12.4: Diamagnetism

We mentioned in Section 12.1 that there are five types of magnetism exhibited by various materials. In this section we deal with the first of these, namely, diamagnetism.

Diamagnetic materials have a very weak negative susceptibility, typically of order $10^{-6}$. That is to say, the relative permeability is slightly less than 1. Consequently, when a diamagnetic material is placed in a magnetic field, $B < \mu_0 H$.

If you are now hearing about this phenomenon for the first time, you may be a little surprised, and you will be expecting me to present a very short list of quite exotic materials known to be diamagnetic. So, here comes a further surprise: All materials are diamagnetic. Some materials may also be paramagnetic or ferromagnetic, and their positive paramagnetic or ferromagnetic susceptibilities may be larger than their negative diamagnetic susceptibility, so that their overall susceptibility is positive. But all materials are diamagnetic, even if their diamagnetism is hidden by their greater paramagnetism or ferromagnetism.

All materials are diamagnetic.

A proper account of the mechanism at the atomic level of the cause of diamagnetism requires a quantum mechanical treatment, but we can understand the phenomenon qualitatively classically. We just have to think of an atom as being a nucleus surrounded by electrons moving in orbits around the nucleus. When an atom (or a large collection of atoms in a macroscopic sample of matter) is placed in a magnetic field, a current is induced within the atom by electromagnetic induction. That is, the electrons are caused to orbit around the nucleus, and hence to give the atom a magnetic moment, in such a direction as to oppose the increase in the magnetic field that causes it. The result of this happening to all of the atoms in a macroscopic sample is that $B$ will now be less than $\mu_0 H$, and the susceptibility will be negative. But, you may argue,
these induced currents and their associated opposing magnetic moments will last only so long as the external field is changing. In fact it persists as long as the magnetizing field persists. The reason is as follows. In Chapter 10, we were dealing with wires and coils and resistors, and any current induced by a changing magnetic field was rapidly dissipated. For an electron in an orbit around a nucleus, however, there is no resistance, so, once it is set in motion, it will stay in motion. The same situation would arise if we were to induce a current in a loop of wire made of superconducting material whose resistance is zero. The current, once induced, continues, and is not dissipated away as heat.

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