Magnetic Moments of Atoms

Illustration

- If we talk about the properties of atoms, we *must* use quantum mechanics. If you are familiar with the mathematical formalism of operators, eigenstates etc., its straight forward (but still complicated). If you don't feel so hot about this, it is almost hopeless.
  - But not quite. All one has to know or accept is that even in quantum mechanics there is such a thing as momentum, and in particular **angular momentum**. True, the angular momentums resulting from electrons "orbiting" the nucleus in a certain orbital are quantized, and their projection onto some direction is quantized, too, but nevertheless we can assign a total angular momentum $\underline{J}$ to a given atom in a given state, which then is always tied in with some quantum number J (notice: no underlining) going with $\underline{J}$.
  - Usually with "a given state" we mean the ground state of that atom, but it could have an excited state or it could even be ionized - and this might change its total angular momentum $\underline{J}$.
- There are always two components to the total angular momentum:
  1. The total orbital angular momentum $\underline{L}$ (correlated to some quantum number L) resulting, if you like, from summing up (with quantum mechanical rules) the angular momentums resulting from the electrons "orbiting" the nucleus.
  2. The total spin angular momentum $\underline{S}$ (correlated to some quantum number S; use the (German) link for an example) resulting from summing up (with quantum mechanical rules) the intrinsic angular momentums of the electrons that are coupled to their spin.
- If we have determined L and S (and I'm not saying that this is trivial, just that it is doable), we obtain for the magnetic moment of an isolated atom the following rather simple formula:

$$\mu_{atom} = - g \cdot \mu_B \cdot J$$

- The interesting quantity is g, the **g**-factor or **Landé**-factor; it is given by

$$g = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}$$

  - OK, not overly helpful at first sight, but nevertheless quite useful. We could start to calculate magnetic moments of isolated atoms - but that is not too exciting for technical purposes, where we rarely use the magnetic properties of dilute gases. We could also, however, use this as a base to wonder about the magnetic moments of *ions*, as we find them e.g., in crystal lattices including metals (ions in the "electron gas"!). Now that would be useful.
- If we do this as best as possible for some interesting crystals like **Fe**, **Ni**, **Co** or some of their compounds, we find that the theoretical results are often quite close to the measured values, but sometimes they are spectacularly wrong.
  - That simply means that the bonding between atoms, which we haven't considered yet, might come into the act, too, heavily modifying the magnetic properties of isolated atoms or simple ions.
  - Slowly things start to look complicated. And we aren't even near to explaining ferromagnetism - a very specific interaction of the magnetic moments of neighboring atoms.
  - So relax, lean back, and just accept that atoms might have some specific magnetic moment, that might depend on how they are incorporated into some solid, but that it is always in the order of a Bohr magneton. if you do that, you can go right on to chapter 4.1.3.