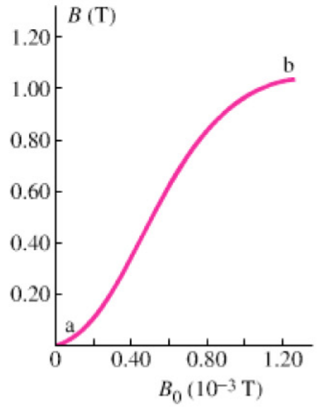

FIGURE 20–43 Total magnetic field B in an iron-core toroid as a function of the external field B_0 (B_0 is caused by the current I in the coil).

Fig. 20–43. (Note the different scales: $B \gg B_0$.) At the initial point a, the domains are randomly oriented. As B_0 increases, the domains become more and more aligned until at point b, nearly all are aligned. The iron is said to be approaching **saturation**. Next, suppose current in the coils is reduced, so the field B_0 decreases. If the current (and B_0) is reduced to zero, point c in Fig. 20–44, the domains do *not* become completely random. Instead, some permanent magnetism remains in the iron core. If the current is increased in the opposite direction, enough domains can be turned around so the total B becomes zero at point d. As the reverse current is increased further, the iron approaches saturation in the opposite direction, point e. Finally, if the current is again reduced to zero and then increased in the original direction, the total field follows the path efgb, again approaching saturation at point b.

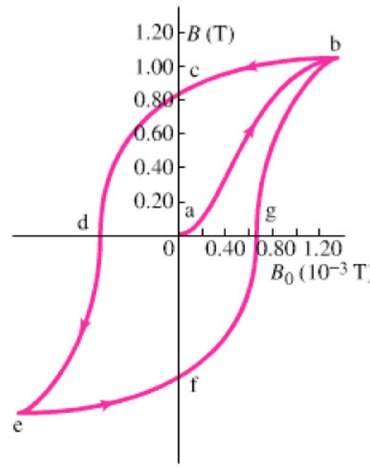

FIGURE 20–44 Hysteresis curve.

Hysteresis

Notice that the field did not pass through the origin (point a) in this cycle. The fact that the curve does not retrace itself on the same path is called **hysteresis**. The curve bcdefgb is called a **hysteresis loop**. In such a cycle, much energy is transformed to thermal energy (friction) due to realigning of the domains. Note that at points c and f, the iron core is magnetized even though there is no current in the coils. These points correspond to a permanent magnet.

Summary

A magnet has two **poles**, north and south. The north pole is that end which points toward geographic north when the magnet is freely suspended. Like poles of two magnets repel each other, whereas unlike poles attract.

We can imagine that a **magnetic field** surrounds every magnet. The SI unit for magnetic field is the **tesla** (T).

Electric currents produce magnetic fields. For example, the lines of magnetic field due to a current in a straight wire form circles around the wire, and the field exerts a force on magnets (or currents) near it.

A magnetic field exerts a force on an electric current. For a straight wire of length l carrying a current I, the force has magnitude

$$F = IlB\sin\theta, \qquad \textbf{(20–1)}$$

where θ is the angle between the magnetic field $\vec{\mathbf{B}}$ and the current. The direction of the force is perpendicular to the current-carrying wire and to the magnetic field, and is given by a right-hand rule. Equation 20–1 serves as the definition of magnetic field $\vec{\mathbf{B}}$.

Similarly, a magnetic field exerts a force on a charge q moving with velocity v of magnitude

$$F = qvB\sin\theta, \qquad \textbf{(20–3)}$$

where θ is the angle between $\vec{\mathbf{v}}$ and $\vec{\mathbf{B}}$. The direction of $\vec{\mathbf{F}}$ is perpendicular to $\vec{\mathbf{v}}$ and to $\vec{\mathbf{B}}$ (again a right-hand rule). The path of a charged particle moving perpendicular to a uniform magnetic field is a circle.

The magnitude of the magnetic field produced by a current I in a long straight wire, at a distance r from the wire, is

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}. \qquad \textbf{(20–6)}$$

Two currents exert a force on each other via the magnetic field each produces. Parallel currents in the same direction attract each other; currents in opposite directions repel.

The magnetic field inside a long tightly wound solenoid is

$$B = \mu_0 NI/l, \qquad \textbf{(20–8)}$$

where N is the number of loops in a length l of coil, and I is the current in each loop.