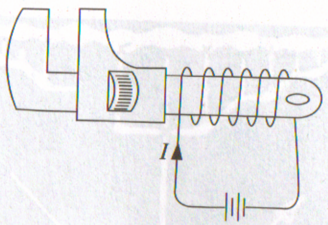


Figure 6.27

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 $\mathbf{M}$.)

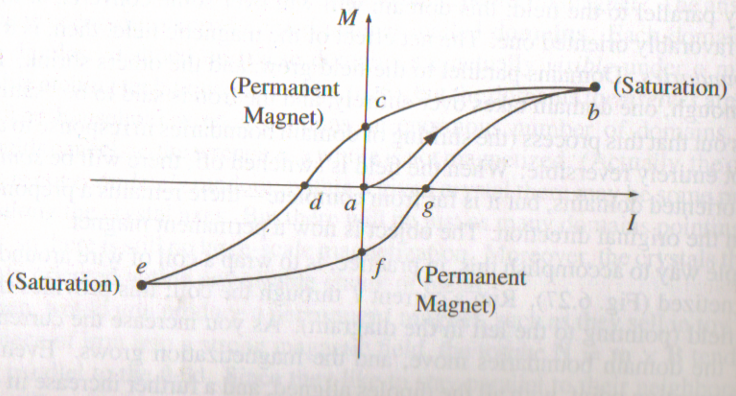


Figure 6.28

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



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

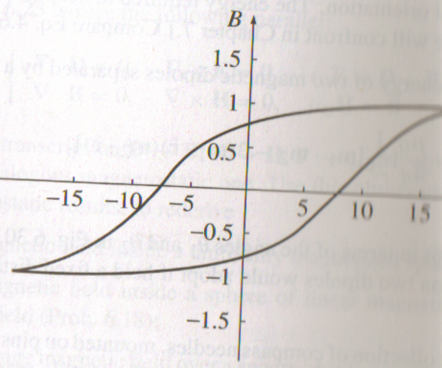


Figure 6.29

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

**Problem 6.20** How would you go about *demagnetizing* a
wrench we have been discussing, at point $c$ in the hysteresis
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 fi