Ampère's law says that the line integral of $\mathbf{B} \cdot d\mathbf{s}$ around any closed path equals $\mu_0 I$, where I is the total steady current passing through any surface bounded by the closed path:

$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I \qquad \textbf{(30.13)}$$

Using Ampère's law, one finds that the fields inside a toroid and solenoid are

$$B = \frac{\mu_0 N I}{2\pi r} \qquad \text{(toroid)} \qquad \textbf{(30.16)}$$

$$B = \mu_0 \frac{N}{\ell} I = \mu_0 n I \qquad \text{(solenoid)} \qquad \textbf{(30.17)}$$

where N is the total number of turns.

The **magnetic flux** $\mathbf{\Phi_B}$ through a surface is defined by the surface integral

$$\Phi_B \equiv \int \mathbf{B} \cdot d\mathbf{A} \qquad \textbf{(30.18)}$$

Gauss's law of magnetism states that the net magnetic flux through any closed surface is zero.

The general form of Ampère's law, which is also called the **Ampère-Maxwell law,** is

$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} \qquad \textbf{(30.22)}$$

This law describes the fact that magnetic fields are produced both by conduction currents and by changing electric fields.

QUESTIONS

1. Is the magnetic field created by a current loop uniform? Explain.
2. A current in a conductor produces a magnetic field that can be calculated using the Biot–Savart law. Because current is defined as the rate of flow of charge, what can you conclude about the magnetic field produced by stationary charges? What about that produced by moving charges?
3. Two parallel wires carry currents in opposite directions. Describe the nature of the magnetic field created by the two wires at points (a) between the wires and (b) outside the wires, in a plane containing them.
4. Explain why two parallel wires carrying currents in opposite directions repel each other.
5. When an electric circuit is being assembled, a common practice is to twist together two wires carrying equal currents in opposite directions. Why does this technique reduce stray magnetic fields?
6. Is Ampère's law valid for all closed paths surrounding a conductor? Why is it not useful for calculating **B** for all such paths?
7. Compare Ampère's law with the Biot–Savart law. Which is more generally useful for calculating **B** for a current-carrying conductor?
8. Is the magnetic field inside a toroid uniform? Explain.
9. Describe the similarities between Ampère's law in magnetism and Gauss's law in electrostatics.
10. A hollow copper tube carries a current along its length. Why does $\mathbf{B} = 0$ inside the tube? Is **B** nonzero outside the tube?
11. Why is **B** nonzero outside a solenoid? Why does $\mathbf{B} = 0$ outside a toroid? (Remember that the lines of **B** must form closed paths.)
12. Describe the change in the magnetic field in the interior of a solenoid carrying a steady current I (a) if the length of the solenoid is doubled but the number of turns remains the same and (b) if the number of turns is doubled but the length remains the same.
13. A flat conducting loop is positioned in a uniform magnetic field directed along the x axis. For what orientation of the loop is the flux through it a maximum? A minimum?
14. What new concept does Maxwell's general form of Ampère's law include?
15. Many loops of wire are wrapped around a nail and then connected to a battery. Identify the source of **M**, of **H**, and of **B**.