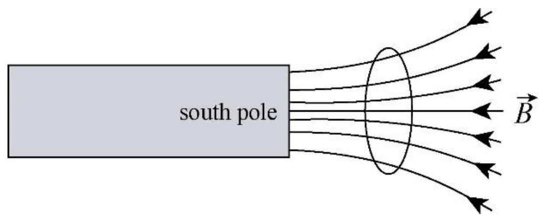
Chapter 32

1. (a) A sketch of the field lines (due to the presence of the bar magnet) in the vicinity of the loop is shown below:



(b) The primary conclusion of Section 32-9 is two-fold: $\vec{\mu}$ is opposite to $\vec{B}$, and the effect of $\vec{F}$ is to move the material toward regions of weaker magnetic fields. The direction of the magnetic moment vector (of our loop) is toward the right in our sketch, or in the $+x$ direction.

(c) The direction of the current is clockwise (from the perspective of the bar magnet).

(d) Since the magnitude of B relates to the "crowdedness" of the field lines, we see that $\vec{F}$ is toward the right in our sketch, or in the $+x$ direction.

11. (a) Here, the enclosed electric flux is found by integrating

$$\Phi_E = \int_0^r E\, 2\pi r\, dr = t(0.500\ \text{V/m}\cdot\text{s})(2\pi)\int_0^r \left(1-\frac{r}{R}\right) r\, dr = t\pi\left(\frac{1}{2}r^2 - \frac{r^3}{3R}\right)$$

with SI units understood. Then (after taking the derivative with respect to time) Eq. 32-3 leads to

$$B(2\pi r) = \varepsilon_0\mu_0\pi\left(\frac{1}{2}r^2 - \frac{r^3}{3R}\right).$$

For r = 0.0150 m and R = 0.0300 m, this gives $B = 2.78 \times 10^{-20}$ T.

(b) The integral shown above will no longer (since now $r > R$) have r as the upper limit; the upper limit is now R. Thus,

$$\Phi_E = t\pi\left(\frac{1}{2}R^2 - \frac{R^3}{3R}\right) = \frac{1}{6}t\pi R^2 .$$

Consequently, Eq. 32-3 becomes

$$B(2\pi r) = \frac{1}{6}\varepsilon_0\mu_0\pi R^2$$

which for r = 0.0400 m, yields

$$B = \frac{\varepsilon_0\mu_0 R^2}{12r} = \frac{(8.85\times10^{-12}\ )(4\pi\times10^{-7})(0.030)^2}{12(0.0400)} = 2.09\times10^{-20}\ \text{T}.$$

15. (a) Eq. 32-11 applies (though the last term is zero) but we must be careful with $i_{d,\text{enc}}$. It is the enclosed portion of the displacement current. Thus Eq. 32-17 (which derives from Eq. 32-11) becomes, with i_d replaced with $i_{d,\text{enc}}$,

$$B = \frac{\mu_0 i_{d\ \text{enc}}}{2\pi r} = \frac{\mu_0 (5.00\ \text{A})(r / R)}{2\pi r}$$

which yields (after canceling r, and setting R = 0.0300 m) B = 33.3 μT.

(b) Here i_d = 3.00 A, and we get $B = \frac{\mu_0 i_d}{2\pi r} = 16.7\ \mu\text{T}$.

25. We use Eq. 32-27 to obtain

$$\Delta U = -\Delta(\mu_{s,z}B) = -B\,\Delta\mu_{s,z},$$

where $\mu_{s,z} = \pm eh/4\pi m_e = \pm\mu_B$ (see Eqs. 32-24 and 32-25). Thus,

$$\Delta U = -B\left[\mu_B - \left(-\mu_B\right)\right] = 2\mu_B B = 2\left(9.27\times10^{-24}\ \mathrm{J/T}\right)\left(0.48\,\mathrm{T}\right) = 8.9\times10^{-24}\ \mathrm{J}\ .$$

26. (a) From Eq. 32-10,

$$
\begin{aligned}
i_d &= \varepsilon_0 \frac{d\Phi_E}{dt} = \varepsilon_0 A \frac{dE}{dt} = \varepsilon_0 A \frac{d}{dt}\left[\left(9.0\times10^5\right) - \left(4.0\times10^4 t\right)\right] = -\varepsilon_0 A\left(4.0\times10^4\ \text{V/m}\cdot\text{s}\right) \\
&= -\left(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(2.0\times10^{-2}\,\text{m}^2\right)\left(4.0\times10^4\ \text{V/m}\cdot\text{s}\right) \\
&= -7.1\times10^{-9}\,\text{A}.
\end{aligned}
$$

Thus, the magnitude of the displacement current is $|\, i_d \,| = 7.1\times10^{-9}\,\text{A}$.

(b) The negative sign in i_d implies that the direction is downward.

(c) If one draws a counterclockwise circular loop s around the plates, then according to Eq. 32-18,

$$\oint_s \vec{B}\cdot d\vec{s} = \mu_0 i_d < 0,$$

which means that $\vec{B}\cdot d\vec{s} < 0$. Thus $\vec{B}$ must be clockwise.

34. From Sample Problem 32.01 — "Magnetic field induced by changing electric field," we know that $B \propto r$ for $r \le R$ and $B \propto r^{-1}$ for $r \ge R$. So the maximum value of B occurs at $r = R$, and there are two possible values of r at which the magnetic field is 60% of B_{max}. We denote these two values as r_1 and r_2, where $r_1 < R$ and $r_2 > R$.

(a) Inside the capacitor, $0.60B_{max}/B_{max} = r_1/R$, or $r_1 = 0.60R = 0.60(30\text{ mm}) = 18\text{ mm}$.

(b) Outside the capacitor, $0.60B_{max}/B_{max} = (r_2/R)^{-1}$, or

$$r_2 = R/0.60 = 50\text{ mm}.$$

(c) From Eqs. 32-15 and 32-17,

$$B_{max} = \frac{\mu_0 i_d}{2\pi R} = \frac{\mu_0 i}{2\pi R} = \frac{\left(4\pi \times 10^{-7}\text{ T}\cdot\text{m/A}\right)\left(5.0\text{ A}\right)}{2\pi\left(0.040\text{ m}\right)} = 2.5\times10^{-5}\text{ T}.$$

36. From Eq. 28-11, we have $i = (\mathcal{E} / R)\, e^{-t/\tau}$ since we are ignoring the self-inductance of the capacitor. Equation 32-16 gives

$$B = \frac{\mu_0 i_d r}{2\pi R^2} .$$

Furthermore, Eq. 25-9 yields the capacitance

$$C = \frac{\varepsilon_0 \pi (0.05 \text{ m})^2}{0.003 \text{ m}} = 2.318 \times 10^{-11} \text{F} ,$$

so that the capacitive time constant is

$$\tau = (20.0 \times 10^6\ \Omega)(2.318 \times 10^{-11} \text{ F}) = 4.636 \times 10^{-4} \text{ s}.$$

At $t = 750 \times 10^{-6}$ s, the current is

$$i = \frac{9.60 \text{ V}}{20.0 \times 10^6\ \Omega} e^{-t/\tau} = 9.52 \times 10^{-8} \text{ A} .$$

Since $i = i_d$ (see Eq. 32-15) and $r = 0.0300$ m, then (with plate radius $R = 0.0500$ m) we find

$$B = \frac{\mu_0 i_d r}{2\pi R^2} = \frac{(4\pi \times 10^{-7} \text{ T} \cdot \text{m/A})(9.52 \times 10^{-8} \text{ A})(0.030 \text{ m})}{2\pi (0.0500 \text{ m})^2} = 2.28 \times 10^{-13} \text{ T} .$$