2.6: Permeability

Permeability describes the effect of material in determining the magnetic flux density. All else being equal, magnetic flux density increases in proportion to permeability.

To illustrate the concept, consider that a particle bearing charge q moving at velocity $\mathbf{v}$ gives rise to a magnetic flux density:

$$\mathbf{B}(\mathbf{r}) = \mu \frac{q\mathbf{v}}{4\pi R^2} \times \hat{\mathbf{R}} \tag{2.6.1}$$

where $\hat{\mathbf{R}}$ is the unit vector pointing from the charged particle to the field point $\mathbf{r}$, R is this distance, and "$\times$" is the cross product. Note that $\mathbf{B}$ increases with charge and speed, which makes sense since moving charge is the source of the magnetic field. Also note that $\mathbf{B}$ is inversely proportional to $4\pi R^2$, indicating that $|\mathbf{B}|$ decreases in proportion to the area of a sphere surrounding the charge, also known as the *inverse square law*. The remaining factor, μ, is the constant of proportionality that captures the effect of material. We refer to μ as the *permeability* of the material. Since $\mathbf{B}$ can be expressed in units of Wb/m^2 and the units of $\mathbf{v}$ are m/s, we see that μ must have units of henries per meter (H/m). (To see this, note that 1 H $\triangleq$ 1 Wb/A.)

> Permeability (μ, H/m) describes the effect of material in determining the magnetic flux density.

In free space, we find that the permeability $\mu = \mu_0$ where:

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$$

It is common practice to describe the permeability of materials in terms of their *relative permeability*:

$$\mu_r \triangleq \frac{\mu}{\mu_0}$$

which gives the permeability relative to the minimum possible value; i.e., that of free space. Relative permeability for a few representative materials is given in Appendix A2.

Note that μ_r is approximately 1 for all but a small class of materials. These are known as *magnetic materials*, and may exhibit values of μ_r as large as $\sim 10^6$. A commonly-encountered category of magnetic materials is *ferromagnetic* material, of which the best-known example is iron.