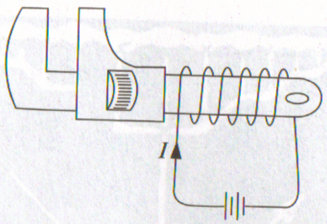

Figure 6.27

magnet. If you want to eliminate the remaining magnetization, you'll have to run a current backwards through the coil (a negative I). Now the external field points to the right, and as you increase I (negatively), M drops down to zero (point d). If you turn I still higher, you soon reach saturation in the other direction—all the dipoles now pointing to the *right* (e). At this stage switching off the current will leave the wrench with a permanent magnetization to the right (point f). To complete the story, turn I on again in the positive sense: M returns to zero (point g), and eventually to the forward saturation point (b).

The path we have traced out is called a **hysteresis loop**. Notice that the magnetization of the wrench depends not only on the applied field (that is, on I), but also on its previous magnetic "history."[8] For instance, at three different times in our experiment the current was zero (a, c, and f), yet the magnetization was different for each of them. Actually, it is customary to draw hysteresis loops as plots of B against H, rather than M against I. (If our coil is approximated by a long solenoid, with n turns per unit length, then $H = nI$, so H and I are proportional. Meanwhile, $\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$, but in practice M is huge compared to H, so to all intents and purposes $\mathbf{B}$ is proportional to $\mathbf{M}$.)

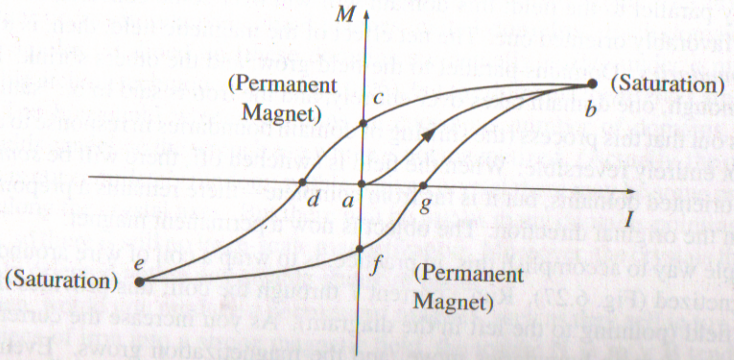

Figure 6.28

[8]Etymologically, the word *hysteresis* has nothing to do with the word *history*—nor with the word *hysteria*. It

To make the units consistent (teslas), I have plotted (μ
notice, however, that the vertical scale is 10^4 times greater tha
speaking, $\mu_0\mathbf{H}$ is the field our coil *would* have produced in
what we *actually* got, and compared to $\mu_0\mathbf{H}$ it is gigantic. A
when you have ferromagnetic materials around. That's why
powerful electromagnet will wrap the coil around an iron cor
external field to move the domain boundaries, and as soon a
all the dipoles in the iron working with you.

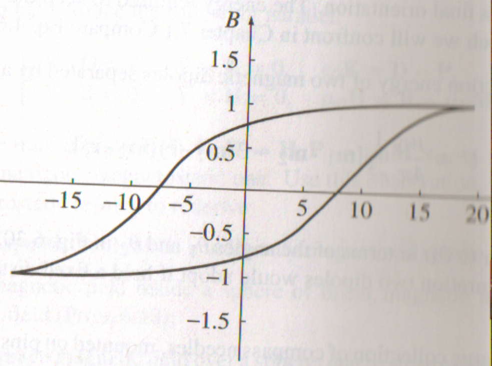

Figure 6.29

One final point concerning ferromagnetism: It all follows, r
the dipoles within a given domain line up parallel to one another
compete with this ordering, but as long as the temperature doesn
budge the dipoles out of line. It's not surprising, though, that
destroy the alignment. What *is* surprising is that this occurs at a
C, for iron). Below this temperature (called the **Curie point**), iro
it is paramagnetic. The Curie point is rather like the boiling point
there is no *gradual* transition from ferro- to para-magnetic beha
between water and ice. These abrupt changes in the properties o
sharply defined temperatures, are known in statistical mechanics

Problem 6.20 How would you go about *demagnetizing* a per
wrench we have been discussing, at point c in the hysteresis loo
restore it to its original state, with $M = 0$ at $I = 0$?

Problem 6.21

(a) Show that the energy of a magnetic dipole in a magnetic field