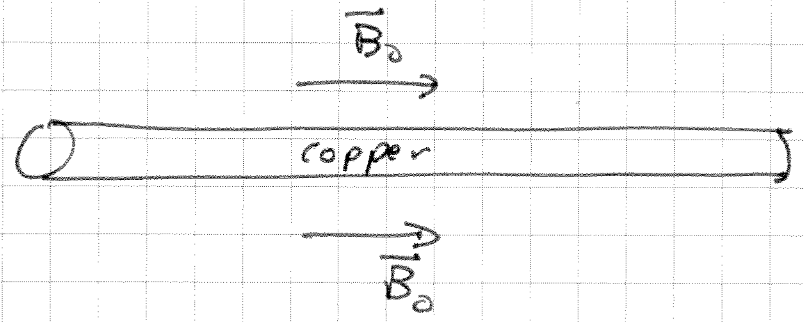
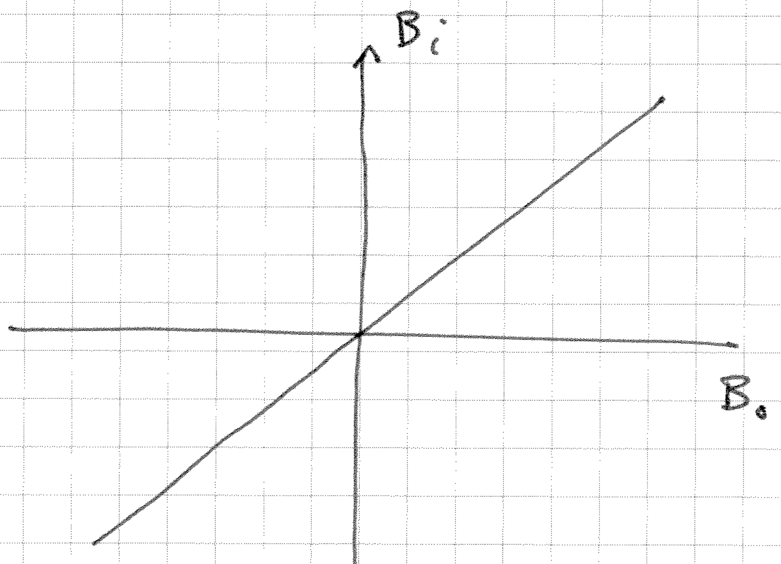
Ferromagnetism

For a thin material with relative permeability μ_r in an applied field $\vec{B}_0$ we found the field in the material was $\vec{B}_i = \mu_r \vec{B}_0$

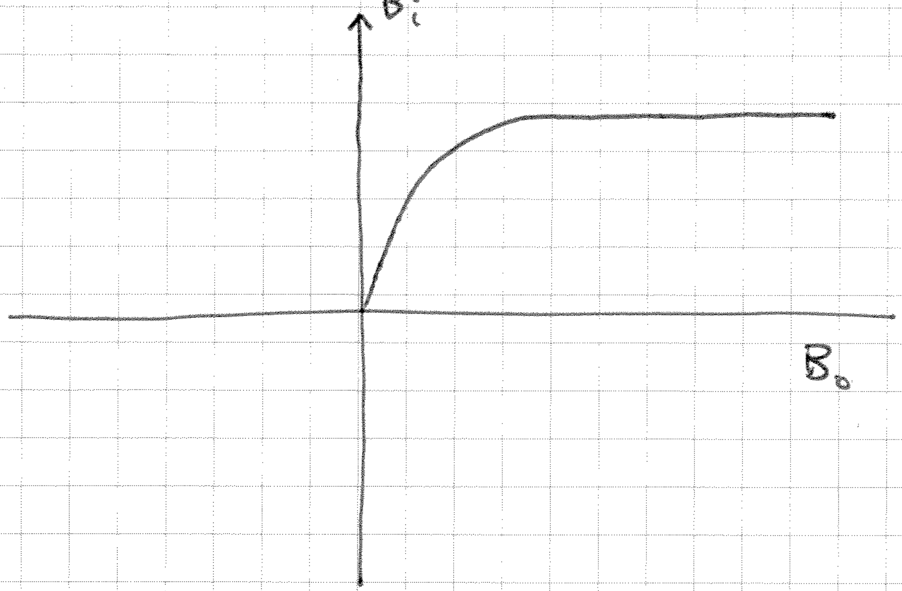


If we plotted the field in the material against the applied field we would find.

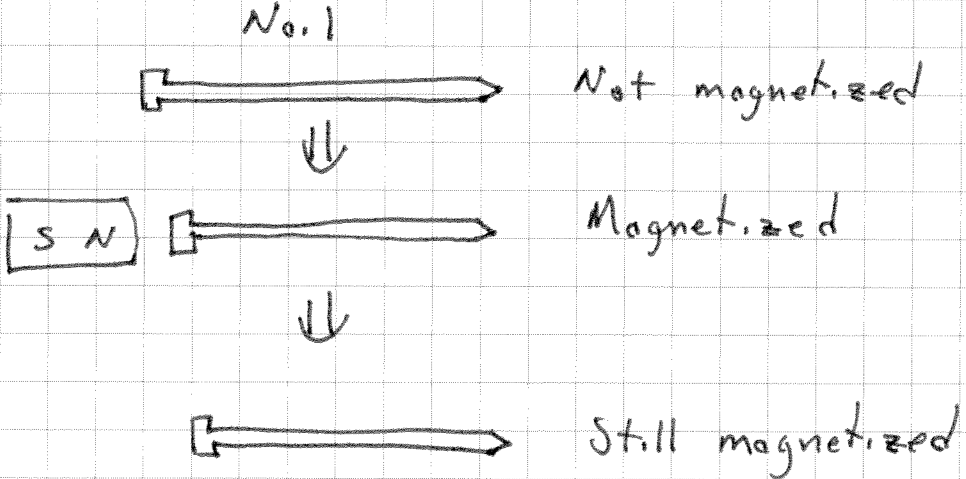


and naturally when $\vec{B}_0$ is removed, $\vec{B}_i$ becomes zero.

If we tried the same thing with an iron cylinder, we would fine very different behavior



and the $\overrightarrow{B_i}$ would remain after $\overrightarrow{B_o}$ is taken away.



Iron is a <u>Ferromagnetic</u> Material

Ferromagnetism A long range ordering of electron spins (dipole moments) due to the exchange interaction (a purely quantum mechanical effect relying on the fact that electrons are identical particles).

$\Longrightarrow$ Large, non-linear magnetic response

Anti Ferromagnetism - Long range order involving opposed spins, small magnetic response.

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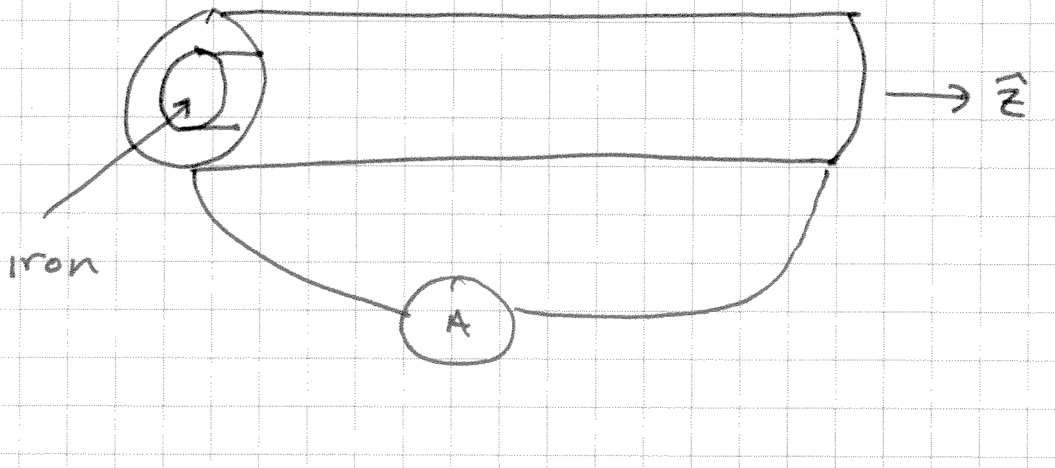
Investigate Ferromagnetic response using a solenoid with an iron core.

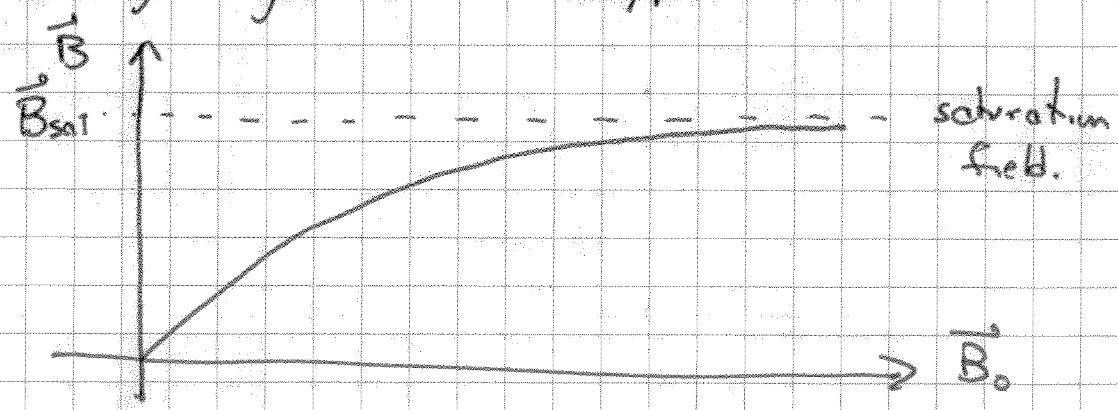


The solenoid produces an applied field of

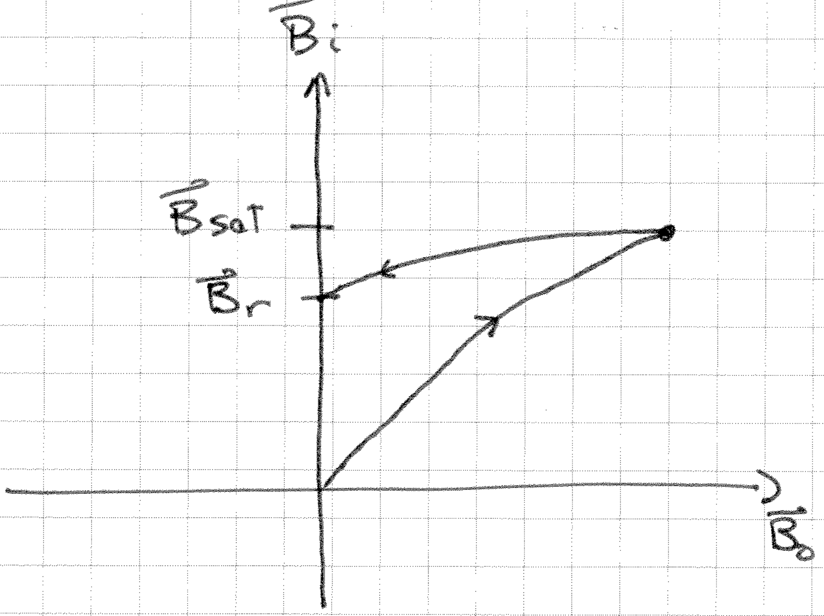
$$\vec{B}_0 = \mu_0 n I \hat{z} = \mu_0 K_f \hat{z}$$

$$K_f = n I$$

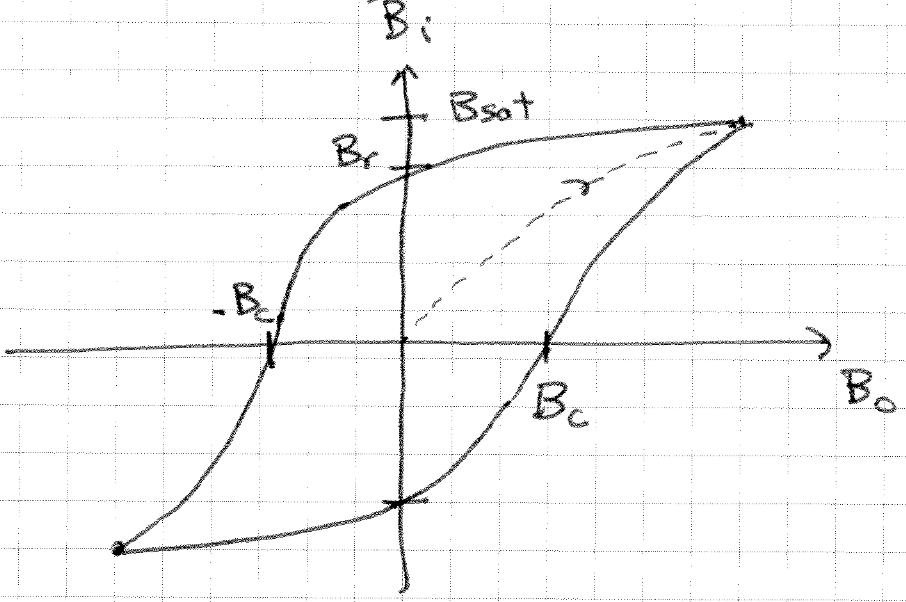
Ferromagnetics occurs because of the long range alignment of electron spins. This alignment occurs over macroscopic regions of the material called <u>domains</u>. However, the domain spins are randomly oriented in most ferromagnetic materials resulting in zero net magnetization. When a field is applied, domains pointing toward the field grow at expense of domains not aligned with the field producing a net magnetization. If the field is then removed, the net magnetization remains because the aligned domains are in the low energy state. Eventually, at some field B_{sat} all the domains are aligned and the field in the material will no longer grow with the applied field.



If we drive our iron core solenoid to saturation, then turn down the applied field B_o, some magnetization remains at $\vec{B}_o = 0$ called the <u>residual magnetization</u> $\vec{B}_r$. This is the field of the iron acting as a permanent magnet.



To remove $\vec{B}_r$, we have to apply a field in the opposite direction, $\vec{B}_c$ called the ~~coer~~ ~~coersive field.~~ <u>coercive</u> field.

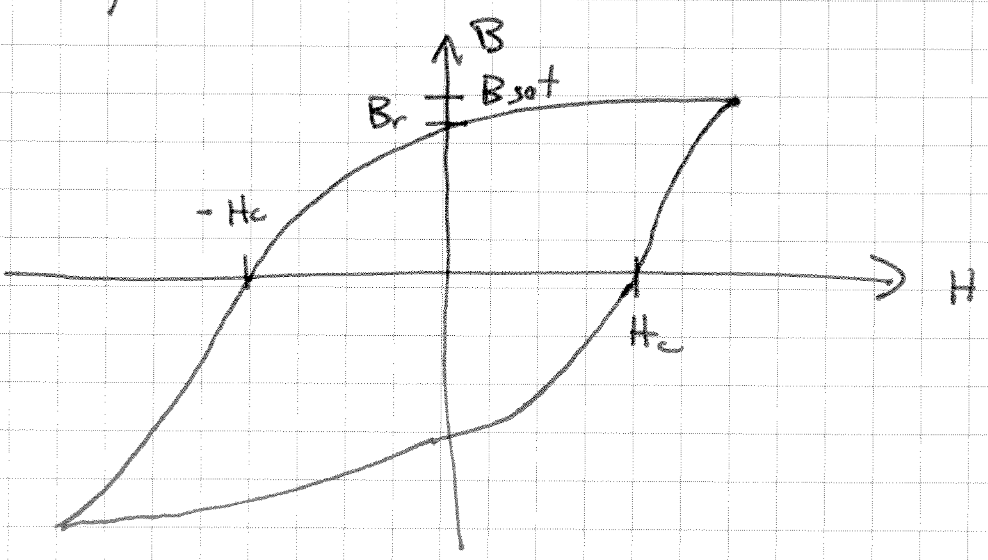


B_r - Residual Magnetization (Magnetic Field)
- Field at $B_o = 0$

B_{sat} - Saturation Field - Maximum Field

B_c - Coercive Field - Field required to erase magnetization.

This plot is more traditionally made vs H where $\vec{H}_c$ is called the coercive force, but naturally it is not a force.



The curve is called a hysteresis loop and the area within the loop is related to the energy to drive the system through one cycle

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Units $[H] = \frac{\text{Amp}}{m} = \frac{A}{m}$

In CGS, the H field is given the unit

Oersted, $1[Oe] = \frac{1000}{4\pi} \frac{A}{m} = 79.58 \frac{A}{m}$

and in CGS the magnetic field is measured in Gauss, $1G = 10^{-4}T$

For a solenoid, or anything

$B_o = \mu_o H$ If $H = 1[Oe]$

$= 4\pi \times 10^{-7} \frac{Tm}{A} \cdot 79.6 \frac{A}{m}$

$= 1 \times 10^{-4}\ T = 1G$

cuts the horizontal axis at − 24, which is therefore the value of the coercive force. On increasing the reversed magnetizing force to H = − 90, the reversed magnetization increases to the value B = − 14,000, or a little more. Then when these reversed magnetizing forces are reduced to zero, the curve returns towards the right, crossing the vertical axis at B = − 10,500 (the negative remanence); and on re-reversing the magnetizing force it is found that when H = + 24, the

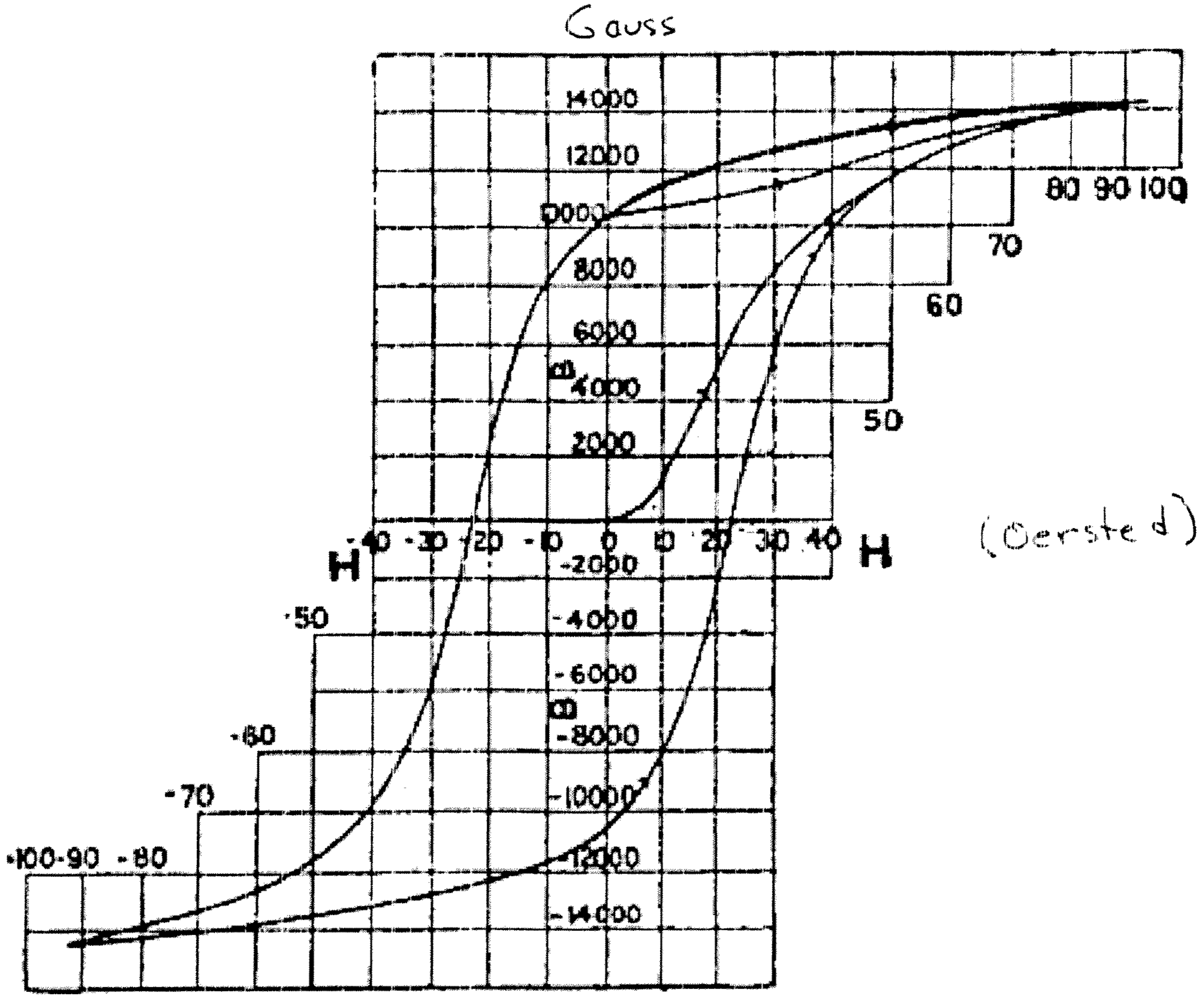

FIG. 88.—CYCLE OF MAGNETIC OPERATIONS ON ANNEALED STEEL WIRE.

magnetization is once more zero. After this point, increasing H causes the magnetization to run up very rapidly, not quite following its former track, but coming up as before to the