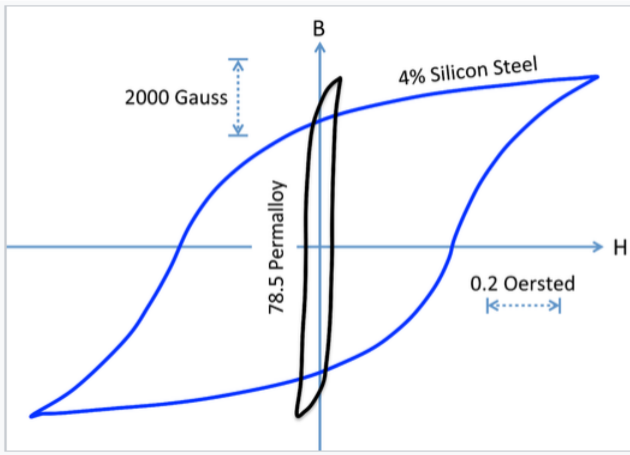
6.9: Hard and Soft Magnets

Whether a ferro- or ferrimagnetic material is a **hard** or a **soft magnet** depends on the strength of the magnetic field needed to align the magnetic domains. This property is characterized by $\mathbf{H_c}$, the coercivity. Hard magnets have a high coercivity (H_c), and thus retain their magnetization in the absence of an applied field, whereas soft magnets have low values.

The figure at the right compares hysteresis loops for hard and soft magnets. Recall that the energy dissipated in magnetizing and demagnetizing the material is proportional to the area of the hysteresis loop. We can see that soft magnets, while they can achieve a high value of B_{sat}, dissipate relatively little energy in the loop. This makes **soft magnets** preferable for use in **transformer cores**, where the field is switched rapidly. **Permalloy**, an alloy consisting of about 20% Fe and 80% Ni, is a soft magnet that has very high magnetic permeability μ (i.e., a large maximum slope of the B vs. H curve) and a very narrow hysteresis loop.

Some materials, such as iron metal, can exist as either hard or soft magnets. Whether bcc iron is a hard or soft magnet depends on the crystal grain size. When crystal grains in iron are sub-micron size, and comparable to the size of the magnetic domains, then the magnetic domains are pinned by crystal grain boundaries. When the magnetic domains are pinned a stronger coercive magnetic field needs to be applied to cause them to re-align. When iron is annealed, the crystal grains grow and the magnetic domains become more free to align with applied magnetic fields. This decreases the coercive field and the material becomes a soft magnet.



Hysteresis loops comparing a hard magnet (iron-silicon steel) to a soft magnet (permalloy) on the same scale. H_c for permallloy is 0.05 Oe, about 10 times lower than that of the hard magnet. The remanent magnetizations of the two materials are comparable.

Hard magnets such as CrO_2, γ-Fe_2O_3, and cobalt ferrite ($CoFe_2O_4$) are used in magnetic recording media, where the high coercivity allows them to retain the magnetization state (read as a logical 0 or 1) of a magnetic bit over long periods of time. Hard magnets are also used in disk drives, refrigerator magnets, electric motors and other applications. Drive motors for hybrid and electric vehicles such as the Toyota Prius use the hard magnet $Nd_2Fe_{14}B$ (also used to make strong refrigerator magnets) and require 1 kilogram (2.2 pounds) of neodymium.[6]. A high-resolution transmission electron microscope image of $Nd_2Fe_{14}B$ is shown below and compared to the crystal structure with the unit cell marked.