Magnetic Energy in Ferromagnetic Material

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Summary

The storage and flow of magnetic energy in ferromagnetic materials is examined and discussed. It is shown that within both hard and soft ferromagnetic materials, large quantities of magnetic energy exist, far in excess of any electrical input; this energy is supplied by the electron spins responsible for the material's magnetic properties, which may be considered as *quantum dynamos*. This excess energy is readily deduced from classical theory, but is generally hidden from view (and therefore not generally known to exist) because of the use of magnetization **M** as a continuously distributed attribute, which forbids the presence of free-space within the material. In fact the quantum dynamos responsible for **M** are individual entities, widely separated at the atomic length scale, and it is shown that the excess energy supplied by these *does* exist in that inter-atomic space. It is also shown that that there are two types of magnetic energy flow, only one of which appears in universally accepted scientific texts. This "known" energy-flow vector connects with an external electric circuit via voltage induced in coils, hence correctly describes the relatively small proportion of magnetic energy in the inter-atomic space that is transported from or to the electric domain, and that small proportion is the *only* energy according to the present incomplete scientific theory. The other flow vector, which has been overlooked, does not create induced voltage, therefore has no connection to the electric circuit, but correctly describes magnetic energy flowing entirely within the magnetic domain, *including the large quantity of inter-atomic magnetic energy which flows to or from the quantum dynamos*. It is shown that other flows of this "unknown" variety, flowing to or from this abundant energy store, can be initiated by a changing magnetic reluctance, created either by mechanical movement of a ferromagnetic armature or by non-linear material characteristic. Combinations of permanent magnets, non-linear material and/or mechanical movement can alter the balance between the energy which is accessible and that which is hidden, giving us a method for extracting Nature's gift. Reputable Scientists examining claimed anomalies in the generation of electrical energy, being unaware of the second type of magnetic flow and of the excess inter-atomic magnetic energy, therefore perform incomplete analyses which often wrongly debunk these claims.

1. Introduction

This paper considers aspects of the energy stored in ferromagnetic material, and in particular discusses some anomalous energy behaviour. The aim is to demonstrate where that anomalous energy originates.

2. Linear Materials

Consider a ferromagnetic material with linear characteristic, i.e. the slope of B v. H is a straight line (figure 1). We know that an area on this chart represents an energy density, so we must multiply such an area by the volume of the material to get an energy figure. This is OK if we are dealing with a complete core, but often we are interested in a magnetic circuit where there is more than one material (e.g. a core with an air gap), or one where the B changes because of the geometry (e.g. the core has a restriction). Then a more useful chart is one of flux (Φ) v. mmf (U). For a given core section the conversion from B to Φ simply involves multiplying by the cross section area, and U can be got from H by multiplying by the core length. The derived chart (figure 2) has the same shape as the BH curve, but now the area gives energy directly. Advantage of the ΦU chart is that $\Phi \cdot U$ relates to the total energy, and in a series magnetic circuit all parts are linked by the same Φ, so it is an easy matter to establish the mmf drop across each and get the energies separately. Alternatively in a parallel circuit all parts are linked by the same U, then the individual Φ's give the separate energies. In the two charts shown, taking the field from zero to its energised value B (or Φ) at an excitation level H (or U), conventionally the energy stored in the core is obtained from the area of the yellow triangle, hence the energy density is $B \cdot H/2$ and the actual energy is $\Phi \cdot U/2$. If the excitation is electrical, i.e. a current flowing in a coil around the core, then it will be appreciated that the mmf U comes from the current in the coil, and the change of flux from zero to Φ creates an induced voltage across that current source whose voltage-time integral is proportional to that flux change. Hence $\Phi \cdot U/2$ correctly gives the $I \cdot V \cdot t$ (or to be more exact $I \cdot \int V.dt$), the electrical energy taken from that source into the core on inductor charge, or given up from the core on inductor discharge. That energy is also given by the familiar $0.5 \cdot LI^2$, the energy stored in an inductor L carrying a current I.

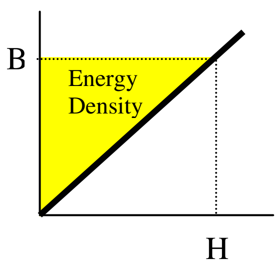


Figure 1. BH Chart

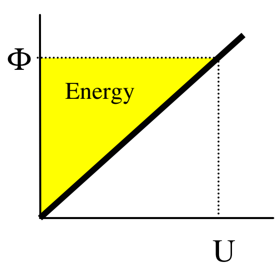


Figure 2. ΦU Chart

3. Non-Linear Materials

Now consider a core with a non-linear characteristic, one which saturates (figure 3). This is simplified for the purpose of discussion as having two straight line sections with a sharp break point at B_1, H_1. Taking the core up to B_1 involves an input energy shown by the yellow triangle, as before. Now take the core beyond the saturation knee to the point B_2,H_2. The additional input electrical energy is shown by the green area, but the actual energy stored in the core from $B_2 \cdot H_2/2$ is now greater than the input energy. The anomalous energy is shown in red. Is this energy real, and if so where does this energy come from? If we could suddenly swap the saturated core with a linear one whose permeability is B_2/H_2, whose reluctance is U_2/Φ_2, the magnetic conditions would be unchanged: then we could discharge the core, going down the straight line from B_2,H_2 to the origin, and get out all the red+green+yellow energy. But having put in the yellow+green energy in the first place, we would gain the anomalous red energy, we would have COP>1. We would in fact go round the red triangle in a clockwise direction. This suggests the anomalous energy is real, and can be extracted.

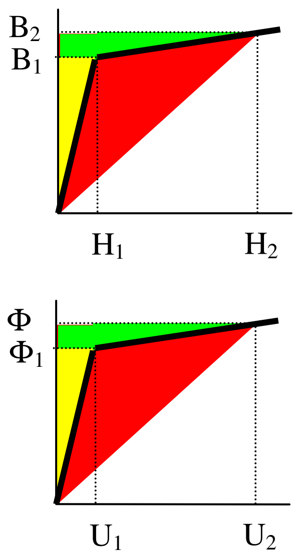


Figure 3. Non-linear Core

4. Energy Flow Vectors

To find the source of this energy, let us now look into the energy flows which take place in or external to the core. We will assume that the core has low reluctance connections to the area of interest, so that we can consider these connections to be like *magnetic conductors* having minimal mmf drop, then all the mmf occurs across the non-linear *magnetic load* section (figure 4). We know that there is a vector magnetic field **A** encircling the core, related to the flux Φ in the core. Taking the initial flux rise to Φ_1, as Φ is changing with time then so is **A**, giving rise to an electric field **E**=-dA/dt. That (changing) flux also produces a (changing) scalar magnetic potential across the magnetic load, so there is a radial **H** field emanating from the magnetic conductor as shown. The vector product **E**×**H** is the Poynting power density flow vector **P** pointing towards the load. Taking a closed surface integral of that **P** vector around the magnetic load yields the energy flowing into the load, that energy of course coming from the drive-current source. We have a power flow vector exactly accounting for the electrical flow supplying the yellow energy.

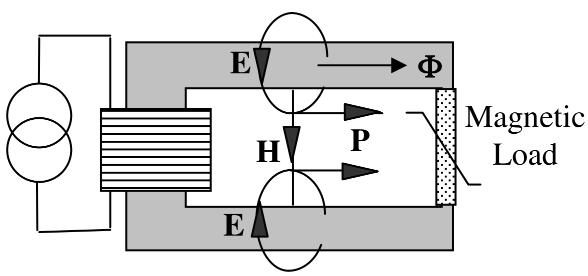


Figure 4. Power Density **P** Vector

Next let us assume the non linear magnetic load has an incremental reluctance above saturation that is extremely high, so that the green energy is negligible (figure 5). Thus the move from U_1 to U_2 is accompanied by a constant flux Φ_1. That constant flux produces a constant **A**, hence there is no induced voltage. But there *is* a power flow present, seen externally not as **E**×**H** (which is the same as **H**×d**A**/dt), but as d**H**/dt×**A** (see figure 6). This new power density vector d**H**/dt×**A** is not recognized in contemporary EM texts, which is a grave omission. *It represents magnetic energy flow which is not accompanied by induced electrical signals*. If we take a closed surface integral of this vector around the magnetic load, it correctly accounts for the anomalous red area. Because this d**H**/dt×**A** flow is not electric sourced, it would be wrong to call it the Poynting vector, it deserves a new name and symbol. In some texts the Poynting vector is given the symbol **S,** so we will adopt **S** for this new vector, keeping **P** as the symbol for Poynting. Of course, as in electrics, there will be some debate as to whether the energy actually flows through external space or inside the magnetic conductor. Inside that conductor we get the power as Φ·dU/dt, which is one component of the more general d(Φ·U)/dt. (Φ·U is magnetic energy, so the time variation of this product *must* yield energy flow, power. The differentiation rule for the product Φ·U yields the two components Φ·dU/dt and U·dΦ/dt). During the earlier yellow energy-flow phase, the other component, U·dΦ/dt, was in operation, which connected to the coil current source via the voltage induced from dΦ/dt. It is interesting that when Φ is constant while U is changing, *there is no voltage to pull power from the drive-current source*, so where does that extra magnetic energy come from? To answer that question we must look at an established methodology for permanent magnets, and apply it to soft ferromagnetic material. That methodology is the concept of equivalent surface current flow, which is discussed in Section 6. Meanwhile the next section examines this new **S**= d**H**/dt×**A** energy density flow vector in more detail, to demonstrate that it is real.

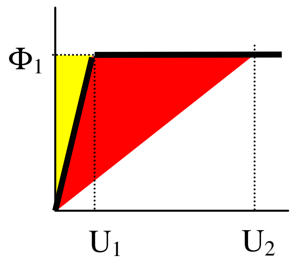


Figure 5. Non-linear Load

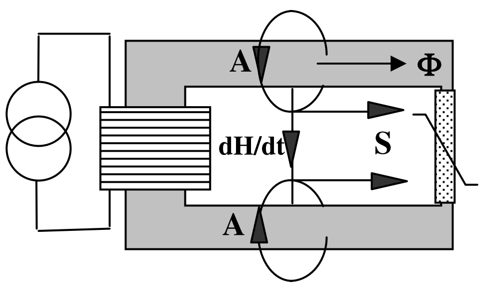


Figure 6. Power Density S Vector

5. Energy Flow in a Reluctance Motor.

A reluctance motor is a device where the magnetic reluctance of a magnetic circuit is made to change, usually by moving a ferrous armature into an air gap. If the gap is energized, e.g. by current flow in a coil, the armature is pulled into the gap, hence providing a motor action. Consider such a motor where the permeability of the C core is so high that it can be considered as a magnetic conductor. When energised with fixed ampere-turns (mmf), as the armature enters the gap the flux increases, thus placing an induced voltage across the current source and drawing energy from it. The constant mmf across the gap creates a constant radial **H** field, while the changing flux creates a circular **E** field. The resulting **P**=**E**×**H** Poynting vector describes the power flow from the coil into the closing gap.

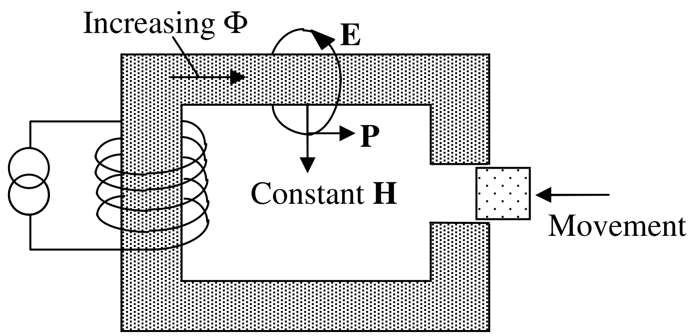


Figure 7. Gap Energized by Coil

Now consider a similar situation but this time the gap is energized by a permanent magnet (figure 8). The magnet provides an almost constant flux, so now as the gap closes (and its reluctance decreases) its mmf-drop *reduces*. *There is a power flow in the opposite direction, away from the gap*. It is easily shown that over this pull-in phase the mechanical energy released to the armature is equal to the magnetic energy "lost" from the gap; that energy flows back into the magnet. The external flow **S**-vector is seen to be the **S**=d**H**/dt×**A** discussed earlier.

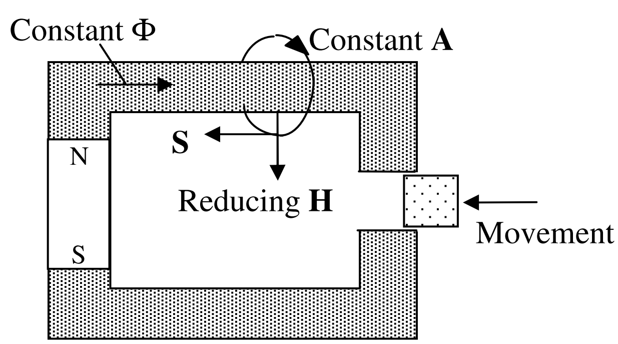


Figure 8. Gap Energized by a Magnet

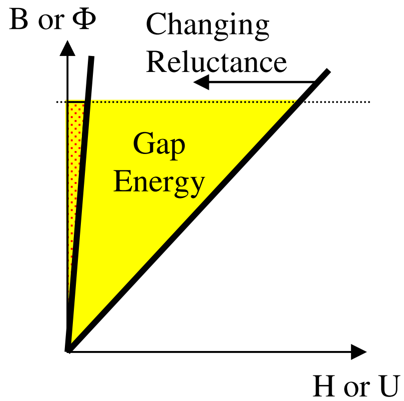


Figure 9. Gap Reluctance

We will now use graphical methods on BH and ΦU charts to show this "backward" flowing energy. First consider just the gap with its reducing reluctance (figure 9). Initially the energy in the gap is shown as the yellow triangle, but when its reluctance is reduced to an almost zero value that energy virtually disappears. Now consider the energy at the magnet (figure 10), where we start with the classical load-line applied to the BH curve. Calculation of the load-line involves the reluctance of the *air space* occupied by the magnet. We will simply refer to this as the magnet reluctance $\mathcal{R}_M$. Also involved in the load line is the reluctance of the magnetic circuit external to the magnet, which in this case is the gap reluctance $\mathcal{R}_{GAP}$. The ratio of $\mathcal{R}_M$ to $\mathcal{R}_{GAP}$ determines the slope of the load line. We will also simplify the magnet BH loop by considering the top to be a straight line with slope μ_0 (which is a close approximation to modern square loop material). When we transfer that load-line from the BH graph to a ΦU graph, we find the slope of the load line to be the direct inverse of $\mathcal{R}_{GAP}$, the external reluctance across the magnet (the inverse of $\mathcal{R}_M$ is the gap permeance $\mathcal{P}_{GAP}$). We also find the slope of the ΦU loop top to be the inverse of the magnet reluctance $\mathcal{R}_M$ (the inverse of $\mathcal{R}_M$ is the magnet permeance $\mathcal{P}_M$). If we extrapolate the straight line slope of the top of the hysteresis loop back until it cuts the negative H or U axis (at $-H_{ATOMIC}$ or $-U_{ATOMIC}$, figure 11) we find that we are modelling a simple magnetic circuit of two reluctances in series.

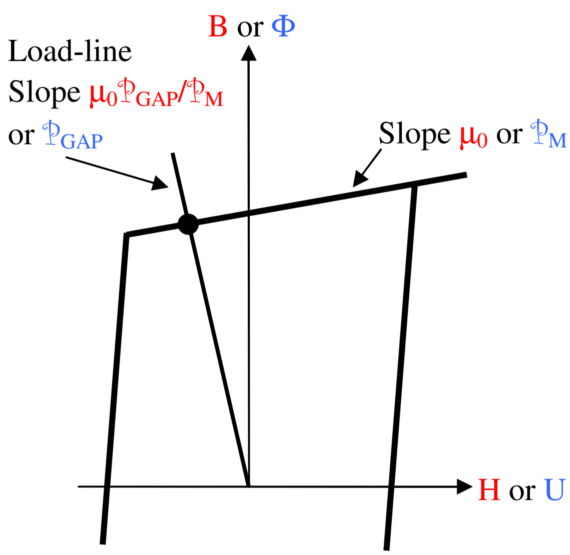


Figure 10. Magnet Load-line

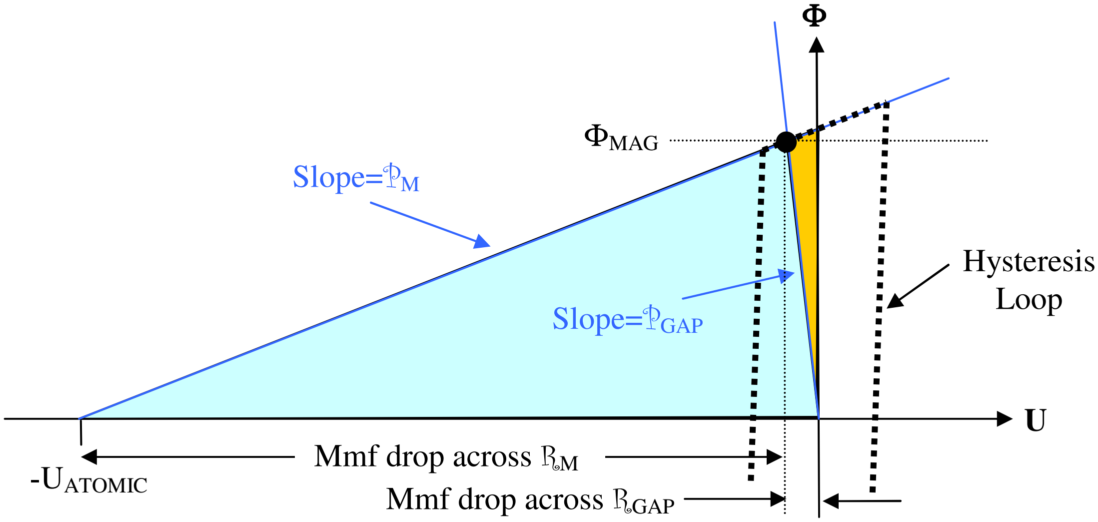


Figure 11. Magnet Load-line on ΦU Graph

Magnetic engineers have for many years used the BH loop load-line method for establishing a magnet's operating point without realizing the simple significance of their actions. They are simply placing the magnet's mmf (U_{ATOMIC}) across the series combination of $\Re_M$ and $\Re_{GAP}$, and using a graphical method for establishing the resultant flux Φ_{MAG}. For magnets with rounded hysteresis loops (like Alnico) the graphical method may be necessary, but for square loop material operating along the top section (i.e. no change of material magnetization) it is simply "magnetic Ohm's Law".

Now we have an insight into magnetic energy hidden in the magnet and released to the gap; with the gap present, the magnet's hidden energy is denoted by the light blue area on figure 11. When the gap is closed, its reluctance tends to zero yielding a vertical line, so the energy shown in gold is returned to the magnet. This explains the "backward" energy flow $W=\Phi\cdot dU/dt$.

We have shown that the magnetic power flow $W=d(\Phi\cdot U)/dt$ has two components. $W=U\cdot d\Phi/dt$ is one component which dictates power transferred into or out of the material through a coil, the $d\Phi/dt$ being responsible for voltages induced into the coil hence the transfer of power from/to the electric domain. The other component $W=\Phi\cdot dU/dt$ has no connection to the electric domain if Φ remains constant with time, but can be initiated via connection to the mechanical domain (or any other method which changes the value of load reluctance). Both components are present in mixed systems containing coils and magnets. A permanent magnet has a considerable quantity of energy hidden within it which is accessible via the second component.

6. Equivalent-Current Circuits

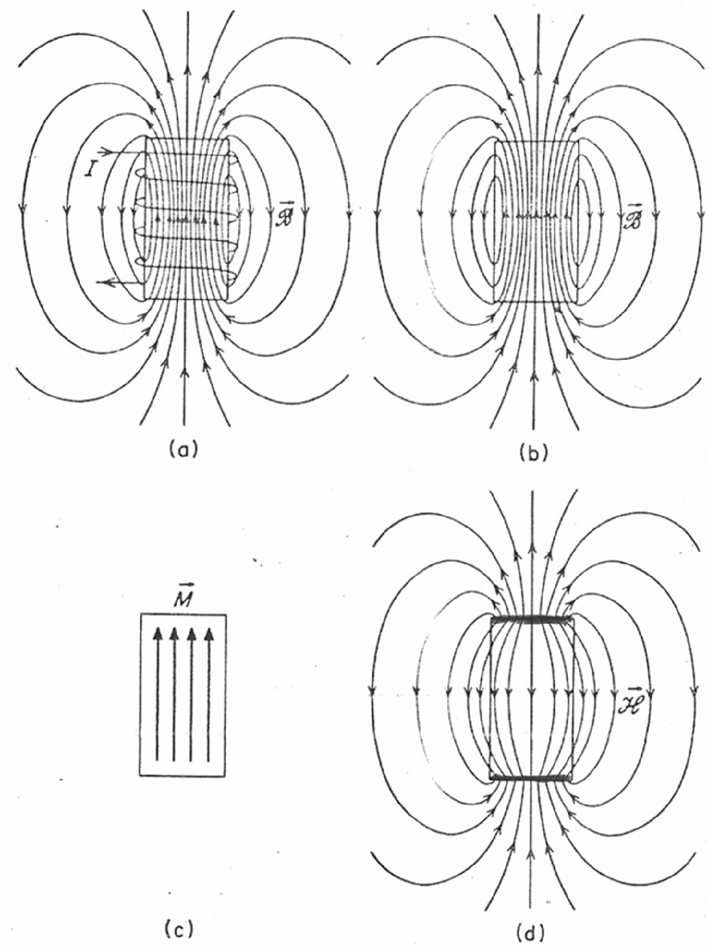
6.1. Permanent Magnets

It is recognized that the magnetic field from a permanent magnet emanates from atomic magnetic dipoles, being due to their electron spin. Although a PM is often modelled as a single magnetic dipole, it is actually an array of large numbers of these atomic dipoles, these *quantum dynamos*. One method for modelling a magnet is to replace it by an electrical equivalent circuit, a close wound solenoid wound on an air core of dimensions identical to the magnet. This approach is well known, see for example *Electromagnetic Theory for Engineers and Scientists* by Allen Nussbaum (Prentice Hall Inc., New Jersey), which has an entire section entitled *Equivalent Currents and Magnetic Materials*. Note that in the equivalent circuit the solenoid has an air core, the material is treated as having unity relative-permeability, its magnetic properties coming from the coil current, which is really of atomic origin. If we delve into the real core material, we find that unity relative-permeability is justified for the empty space between atoms which makes up the bulk of the material. The remanent field B_R of the magnet (or of its equivalent solenoid) flows through that empty space, yielding an energy density $0{\cdot}5{\cdot}B_R^2/\mu_0$. When multiplied by the volume of the magnet, we find a stored magnetic energy value considerably in excess of the so called *energy product* of the magnet (this excess energy is shown by the light blue and gold areas on figure 11). To give an indication of this hidden energy, 1 cubic metre of material having a B_R of 1 Tesla contains about 400,000 Joules. Why has this enormous store of quantum derived energy been ignored?

Contemporary magnetic theory contains several oversights which derive from its past history, in particular the mis-concept of negative **H** within the magnetized region.

- The material magnetization **M** is considered as a continuously distributed attribute, much as a fluid is when it fills a container. This continuous distribution prohibits the presence of free-space within the material. In fact the magnetization is not continuous, there exists a discrete number of atomic dipoles separated by significant distances on the atomic scale, there is considerable free-space inside the material.
- Magnetic fields were originally considered to emanate from magnetic poles, and although poles have been banished from modern theory (except as a convenient method for calculating magnetic effects), this incorrect concept still exists today where end faces (pole faces!) of the magnetization "fluid" act like poles, sending **H** lines both outward (positive) and inward (hence negative).
- The concept of such a negative **H**, yet positive **B** leads to a negative energy-density product **B·H;** a negative energy seemed appropriate for something that freely supplies magnetic force, but it is shown later to be erroneous.
- A load line on a magnet's BH chart takes the operating point of the magnet into the second quadrant where **H** is negative. This is an incorrect viewpoint, since the H=0 axis ignores the presence of the H_{ATOMIC} provided by the atomic dipoles. The correct H=0 axis should be well to the left (see for example figure 19).

The following image taken from Nussbaum shows (a) a **B** plot for a solenoid, (b) an equivalent magnet, (c) the magnetization **M** in the magnet and (d) a plot of **H** for the magnet. The thick lines in (d) represent the imaginary poles.



5-19 (a) A plot of $\mathscr{B}$ for an air-core solenoid; (b) an equivalent magnet; (c) the magnetization; (d) a plot of $\mathscr{H}$ (after Pugh and Pugh, *Principles of Electricity and Magnetism*, Addison-Wesley Publishing Co., Reading, Mass.)

Figure 12, Taken from Nussbaum's *Electromagnetic Theory for Engineers and Scientists*

For the solenoid 12(a), the H lines are contiguous with the B lines, since they are everywhere in air. However for the magnet, 12(d) shows reverse facing H lines inside the material. These reverse lines are as fictitious as the imaginary poles, but continue to exist because of our non-recognition of the atomic mmf (U_{ATOMIC} in figure 11), even though we simulate that U_{ATOMIC} with the ampere-turns of the solenoid equivalent in 12(a). If we draw our BH or ΦU charts with the H or U zero point *not* with respect to that applied, but with respect to true zero (i.e. shifted left by a value H_{ATOMIC} or U_{ATOMIC}, then the negative case does not arise.

The next figure (figure 13) shows a FEMM simulation for a simplistic array of 55 magnetic dipoles (current loops), intended to represent the dipoles of a permanent magnet. It shows the **B** field magnitude both inside and outside the “material”. Because the inter-dipole space is air, of relative permeability 1, the contour plot also represents $H=B/\mu_0$. Note that H is everywhere positive, the energy product B·H is positive. *There is no negative energy as found in modern texts on magnetic theory.*

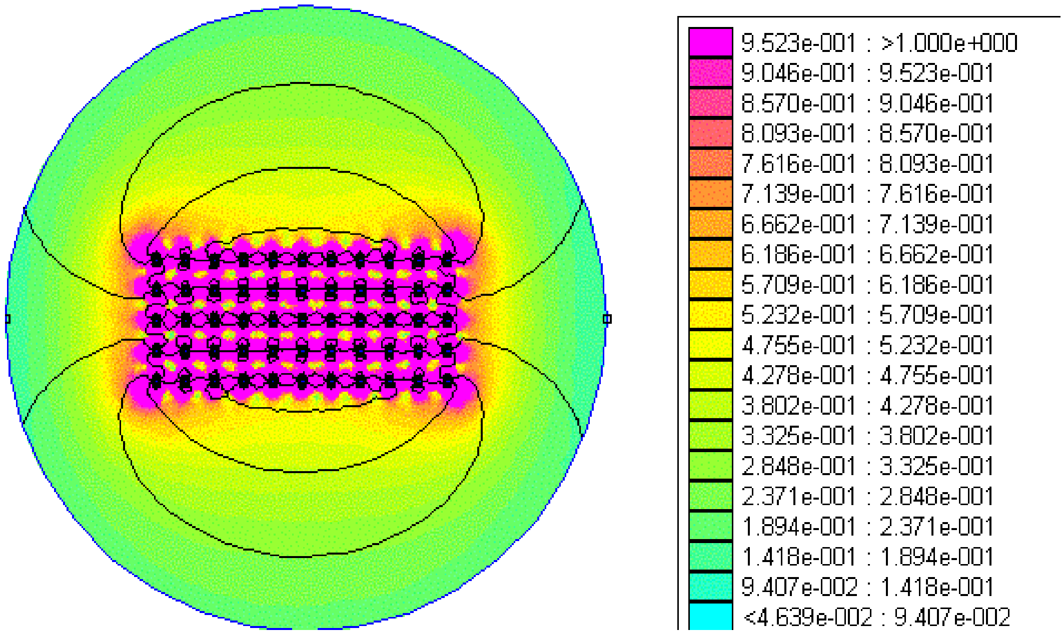


Figure 13. FEMM Simulation of a Permanent Magnet Dipole Array

For comparison figure 14 shows an equivalent solenoid. In both cases the B field is in air or vacuum, *there is no negative H*.

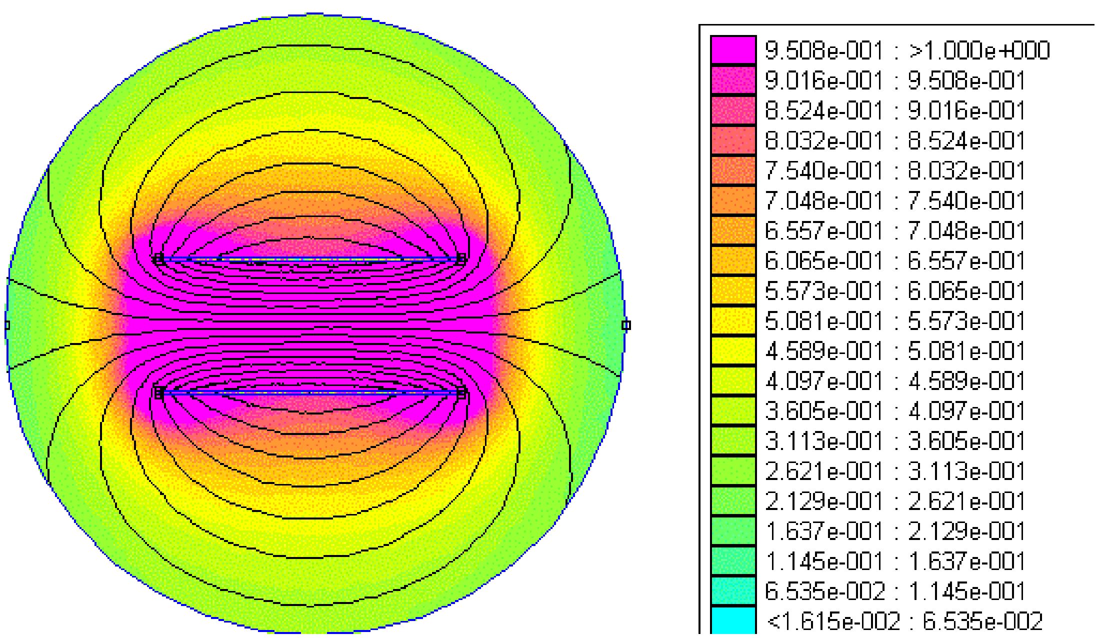


Figure 14. FEMM simulation of a Solenoid

6.2. Soft Ferromagnetic Materials

Although not mentioned in EM texts, the equivalent current method also applies to soft ferromagnetic material, since the source for the magnetic field is a similar array of atomic dipoles or *quantum dynamos*. Whereas in a PM the aligned array of dipoles is frozen into the material, in soft cores the alignment is variable, being controlled by the applied H field. We can therefore model a soft ferromagnetic core as an equivalent air cored solenoid whose coil current is of quantum atomic origin. Take a simple inductor having its magnetic circuit continuous (figure 15), shown here as a complete ring core of relative permeability μ_R. When charged with current we know the **B** field inside the core is given by $\mathbf{B}=\mu_R\,\mu_0\mathbf{H}$, where **H** is the induction from the coil current. We also know that the energized core is magnetized, having a magnetization **M**. This magnetization is the volume density of the atomic dipoles which have been aligned by the applied **H.** **M** has dimensions of dipole moment per cubic meter, which in basic dimensions is amp/m, exactly the same as **H**. Another expression for **B** is $\mathbf{B}=\mu_0(\mathbf{H}+\mathbf{M})$, where **M** is related to **H** by $\mathbf{M}=\chi\mathbf{H}$. χ is known as the magnetic susceptibility, which can be positive or negative. Materials with negative χ are diamagnetic, but we are interested in positive χ which applies to paramagnetic and particularly to ferromagnetic materials.

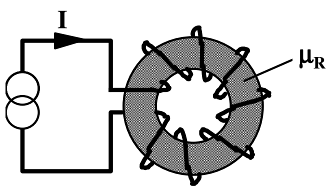


Figure 15. Simple inductor

This next figure (16) shows the same inductor modelled by the equivalent surface-current method. The core is replaced by a close wound single layer toroid wound on air. This imaginary coil is driven with a current so as to produce χ times the ampere-turns of the inductor. The air core thus receives flux from two sources, the total flux being $(1+\chi)$ times that from the inductor coil alone (which alone would produce $\mathbf{B}=\mu_0\mathbf{H}$ in the air core). Thus this equivalent circuit correctly reproduces the $\mathbf{B}=\mu_R\,\mu_0\mathbf{H}$ of the real core. It is possible to build a powered simulation of this equivalent circuit, as shown (figure17). Here the drive-current is sensed, then this signal is fed to a current controller which drives the equivalent-circuit coil to produce the correct ampere turns. Of course the synthesised circuit requires a power source which in the real world is supplied by Nature. When we apply current to the terminals of the real coil, we find that the combined coil-driven B plus atomic-driven B induces voltage acting against that drive (Lenz's Law), and that limits the power drawn. The energy taken from the

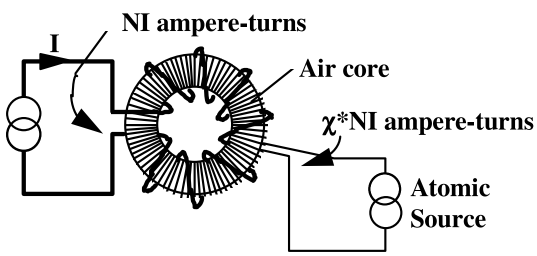


Figure 16.

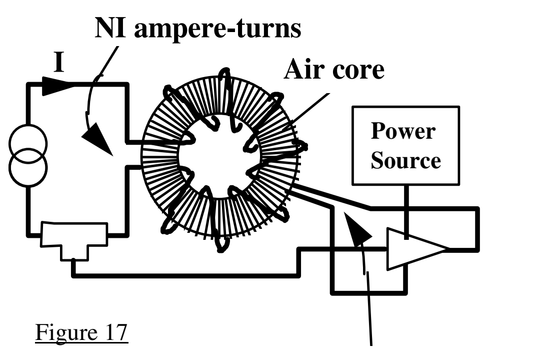


Figure 17

current source by our real inductor (figure 15), which we know to be $0.5 \cdot LI^2$, is exactly replicated by the simulation (figure17). But that value is *not* the energy stored in the air core, that energy is much greater, the simulated atomic power supply supplies the extra. *In the real world the atomic dipoles, the quantum dynamos, supply the extra energy*. The actual energy stored in the air core, in the free space between the atoms, is $\mu_R \cdot 0.5 \cdot LI^2$. *With modern magnetic materials having extraordinarily high μ_R (like 10,000), Nature's quantum dynamos provide some 10,000 times more energy that we put in!* Is that energy the source we are looking for?

6.3. An Interesting Experiment

As an aside it would be most instructive, and it would make an excellent college experiment to enhance our teaching of this subject, to construct a transformer using the synthesised atomic current coil (figure 18). It would be necessary to ensure that the primary and secondary load currents do not affect the synthesised current, since they cancel out with respect to ampere-turns. Only the primary magnetizing current must be sampled for the atomic current control. A simple way to ensure this is to build a transformer with identical primary and secondary turns (preferably bifilar wound, although for clarity they are shown separated in the figure). In the common ground feed to the two windings the load currents cancel, leaving only the magnetizing current.

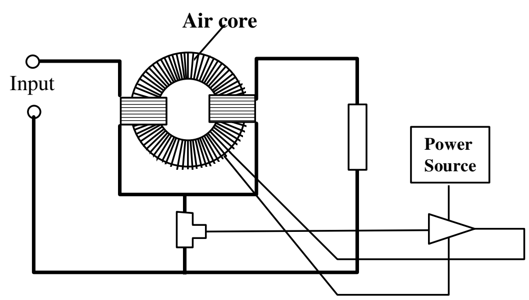


Figure 18. Transformer Experiment

7. More on BH Curves

Let us look again at the BH curve in the light of the presence of atomic **H**. Putting χ**H** in place of **M** we get **B**=μ_0 (**H**+ χ**H**). Therefore the real BH characteristic for a material becomes as shown in figure 19. As we increase **H**, Nature provides additional χ**H** from the atomic dipoles, the quantum dynamos, so the system goes up the curve with slope μ_0. However if we plot B v. H, *ignoring the* χ**H** *contribution*, we obtain the slope $\mu_R\mu_0$, which we recognise as the permeability characteristic of the material. *That ignorance of the χ**H** contribution to*

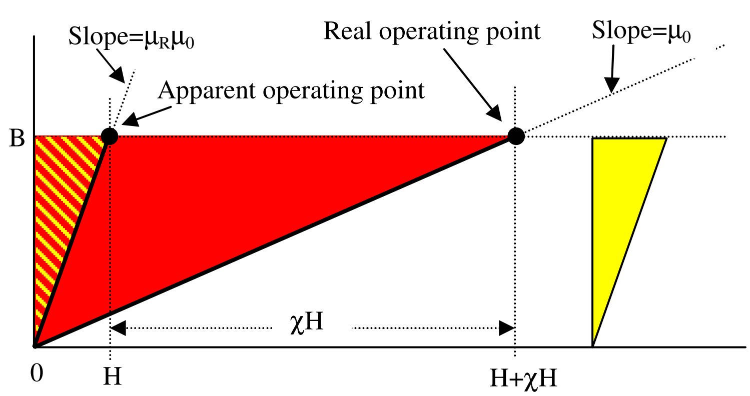


Figure 19. Real and Apparent BH lines

actual energy within the material, as opposed to apparent energy, is a major omission in current EM theory. In figure 19, input energy-density obtained from B·H/2 is the yellow triangle, which we have displaced from its usual position attached to the B axis. Actual energy-density from B·(H+χH)/2 is the red triangle, so red minus yellow (un-hatched red) is the excess energy-density provided by the quantum dynamos. *Note the ratio of yellow (accessible) energy to red (hidden) energy remains constant.*

For reasons which will become apparent, it is convenient to rearrange the real BH characteristic to show **χH** in the negative quadrant (figure 20) (but **χH** is not really negative, this is only for presentational purposes). As before the yellow represents input energy while the red is the total energy, the un-hatched red is the excess. On this chart, as **H** moves to the right, so **χH** moves to the left, (but that situation can not continue indefinitely, eventually saturation is reached).

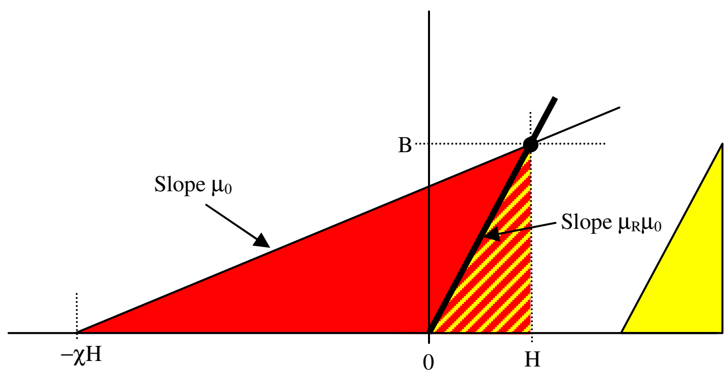


Figure 20. Re-arranged BH Lines

χH comes from the magnetization, the alignment of the atomic dipoles, and the material has a finite number of these. When all the dipoles are aligned, there is no more increase in **χH**, the material is *saturated*. The operating point then moves up the μ_0 slope, as shown in the next figure (21). At the point B_1H_1 above saturation, the total energy density given by $B_2 \cdot (H_2 + \chi H_{SAT})/2$ is the red area, the green trapezoidal shape represents the additional input energy while the yellow triangle is the original input energy up to saturation. *Note that in materials driven above saturation the ratio of yellow (accessible) to red (hidden) energy is no longer constant.*

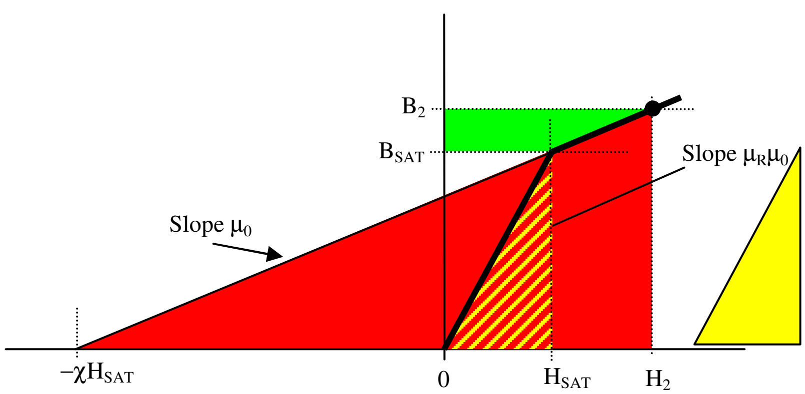


Figure 21. BH Taken above Saturation

So we now have the answer to our original question, where does the anomalous energy come from? It already exists in the magnetized material, put there by Nature's quantum dynamos. Combinations of permanent magnets, non-linear material and/or mechanical movement can alter the balance between the energy which is accessible and that which is hidden, giving us a method for extracting Nature's gift.

8 Conclusions

The equivalent current approach to modelling ferromagnetism shows there to be significant magnetic energy in the air space occupied by the ferrous material (effectively in the inter atomic space), far in excess of the electrical energy taken from the excitation circuit. This excess energy, which exists in both magnetically-hard and soft materials is supplied by the atomic dipoles, but is usually denied to us. It has been shown that in soft materials this excess energy is related to the input mmf and the magnetic susceptibility χ.

The transfer of energy from one part of a magnetic circuit to another is given by a power flow W in the material as the time rate of change of the energy product flux·mmf, $W=d(\Phi\cdot U)/dt$. By the differentiation-of-products Rule, there are two components of this power vector, $\Phi\cdot dU/dt$ and $U\cdot d\Phi/dt$. Only $d\Phi/dt$ yields an induced voltage, and it is this component which is responsible for determining the power drawn from an energized coil or fed back to a load on inductive discharge. This component is directly associated with a $\mathbf{P}= \mathbf{E}\times\mathbf{H}$ power density Poynting vector outside the core, which correctly describes the energy flow via the coil. Present magnetic theory recognizes this as the *only* energy.

The second $U\cdot d\Phi/dt$ flow component in the core, which (to the author's knowledge) is not yet recognized in EM theory, also has a power density vector outside the core, $\mathbf{S}=d\mathbf{H}/dt\times\mathbf{A}$. These correctly describe power flow which has been shown to occur, *but where there may be no induced voltage present, hence no connection to an external electric circuit*. Energy flow from the quantum dynamos to the inter-atomic space inside the core occurs via this flow component, hence is invisible to the external electric circuit. A variable reluctance created either by mechanical movement of a soft armature through a gap, or by a non linear material driven beyond its saturation knee, has also been shown to transfer energy via this second, non-voltage, energy-flow term, and that energy has been shown to flow from or to the inter-atomic space.

It is contended that the absence from contemporary EM theory of the $U\cdot d\Phi/dt$ flow and its associated $d\mathbf{H}/dt\times\mathbf{A}$ vector, and the non-recognition of the quantum derived energy-density $\mathbf{B}\cdot\chi\mathbf{H}/2$, is responsible for the present lack of ability in designing systems which extract energy from the quantum vacuum. When these formulae are introduced they open up access to energies previously thought to be denied, energies which have been presumed to be locked away inside the material.

Combinations of permanent magnets, non-linear material and/or mechanical movement can alter the balance between the energy which is accessible and that which is hidden, giving us a method for extracting Nature's gift. There are many claims for over-unity machines where these claims are rebuffed by the scientific establishment on the basis of contemporary magnetic theory. *Serious omissions in this theory have been identified, these analyses are often flawed.*

Symbols	Description	Dimensions
A	Vector Magnetic Field	Webers/m
B	Flux Density	Tesla=Webers/m^2
H	Induction	Amp-turns/m or Amp/m
E	Electric Field	Volts/m
W	Power	Watts
Φ	Flux	Webers
U	mmf	Amp-turns or Amp
P	**E**×**H** Poynting vector	Watts/m^2
S	d**H**/dt×**A** vector	Watts/m^2
M	Magnetization	Amp/m
μ_0	Free space permeability	Henry/m
μ_R	Relative permeability	dimensionless
χ	Magnetic susceptibility	dimensionless
$\mathcal{P}$	Permeance	Henries
$\mathcal{R}$	Reluctance	Inverse henries