Some Musings on Magnetization
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The historical manner in which magnetism developed has created a science which has some serious disconnects in its formulation, never more so than in the physics of ferromagnetic materials. Even though modern scientists know that the magnetization comes from arrays of discrete atomic dipoles, where in that micro-universe the separation between atoms is huge compared to their size, that inter-atomic space and the magnetic fields therein are generally ignored. Scientists use a term called *magnetization* (usually denoted **M**), which is a volume-density of a "substance" called *dipole-moment*, and proceed as though that "substance" is smoothly spread through all space within the material. They know that dipole-moment is a characteristic of a discrete dipole, and that **M** should really be a discrete number-density, but because that number-density is so very high (like 10^{28} atomic dipoles per cubic meter) it has been found more convenient to imagine **M** as a volume-density smooth function. That inconsistency, the filling of inter-atomic space with that imaginary substance, prohibits the calculation of the actual magnetic fields there and so continues to hide the magnetic energy stored in that space and its vital connection to the atomic dipoles, the *quantum dynamos* that Nature has supplied. For permanent magnets those inter-atomic fields are not trivial, and the stored energy has a density significantly greater than the magnet's maximum BH energy product.

Again for permanent magnets that inconsistency has lead to the nonsense of a negative **H** residing within the magnet, i.e. **H** opposing the **B** field. And it has hidden the true meaning of the reluctance of the air space occupied by the magnet, something that is used when calculating the load line. This calculation is usually performed by rote with little thought as to why it works, yet the answer is very simple. The magnetic domain equivalent circuit for a permanent magnet is an mmf source (i.e. the combined effect of all the aligned atomic dipoles) in series with that air-space reluctance, and the load-line procedure is simply a graphical method of calculating the mmf drop across it. Another clue to the inconsistency is the known feature of permanent magnets having a permeability of unity, i.e. they act like air to alternating fields (eddy currents excluded).

The same arguments apply to soft ferromagnetic material, when magnetized there is within the inter-atomic space magnetic energy that is far in excess of that used to create the magnetization. That excess energy is supplied by Nature, it comes from the quantum domain, from the quantum forces driving each atomic dipole. If each atomic dipole were modelled as a small loop driven by a constant current generator, each current generator would supply that excess energy during the magnetic field build-up (and retrieve that excess energy during magnetic field decay). In the case of alternating excitation this store of hidden energy is cyclic, which opens the door to methods of extracting a portion on each cycle, with that "loss" (which is our gain) being replenished from the quantum forces driving each dipole.

Of particular interest are ferromagnetic materials that exhibit a magnetic resonance, like domain-wall resonance. That resonance enhances the incremental permeability of the material when driven at the resonant frequency, and we can make use of that enhancement. In order to fully utilise this phenomenon we need to change our views on magnetic energy stored within soft ferromagnetic material.

We are taught that the material stores the quantity of energy we input as given by $\frac{1}{2}Li^2$, and that value is translated into a magnetic density of value $\frac{1}{2}B^2/\mu$ where the material obeys $B=\mu H$ having a permeability $\mu=\mu_r\mu_0$. But that discounts the vast inter-atomic space where the magnetic energy is really stored. In reality the energy density stored there is $\frac{1}{2}B^2/\mu_0$, which is μ_r time greater than we are led to believe, and this comes about because the H is increased by the value μ_r. The increase in H comes from the aligned atomic dipoles, which supply an H value of χ times the applied H where χ is the magnetic susceptibility. The sum of the applied H and the dipole's H is then $(1+\chi)$ times the applied H, where $(1+\chi)=\mu_r$.

So instead of imagining a material that has the property of increasing B while H remains at the input value, we should imagine an air space of the material dimensions where H is increased by the addition of χH. The presence of an applied H "conjures up" the additional χH. The "conjuring up" is not a magical process, it comes from an array of atomic dipoles (imagine them as tiny bar magnets) that rotate or flip in response to the applied field. At zero applied H field they have random orientations so their net effect seen from outside the material is zero. But when an applied H field is present they tend to align themselves with the field, hence increasing the H field value, and the permeability is simply our method of accounting for that increase.

When considering a ferromagnetic resonance it is the susceptibility χ that exhibits this, so at resonance we find a χ value that is greater than that at low frequencies. Translating that to our vision of rotating or flipping bar magnets they swing about more at resonance than they do at lower frequencies. And magnets swinging about inside coils induce voltage. Thus charging a coil with current at low frequency creates a small voltage to "load" the current generator, while discharging it at the resonant frequency creates a greater output voltage, hence greater power out than power in. The source of that anomalous energy is those atomic dipoles.