A conceptual tour of TeachSpin's 'Foundational Magnetic Susceptibility'

Anyone's first play with permanent magnets allows a sorting of materials into the categories 'magnetic' vs. 'non-magnetic'. But it turns out that even materials we generally call non-magnetic do display a magnetic response; and even if it is a much weaker response than we associate with ferromagnetism, it is nevertheless a highly revealing response. TeachSpin's new product offering in 'Foundational Magnetic Susceptibility' allows this response to be *demonstrated*, *quantified*, and *explained*.

Michael Faraday was the first to show that non-ferromagnetic materials nevertheless showed non-zero magnetic response. He found that some materials (labelled paramagnetic) were attracted into regions of larger magnetic field, while others (labelled diamagnetic) we repelled out of those high-field regions. Both phenomena are described in electromagnetism by assigning to a medium a 'magnetic susceptibility' χ, which describes how much magnetization M (magnetic moment per unit volume) arises when the material is immersed in a pre-existing magnetic field H. For materials that are linear and isotropic, χ is a scalar, and the response M is given by $\boldsymbol{M} = \chi \boldsymbol{H}$. The susceptibility χ is positive for paramagnetic, and negative for diamagnetic, materials. It is also dimensionless, and quite small for most non-ferromagnetic materials.

The susceptibility is interesting not just because its sign allows a sorting into dia- vs. para-magnetic materials, but because it is so readily measured, and so easily connected to an underlying quantum-mechanical description of a material. It is a striking consequence of the Bohr-van Leeuwen theorem that if materials were made of charged particles obeying the laws of classical mechanics, then they would always display $\chi \equiv 0$ at equilibrium! So measuring a value of $\chi \neq 0$ is already a hint that matter needs to be described quantum-mechanically.

Better still, there are quite straightforward quantum-mechanical derivations that describe what the susceptibility of a material ought to be. From a perturbation-theory calculation it emerges that all materials ought to possess a diamagnetic response, whose size is small, and predictable from the mean-square size of electronic wavefunctions, $\Sigma\langle r^2\rangle$. But the same calculation shows that materials with non-zero electron spin content ought also to display Curie paramagnetism, and this in general outweighs the weak underlying diamagnetism of the material.

So the tabletop measurement of magnetic susceptibility provides an easily, non-invasive, and non-destructive way to look inside a material for unpaired electron spins! Thus, student understanding of the periodic table can be reinforced by having them understand (through the Aufbau Principle and Hund's First Rule) just how many unpaired electron spins there ought to be in an atom or molecule.

And happily there are easy ways to measure room-temperature magnetic susceptibility with adequate sensitivity, precision, and accuracy. TeachSpin's product offering uses the Gouy method for maximal experimental and theoretical simplicity.