L12 Magnetization

Lecture outline:
• Magnetization.
• Magnetic permeability.
• Hysteresis.

L12.1 Magnetization

Magnetic materials, eg Fe, Co, Ni, alloys, can be permanently magnetized.

We introduce a new field, the applied field $H$.

In a vacuum, $B = \mu_0 H$, and $H$ has units $\text{Am}^{-1}$.

Eg for a toroidal coil:

Wire is coiled around a toroidal core (N turns).

\[ \int B \cdot ds = BL = \mu_0 Ni \]

so \[ B = \frac{\mu_0 Ni}{L} \] and \[ H = \frac{Ni}{L} \]
L12.2 Magnetization

Now put iron in the core: it becomes magnetized.
The atomic magnetic dipoles in the material line up, producing an internal magnetic field, which may strengthen (or oppose) the original field.
The magnetization \( M = \frac{\text{total magnetic dipole moment}}{\text{volume}} \).
The magnetic field in the material is produced by currents in the tiny magnetic dipoles:

\[ B_i = \mu_0 n \ i, \ \text{with} \ n = \frac{N_L}{L} = \text{number of dipoles per unit length}. \]
The total number of dipoles is \( N = N_A N_L \).
The magnetization is \( M = N i A_d AL \).

Therefore the internal magnetic field is \[ B_i = \mu_0 M. \]

L12.3 Magnetization

Let \( A \) be the area of the cylinder and \( L \) its length. The area of each dipole is \( A_d \), with current \( i \). There are \( N_A = \frac{A}{A_d} \) dipoles in the area \( A \). The cylinder is equivalent to a long solenoid, with field \( B_i = \mu_0 n \ i, \) with \( n = N_L/L = \) number of dipoles per unit length.
The total number of dipoles is \( N = N_A N_L \).
The magnetization is \( M = N i A_d AL \).

Therefore the internal magnetic field is \( B_i = \mu_0 M \).

Now we define \( H \) by: \( B = \mu_0 (H + M) = \mu H \)
\ie \( H \) is the field without the magnetic material, and it is proportional to the applied current.
L12.4 Magnetization

where \( \mu = \) the magnetic permeability \((\text{Hm}^{-1})\)

\[ = \mu_r \mu_0, \text{ with } \mu_r \text{ the relative permeability.} \]

As the current increases, the magnetization may increase non-linearly:

Measure \( \mu_r = \frac{B}{H} \) from the graph

So \( \mu_r \) varies with \( H \).

Could also use "differential permeability"

\[ \frac{dB}{dH} \]

L12.5 Magnetization

Hysteresis

Magnetic materials also show a hysteresis effect, where decreasing the applied magnetic field, or \( H \), doesn't produce the reverse effect of increasing the field:

\( B_r = \) "remanence" or "residual magnetism"

\( H_c = \) "coercivity"
L12.6 Magnetization

hard magnetic materials: $H_c$ is high, area of the loop is large, used for permanent magnets.

soft magnetic materials: $H_c$ is small, area of loop is small, used for transformer cores.

The material can be demagnetized by striking or heating it, or go round the hysteresis loop, gradually reducing its size.

L12.7 Magnetization

Work done around the loop:

Magnetic flux through the magnet

Let $e = \text{induced emf} = -N \frac{d\Phi}{dt} = -N A \frac{dB}{dt}$

Power $= e i$, so work done $= W = - \int (ei) dt$

For a toroidal coil, $H = \frac{Ni}{L}$

so $W = \int N A \frac{dB}{dt} \frac{HL}{N} dt = \int (AL) HB = V \int H dB$

so work/volume = area of the hysteresis loop.