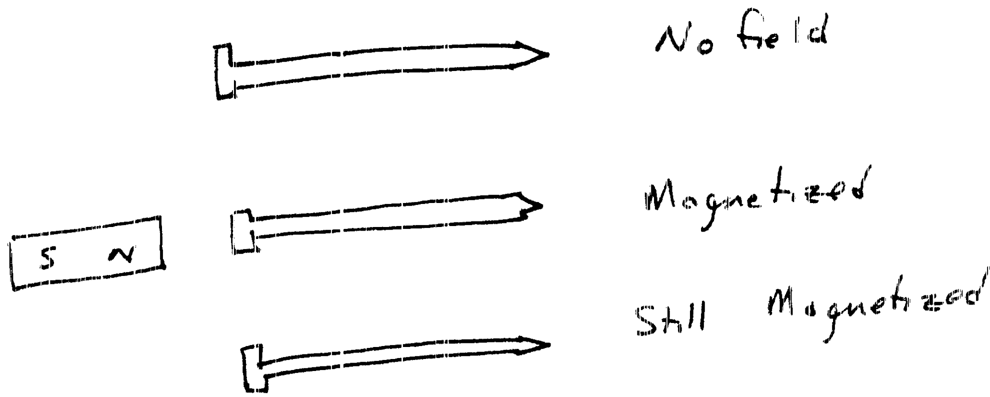
Ferromagnetics

Not all materials are linear magnetic materials. Some have a very large magnetic response that saturates at some field. Some remember the applied field and a field remains after the applied field is removed.

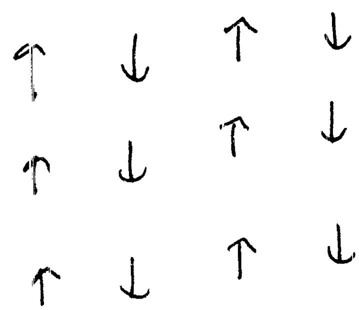
Recall magnetizing a nail



Ferromagnetism — A long range ordering of electronic spins (dipole moments) due to the exchange interaction. The exchange interaction is a purely quantum mechanical effect due to the intrinsic identical nature of all electrons.

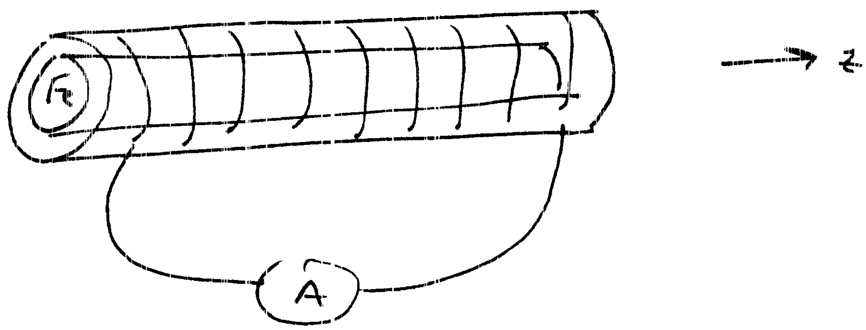
⟹ Large magnetic response

Antiferromagnetics — Long range order involving opposed spins, small magnetic response



Ferrimagnetism — Long range order involving atoms of different species with opposed spins. If magnetic moment different, there is a large magnetic response.

Let's Investigate this using an infinite solenoid



Place a iron core in an infinite solenoid.

$$\vec{J}_f = 0$$

$$\Rightarrow \nabla \times H = 0$$ inside and out, but not at boundary.

We can solve the system in the same way as when there is no core and find.

$$\vec{H}_o = 0$$

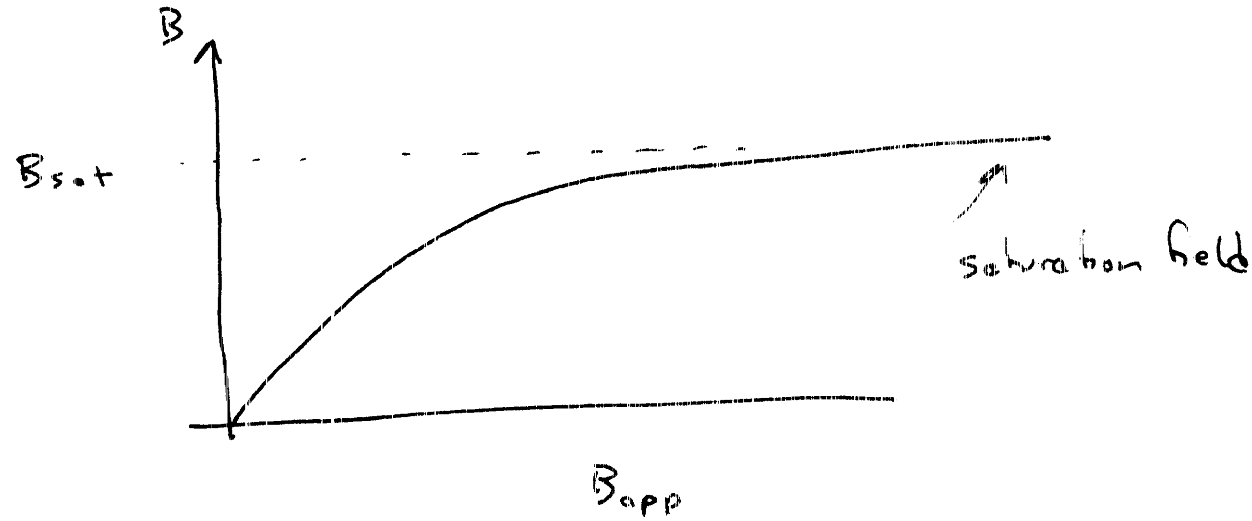
$$\vec{H}_i = K_f \hat{z} = \frac{N}{\ell} I \hat{z}$$

We know the iron is non-linear, but for each value of the applied field $B_0^{app} = \frac{N}{\ell} \mu_0 I$ we can measure the resulting field B^{res}. Define a effective relative permeability as $\frac{B^{res}}{B^{app}} \equiv \mu_r$

Ferromagnetism results from long range order of electronic spins. Normally, this long range order results in <u>domains</u> with a single moment direction. The domains can occupy a substantial region of a piece of metal, but are randomly oriented, resulting in zero field.

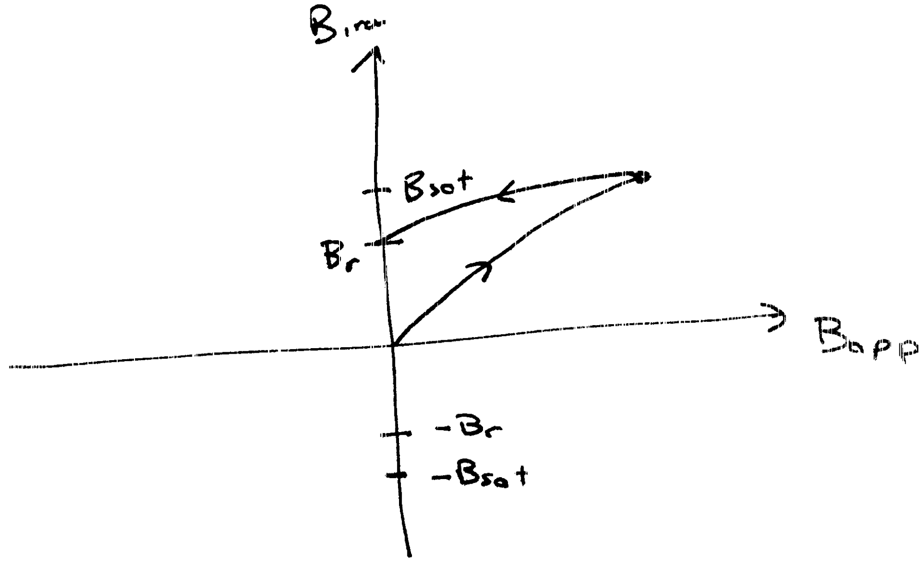
When a field is applies, domains pointing toward the field grow at the expense of domains pointing opposite the field, yielding a net magnetization. Since this is the low energy state, it remains after the applied field is removed.

Once all the domains are aligned, the magnetization no longer increases as B^{app} increases. The material is said to be <u>saturated</u>.



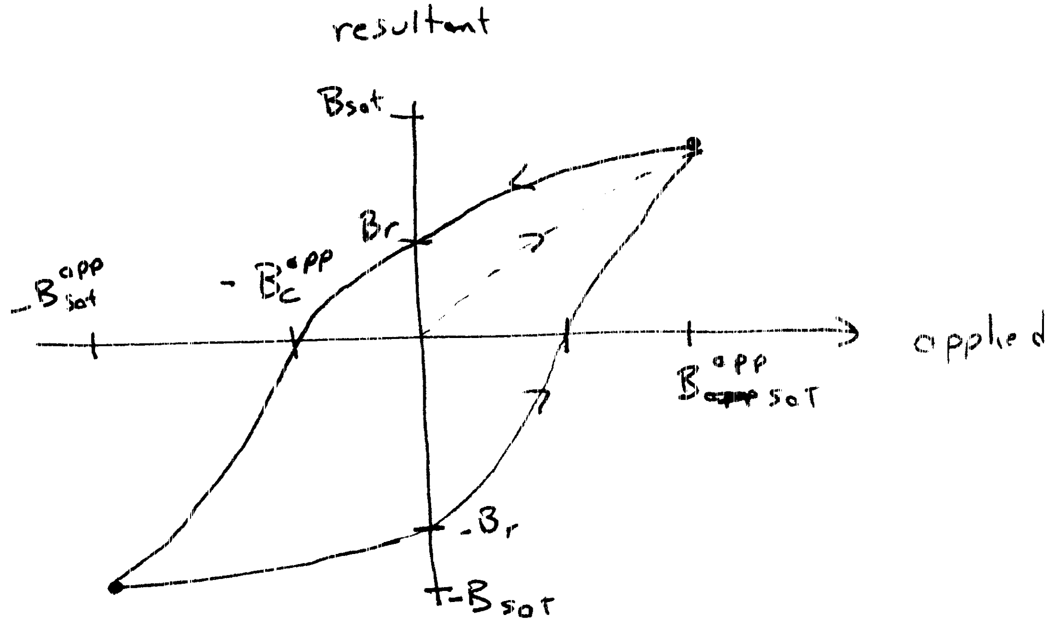
Now, suppose we drive the field to where the magnet initially saturates (after saturation some slight increase happens because the B_{app} is added to B_{iron}). ~~on the~~

Then start to turn down the current. The field naturally decreases.



However, the field does not decrease to zero when $B_{app} = 0$. The remaining field, the <u>residual magnetization</u> B_r, is the magnetic field of the iron acting as a permanent magnet.

To erase the residual field, we have to apply an opposite field. The field required is B_c, the coercive field.



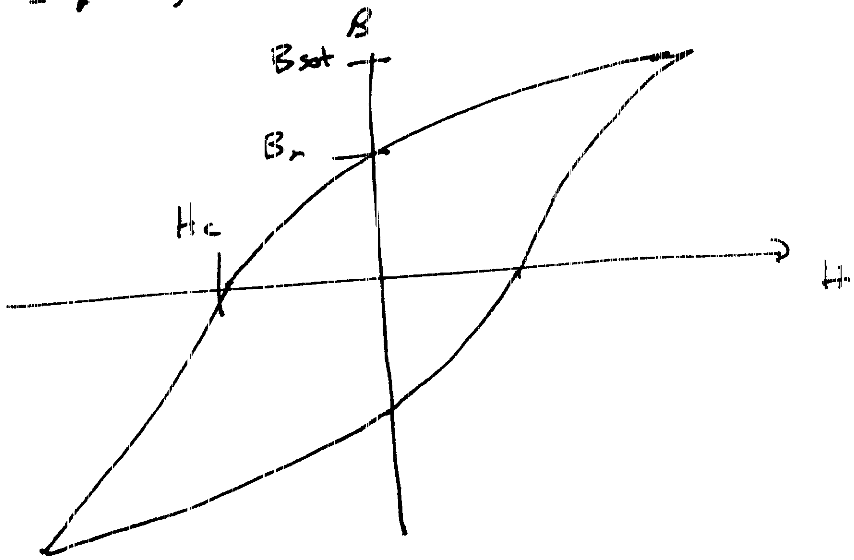
B_r - Residual Magnetization - Field of permanent magnet

B_{sat} - Saturation field - Maximum field contributed by iron.

B_c - Coersize field - Field required to erase magnetization

It is more traditional to plot against H.

Since $H = K_f$ = same for air core and iron core.



H_c - The coersize force (not a force), the H field required to eliminate the magnetization

Note, we will find the energy density in a magnetic field is $\frac{1}{2}\vec{B}\cdot H$ so the area withing the hysteresis curve is related to the energy required to drive the material through one cycle of the curve.

A note about crazy units

$$mmf = \int \vec{H} \cdot d\vec{l} = I_{\text{encl}}$$

$$[H] = \frac{\text{Ampere}}{\text{meter}}$$

The H field is given its own unit in the CGS system, the Oersted.

$$1\ \text{Oe} = \frac{1000}{4\pi}\ \frac{A}{m} = 79.58\ \frac{A}{m}$$

In CGS, the B field is given in Gauss

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

So if there were no core in a solenoid,

$$B_0 = \mu_0 H$$

For 10[Oe], we get $10 \cdot 79.6 \cdot 4\pi \times 10^{-7}\ T$

$$= 1 \times 10^{-3}\ T = 10\ \text{Gauss}$$

or $1[\text{Oe}] \rightarrow 1\,G$

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

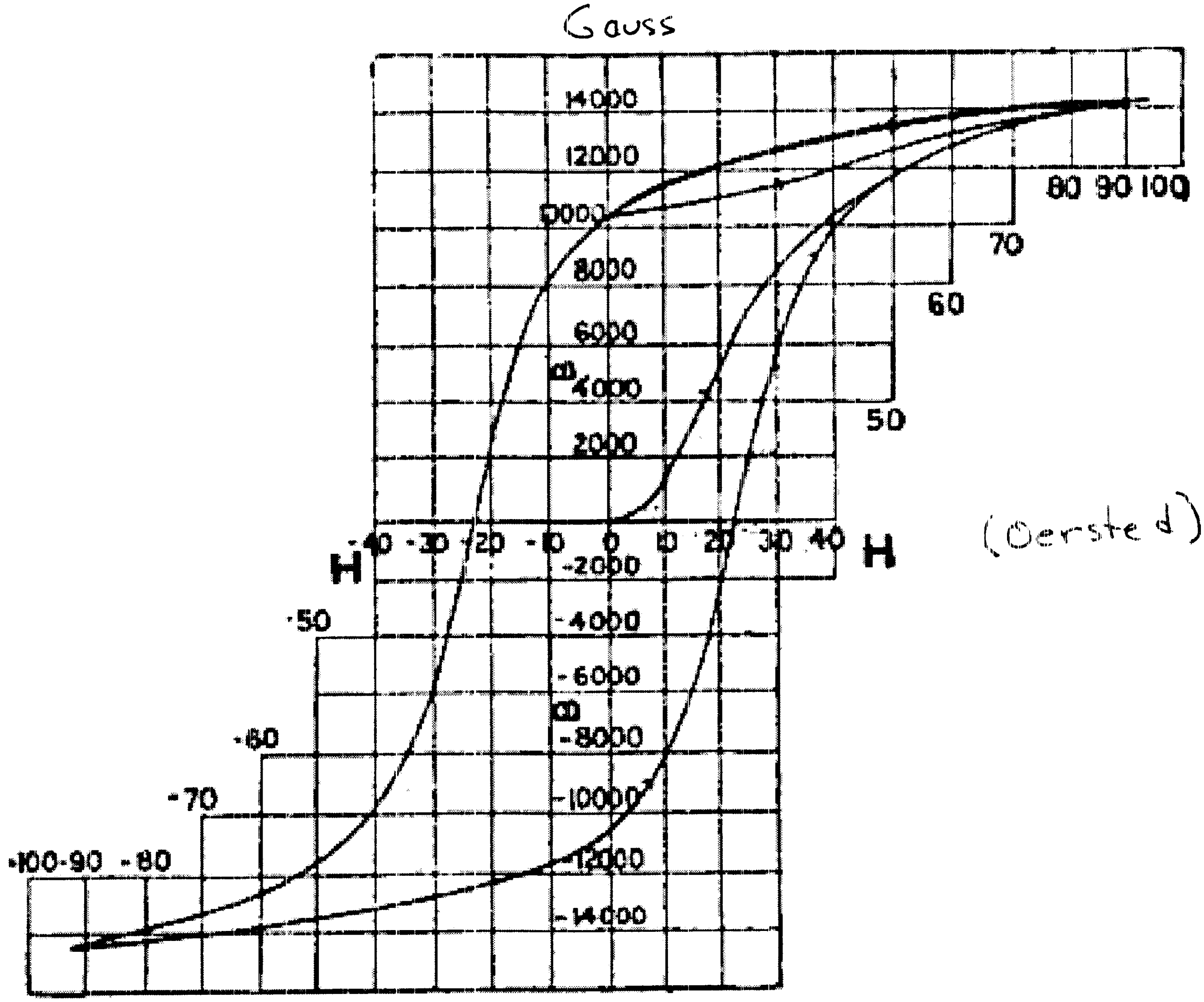


FIG. 88.—CYCLE OF MAGNETIC OPERATIONS ON ANNEALED STEEL WIRE.

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