12.3: Magnetization and Susceptibility

The $H$-field inside a long solenoid is $nI$. If there is a vacuum inside the solenoid, the $B$-field is $\mu_o H = \mu_o nI$. If we now place an iron rod of permeability $\mu$ inside the solenoid, this doesn't change $H$, which remains $nI$. The $B$-field, however, is now $B = \mu H$. This is greater than $\mu_o H$, and we can write

$$B = \mu_o (H + M) \label{12.3.1}$$

The quantity $M$ is called the magnetization of the material. In SI units it is expressed in A m$^{-1}$. We see that there are two components to $B$. There is the $\mu_o H = \mu_o nI$, which is the externally imposed field, and the component $\mu M$, originating as a result of something that has happened within the material.

It might have occurred to you that you would have preferred to define the magnetization from

$$B = \mu_0 H + M \nonumber$$

so that the magnetization would be the excess of $B$ over $\mu_0 H$. The equation $B = \mu_0 H + M$, would be analogous to the familiar

$$D = \epsilon_0 E + P \nonumber$$

and the magnetization would then be expressed in tesla rather than in A m$^{-1}$. This viewpoint does indeed have much to commend it, but so does

$$B = \mu_0 (H + M) \nonumber$$

The latter is the recommended definition in the SI approach, and that is what we shall use here.
The ratio of the magnetization \( M \) ("the result") to \( H \) ("the cause"), which is obviously a measure of how susceptible the material is to becoming magnetized, is called the magnetic susceptibility \( \chi_m \) of the material:

\[
M = \chi_m H. \quad \text{Equation 12.3.2}
\]

On combining this with Equation \( \text{ref{12.3.1}} \) and \( B = mH \), we readily see that the magnetic susceptibility (which is dimensionless) is related to the relative permeability \( \mu_r = \mu/\mu_o \) by

\[
\mu_r = 1 + \chi_m \quad \text{Equation 12.3.3}
\]

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