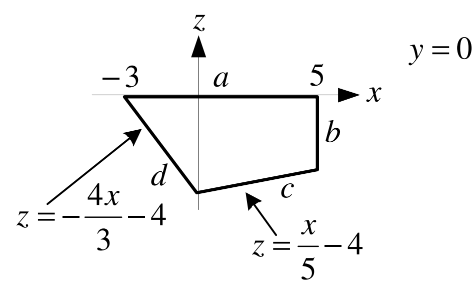
16.28 For the given four-sided loop # in Table 2 (provided by your instructor) in a magnetic field $\vec{H}_\#$ given in Table 1 (provided by your instructor), determine the force (a vector) on each side of the loop. Then, determine the net force on the loop. The current in the loop, I, is either clockwise or counterclockwise (provided by your instructor). Then, determine the torque about the origin for side X (provided by your instructor).

Table 1

#	$\vec{H}_\#$	#	$\vec{H}_\#$
1	$2z\hat{a}_x + (x^2 + y)\hat{a}_y - z\hat{a}_z$	4	$(2z - y)\hat{a}_x + x^2\hat{a}_y + y\hat{a}_z$
2	$-2xy\hat{a}_x - (y^2 + 1)\hat{a}_y + 4yz\hat{a}_z$	5	$y\hat{a}_x - (z - x)\hat{a}_y + (2x - 1)\hat{a}_z$
3	$(z - y)\hat{a}_x + (3z^2 - y)\hat{a}_y + z\hat{a}_z$	6	$2y\hat{a}_x - (2xy - 1)\hat{a}_y + 2xz\hat{a}_z$

Table 2

#	**loop #**	#	**loop #**
1		4	

2		5	
3		6	

16.29 Determine the magnetizing volume and surface currents for a rod of total length d and radius a that has been magnetized to

$$\vec{M} = M_o(\rho + a)\hat{a}_z$$

The axis of the cylindrical rod is along the z axis and the rod is centered about the origin. Note that the magnetization, which is along the length of the rod, varies in the ρ direction.

16.30 Using the hysteresis model

$$B = \frac{B_s B_r (H + H_c)}{B_r H + B_s H_c}$$

for a permanent magnet in the second quadrant, derive the expressions provided in this chapter for B_m and H_m corresponding to the location of the maximum energy product.

16.31 When is the following integral expression true?

$$\int_0^B H dB = -\int_B^0 H dB$$

16.32 A solid sphere of radius R is uniformly magnetized to $M_o\hat{a}_r$. Free space surrounds this magnet. Determine the volume magnetic charge density within the sphere and the surface magnetic charge density at $r = R$. Determine the net charge inside the sphere and along the surface of the sphere. Is this result surprising? Then, using the analogous expressions for the electric field from real charges, determine the magnetic field both inside and outside the magnetized sphere. From this information, determine whether the self energy of this magnet is given by the expression

$$E = \frac{2\pi\mu_o M_o^2 R^3}{3}$$