A New Theory of Magnetism

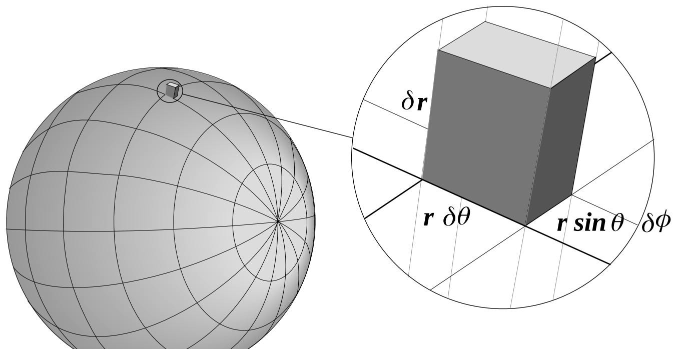
Introduction

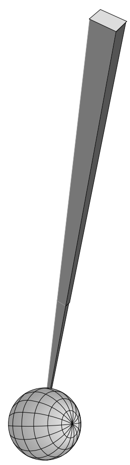
In my first paper "Inertial Mass as an Electromagnetic Phenomena", I described how matter can be modelled by assuming that electrons, up quarks and down quarks are spherical charges of -e, $\frac{2}{3}e$ and -$\frac{1}{3}e$ and of radii $\frac{\mu_0 e^2}{6 \pi m_e}$, $\frac{2 \mu_0 e^2}{9 \pi m_n}$ and $\frac{\mu_0 e^2}{18 \pi m_n}$. Such charges are surrounded by a magnetic field which has an energy content equal to their Kinetic energy and display an inertial property equivalent to their supposed mass. It is not necessary to assume that there is such a thing as mass. That property of matter which we have hitherto called mass is nothing but a manifestation of basic electromagnetic interactions. Such a theory would at once seem erroneous because it failed to explain the gravitational properties of matter, but in my second paper "Gravitational Attraction and Mass as Electromagnetic Phenomena", I show that the internal tension of the electric fields of individual charges causes a minute distortion of the fabric of space all of which add together to give space a four dimensional curvature which produces the phenomena of gravity. The properties we have called inertial mass and gravitational mass are thus seen to be both proportional to the energy content of the electric fields of charges thus establishing the link.

The problem of explaining the inertia of a charge under linear acceleration is relatively simple. It is just a matter of realising that the substance of a magnetic field is energy rather than lines of flux. The magnetic energy has a property of stringiness which we call magnetic induction $\vec{B}$, but this is only a property. If we measure changes in the magnetic field surrounding a moving charge in terms of total energy content, we can then calculate the flow of magnetic energy into or out of the surface of the charge as its velocity changes and use this to calculate the force on the charge. On the other hand, if we try to sum the contents of the magnetic field in units of magnetic flux, the magnetic field is infinite and any attempt to change the velocity of a charge should generate an infinite force resisting that change.

However, the charges from which matter is built are in chaotic orbital motion about one another and we have to explain inertia not only in terms of linear acceleration, but also in terms of the generation of centrifugal force. The theory has to predict the same inertial resistance to acceleration regardless of the angle of the acceleration to the direction of motion of the charge. This turns out to be an extremely difficult thing to do. The solution imposes on us a set of conditions governing the behaviour of magnetic energy density flux. The energy content of the magnetic field surrounding a moving charge can only move parallel to the electric field of the charge.

We might picture a conic element of volume constructed by moving a rectangle $r\,\delta\theta$ by $r \sin\theta\,\delta\phi$ outwards from the surface of the charge. The energy content of the magnetic field within the conic element is trapped and can only move within that element. However, in calculating changes to the magnetic flux, we also have to take into account its directional property.





There are two ways in which the magnetic field surrounding the charge can change: it can change in magnitude and it can change in direction. Within the conic element, change in direction requires magnetic energy density flux to be added with a directional property perpendicular to the directional property of the flux within the element. Thus we find that the magnetic flux moving into or out of the surface of the charge has the energy density of the magnetic field at the surface of the charge, but may have a different directional property.

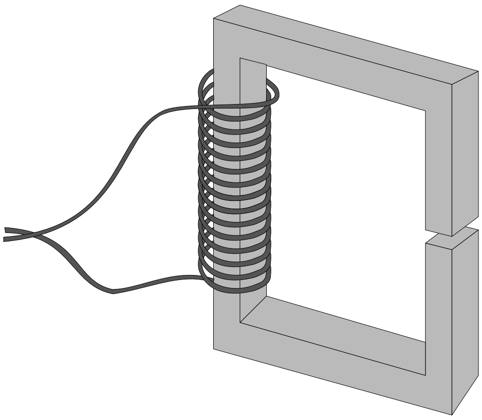
The movement of magnetic energy density flux into or out of an element of the surface of a charge generates an electric field which acts locally on the element of charge within that element of the surface. This produces a force and the total force on the charge is found by integrating this over the surface of the charge. The equation governing this process is:

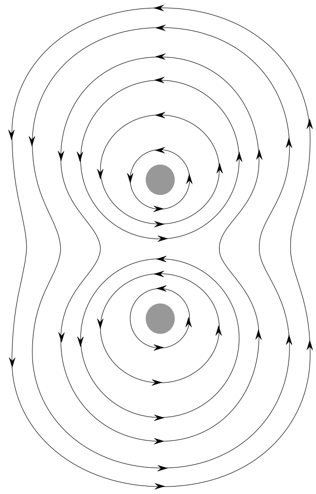
$$\delta\vec{F} = \delta q\,\vec{v} \wedge \vec{B}$$

In spite of the fact that the magnetic induction $\vec{B}$ appears in this is an equation, it is as a property of magnetic energy density flux, not its substance. This equation is not about the movement of lines of force. The velocity $\vec{v}$ is derived from the rate at which magnetic energy is moving into or out of the surface element of the charge.

Faraday's Law and the movement of lines of force

Consider an electronic component called an inductance. If we apply a voltage to the coil, a current will steadily build and a magnetic field will form within its core. As the magnetic field grows, it generates within the coil a voltage opposing the one which we applied to the coil. It is the equilibrium of these two voltages which determines the rate at which the current increases in the core. Faraday's law of induction explains this effect in terms of the movement of the lines of force of the magnetic flux. Magnetic flux is thought to pass through the turns of the coil as the field grows. However, if we look in detail at the movement of the lines of force of the flux in the region of two individual turns of the coil, we see that this is not what happens.





The diagram shows a typical inductance and a cross section of the magnetic field which might surround two turns of the coil in the absence of everything else. Let us look at the region between the turns. We find that the field direction is anti clockwise about both turns of the coil resulting in a change in field direction as we move from one conductor to the other. This change of direction implies that there is a node or point between the wires where the magnetic field is zero in the cross section. In three dimensions, this point becomes a line midway between the turns. Because the magnetic field is zero everywhere along this nodal line, the magnetic lines of force cannot cross this line as the magnetic field grows. The supposed cutting of the turns of the coil described in every textbook on the subject simply does not happen. Lines of force move outwards from the surface of individual turns, but then thin and part as they approach the nodal line only to rejoin with other lines of force. In this way, they studiously avoid cutting other turns of the coil. Similarly, the growth of the magnetic field within the ferromagnetic core due to the rearrangement of domain boundaries is unable to effect a cutting of the turns of the coil by lines of force.

We are thus left with the fact that the mechanism behind Faraday's law is not that supposed by Faraday and all those who have taught and learnt about his law.

The cause of a magnetic field

So far, I have explained why we should consider the primary substance of a magnetic field to be energy and not lines of force. In order to produce a single consistent theory of electricity and magnetism, it is necessary to say not only what a magnetic field is, but why and how it exists. I reject the idea that magnetism is no more than the effect of observing a moving electric field. Such a theory might well explain the observation of the magnetic field surrounding a single charge, but it cannot explain the phenomena of the inductance of a solenoid in a vacuum. The magnetic field in the region surrounding the coil stores energy and therefore it is real and not simply an artefact of the motion of an observer.

The simplest theory by which I can account for the existence of magnetic fields is to assume that they are generated by the relative movement of electric fields through one another. This presupposes that electric fields have separate existence and can coexist within the same region of space. Those familiar with electrostatics will object to such an idea because it contradicts the theory about the energy content of the electric field surrounding two charges of opposite polarity as they are brought closer together. Oddly enough, if one thinks about Einstein's assertion that magnetism is the effect of observing an electric field in relative motion, the extension of this to explaining the magnetic field surrounding a wire carrying a current can only be explained by assuming that the electric fields of the moving conduction band electrons extend out into the region where the magnetic field is observed. Based on the assumption that the relative movement of electric fields through one another generates a tendency for magnetic fields to form, it is possible to deduce a formalised version of Mach's principle in which each moving charge generates a magnetic intensity field $\vec{H}_i$ by virtue of the movement of its electric field through the background presence of the electric fields of all of the other charges in the universe. The influence of individual charges on the background presence depends on the inverse square law with the result that massive bodies capable of possessing gravitational fields impart a property of local zero velocity to surrounding space against which the velocity of moving charges should be measured in determining their magnetic fields.

Magnetic intensity $\vec{H}$ has no real existence, but is a mathematical artefact describing the effect of the motion of charges. Every charge in the universe thus generates a magnetic intensity $\vec{H}_i$ at every point in the universe and these sum at every point in space to form the magnetic intensity $\vec{H}$. In the case of a wire carrying a current, a magnetic energy density field forms around it according to the magnetic intensity and the fundamental property of space μ_0 which we call the permeability of free space. The substance of that magnetic field is energy. Magnetic energy can only be created from other forms of energy at the surface of a charge through the application of a force through a distance. The growing magnetic field draws energy from the charges of the electric current in such a way as to generate forces on individual charges which sum to produce the e.m.f. which opposes the increase in current. This is the nature of induction and I shall explain in detail how it works and why Faraday's law of induction gives the correct answers in spite of the fact that it is based on false assumptions.

Sigma notation

In dropping the concept of an electric current as a flow of some mysterious fluid and taking into account the fact that an electric current is the product of the motion of individual charges, we radically change the mathematics. Now we can no longer do simple algebra, but must take into account the motion of every individual charge. Fortunately, the mathematics of summations is well known and not too hard to apply. Let us define the magnetic intensity at a point using the sigma notation. First we define the magnetic intensity due to the motion of the *i th* charge.

$$\vec{H}_i = \frac{q\,\vec{v}_i \wedge \hat{r}_i}{4\pi r_i^2}$$

The magnetic intensity at a point is then given by:

$$\vec{H} = \sum \vec{H}_i$$

And a magnetic field forms according to the formula:

$$\vec{B} = \mu_0 \vec{H}$$

However the magnetic induction $\vec{B}$ is only a property of the magnetic field and its true nature is that of an energy density field. The energy density at a point is given by the well known formula:

$$Q_m = \frac{1}{2} \vec{B} \cdot \vec{H}$$

If we now take into account the nature of the magnetic intensity as the sum of the individual motions of charges, we might write:

$$Q_m = \frac{1}{2} \vec{B} \cdot \left(\sum_j \vec{H}_j \right)$$

We wish to discover the nature of the involvement of a single charge in the formation of a magnetic field. Our understanding of the magnetic field in the region close to a moving charge is that its energy content has come from the charge. It seems reasonable to suppose that the energy content of a magnetic field, generated by the motion of many charges, must come from the individual charges and be governed by the same principles. This leads us into an interpretation of the previous equation in which we take $\vec{B}$ within the summation to give:

$$Q_m = \sum_j \frac{1}{2} \vec{B} \cdot \vec{H}_j$$

In order to get the correct answer for the inertial resistance to acceleration at an angle to the direction of motion of a charge, it was necessary to assume that magnetic energy can only move too and from a charge parallel to its electric field. The logical extension of this would be to assume that the energy content of a magnetic field consists of the personal contributions of individual charges and that these contributions of magnetic energy are each constrained to move parallel to the electric fields of their owners. This is compatible with the above equation and we can interpret it as meaning that the energy density at a point within a magnetic field is the sum of individual contributions of energy density from all the participating charges. The magnitude of each contribution being determined by the dot product $\vec{B} \cdot \vec{H}_j$. Although there is no limit on the summation which theoreticaly applies to every charge in the universe, we can identify a certain set of charges with the generation of the magnetic field by the fact that these mainly provide positive contributions to the energy density of the magnetic field at any point. The three combined factors of the inverse square law, the balance between positive and negative charge and the nature of the motion of charges allows us to further limit the summation. A charge can be assumed to take no part in any interaction with the magnetic field at a point if the average of its magnetic intensity at that point is zero and the fluctuations between a positive and a negative contribution to the magnetic intensity at that point take place in less time than light can travel from the charge to the point. (The exact relationship being as yet unestablished.) When we look at magnetic fields on the scale of the atom, and of the nucleon, this limitation will no apply and we will find a constant dance of energy between all the charges in the locality and the magnetic field.

I have explained the generation of magnetic fields by assuming that the electric fields $\vec{E}_i$ of all charges have a separate existence so that we can write $\vec{E} = \Sigma \vec{E}_i$. However the magnetic field at any point is singular and to write $\vec{B} = \Sigma \vec{B}_i$ is meaningless because the $\vec{B}_i$ cannot exist. In order to get round this problem we attach the permeability μ_0 to the $\vec{H}_i$ writing:

$$\vec{B} = \sum \mu_0 \vec{H}_i$$

where each $\vec{H}_i$ is a property of the motion of the electric field of the *i th* charge. We can now substitute this into the expression for Q_m.

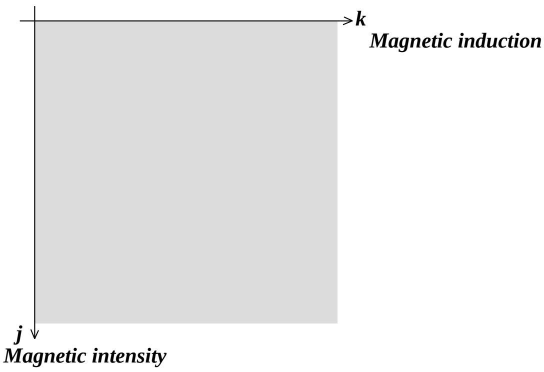
$$Q_m = \frac{1}{2}\left(\mu_0 \sum_k \vec{H}_k\right) \cdot \left(\sum_j \vec{H}_j\right)$$

In order to help us understand the way in which individual charges participate in the existence of the magnetic field, we might imagine that the expression is actually expanded. In that expansion, we get two terms involving two particular individual charges.

$$Q_m = \ldots\ldots + \frac{1}{2}\mu_0\vec{H}_k \cdot \vec{H}_j + \ldots\ldots + \frac{1}{2}\mu_0\vec{H}_j \cdot \vec{H}_k + \ldots\ldots$$

We interpret the first of these as the energy contributed to the magnetic field at a point by the *j th* charge by virtue of the contribution to the magnetic field of the motion of the *k th* charge and note that in the second term, the roles of the two charges are reversed.

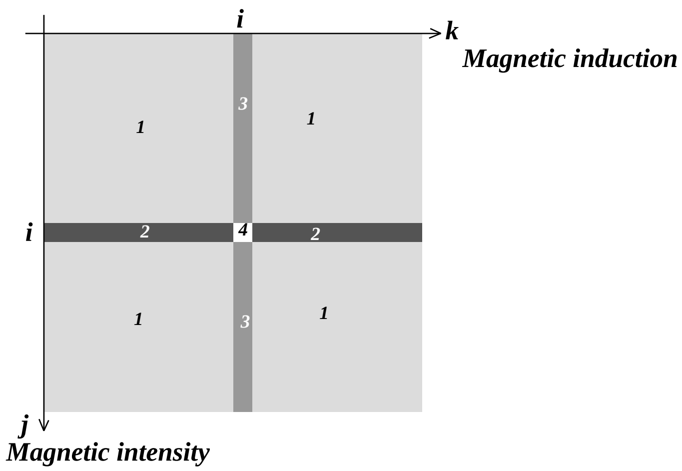
It is possible to represent the whole expansion in a form of set diagram in which $\vec{B} = \sum \mu_0 \vec{H}_i$ is represented along the top and $\vec{H} = \sum \vec{H}_i$ down the side. The shaded area is then a set of points representing the individual terms of the expansion.



We can then impose on this diagram various ways of partitioning the diagram and seek understanding of the nature of magnetism. Every partitioning of the diagram has a corresponding expansion and re-factorization of the expression for the magnetic energy density at a point. One such partitioning is to separate the *i th* charge from the rest of the universe. The expansion then becomes:

$$Q_m = \frac{1}{2}\left(\mu_0 \sum_{k \neq i} \vec{H}_k\right) \cdot \left(\sum_{j \neq i} \vec{H}_j\right) + \frac{1}{2}\left(\sum_{k \neq i} \mu_0 \vec{H}_k\right) \cdot \vec{H}_i + \frac{1}{2}\mu_0 H_i \cdot \left(\sum_{j \neq i} \vec{H}_j\right) + \frac{1}{2}\left(\mu_0 \vec{H}_i\right) \cdot \vec{H}_i$$

Which we can represent diagrammatically as



The areas of the diagram are numbered according to the term in the equation to which they correspond and the interpretation which we give them is as follows.

1 The energy density in the background magnetic field in the absence of *i th* charge.
2 The contribution to the energy density of the background magnetic field by the *i th* charge.
3 The additional contribution to the energy density from all the other charges due to the effect on the

magnetic field of the *i th* charge.

4 The energy density of the field of motion of the *i th* charge in the absence of the background field.

The first thing to notice is that any change in the motion of one charge results in a change in the energy contribution to the magnetic field of every other charge. In the case of a magnetic field generated by a solenoid, this is of little consequence, but when we consider systems of far fewer moving charges such as atoms and nucleons it becomes an important, possibly dominant feature.

The inductance

If we now consider the case of the inductance pictured earlier, we can divide all the charges in the universe into three sets I, M and R containing respectively the charges forming the electric current in the coil, the electrons within the atoms of the core which give it its magnetic properties and the rest. A convenient combination of set notation and sigma notation makes the partitioning obvious. The expansion should have a total of nine terms, but we can leave out those terms involving charges which are elements of the set R because their sum is zero. This leaves us with four terms:

$$Q_m = \frac{1}{2}\left(\mu_0 \sum_{k \in M} \vec{H}_k\right) \cdot \left(\sum_{j \in M} \vec{H}_j\right) + \frac{1}{2}\left(\mu_0 \sum_{k \in M} \vec{H}_k\right) \cdot \left(\sum_{j \in I} \vec{H}_j\right) + \frac{1}{2}\left(\mu_0 \sum_{k \in I} \vec{H}_k\right) \cdot \left(\sum_{j \in M} \vec{H}_j\right) + \frac{1}{2}\left(\mu_0 \sum_{k \in I} \vec{H}_k\right) \cdot \left(\sum_{j \in I} \vec{H}_j\right)$$

These four terms then represent

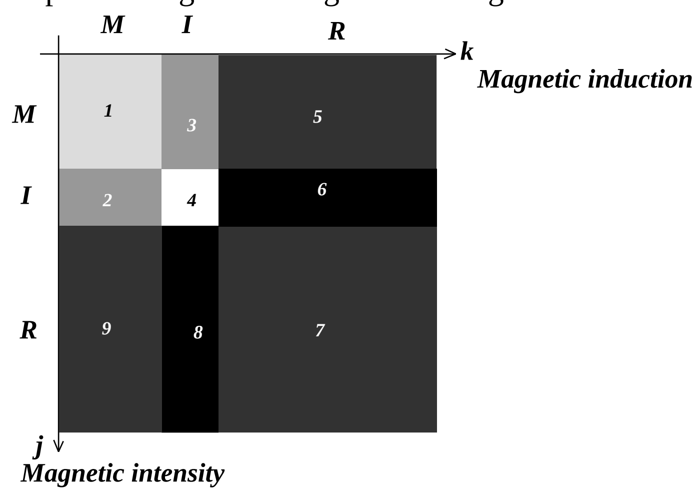
1 energy in the magnetic core which is unaffected.

2 energy from the current due to the presence of the core.

3 energy from the core due to the magnetising effect of the current

4 energy from the current due to the magnetising effect of the current.

Which we can see in the partitioning of the diagram. The regions 5 to 9 each suming to zero.



As the magnetic field changes due to a change in the current, the first and third terms are active, but do not contribute to the interaction between the current and the magnetic field. They should be seen as being responsible for the movement of magnetic energy around the magnetic field and for thermodynamic changes in the core resulting from changes in its state of magnetisation. A complete analysis of this has yet to be done, but we are safe in saying that we can disregard them in calculating the exchange of energy between the electric circuit and the magnetic field.

Let us however concentrate on the second and fourth terms which give energy drawn from the electrons whose motion contributes to the current.

$$\Delta Q_m = \sum_{j \in I} \frac{1}{2} \left(\mu_0 \sum_{k \in M} \vec{H}_k \right) \cdot \vec{H}_j + \sum_{j \in I} \frac{1}{2} \left(\mu_0 \sum_{k \in I} \vec{H}_k \right) \cdot \vec{H}_j$$

We can first factorise the two terms into a single term producing an interesting result.

$$\Delta Q_m = \frac{1}{2} \left(\mu_0 \sum_{k \in (M \cup I)} \vec{H}_k \right) \cdot \left(\sum_{j \in I} \vec{H}_j \right)$$

$$= \frac{1}{2} \vec{B} \cdot \vec{H}_I$$

We then see that the first expression in brackets is the magnetic induction and the second is that part of the magnetic intensity which is due to the current alone (hence the subscript I). This is wholly consistent with the normal way of interpreting $\vec{B}$, $\vec{H}$ and $\mu\mu_0$ within the core of an inductance.

Permeability and m.m.f.

In formulating a theory of magnetism in terms of the individual charges from which matter is built, we have up till now found no place for the conventional definitions of magnetic induction and permeability as they are applied to magnetic materials. It is my oppinion that these concepts hinder rather than help our understanding. The point being that the magnetic intensity $\vec{H}$ is normally related to the magnetic induction by the equation $\vec{B} = \mu_0 \vec{H}$ and that it is an error to ignore the change in $\vec{H}$ within a magnetic material. There is no getting away from the fact that the existing laws work in giving the correct answers, so in this new theory, the old laws are not abandoned, but refined in understanding. I have changed the meaning of the magnetic intensity $\vec{H}$. Formally, the magnetic intensity could be found by adding the effects of any electric currents and permanent magnets within a system. Now it must be found by taking into account the motion of every charge within the system. This leaves us with a problem of replacing the former $\vec{H}$ and a simple way of doing that might be to write it in lower case!

Let us define a new vector quantity $\vec{h}$ which we will call the "magneto motive force per unit of length". We can now use this instead of $\vec{H}$ where magnetic materials are involved. Instead of writing $\vec{B} = \mu \mu_0 \vec{H}$, we more correctly write:

$$\vec{B} = \mu \mu_0 \vec{h}$$

What happens within a magnetic circuit such as that of our inductance is that as domain boundaries move the magnetising effect of the current in the coil is transmitted around the magnetic circuit. The effect of the current in the coil is to provide an m.m.f. (magneto motive force) just as the chemical reactions within a car battery provide an e.m.f. The electric circuit and the magnetic circuit are analogous and just as low resistance copper wire connects the battery to the high resistance of the headlight bulb filament, so the ferrite core connects the coil with the air gap.

The current in the coil produces a magnetic intensity which is given at any point in space by the equation:

$$\vec{H}_I = \sum_{j \in I} \vec{H}_j$$

In the absence of any other matter in the vicinity of the coil we can identify the magneto motive force per unit length with the magnetic intensity.

$$\vec{h} = \vec{H}_I = \sum_{j \in I} \vec{H}_j$$

The m.m.f is defined by taking a closed line integral on some path which threads the coil.

$$m.m.f. = \oint \vec{h} \cdot dl = \oint \vec{H}_I \cdot dl$$

And the connection between $\vec{H}_I$ the component of magnetic intensity due to the current in the coil and $\vec{h}$ the m.m.f per unit length is that their line integrals are equal.

$$\oint \vec{h} \cdot dl = \oint \vec{H}_I \cdot dl = NI$$

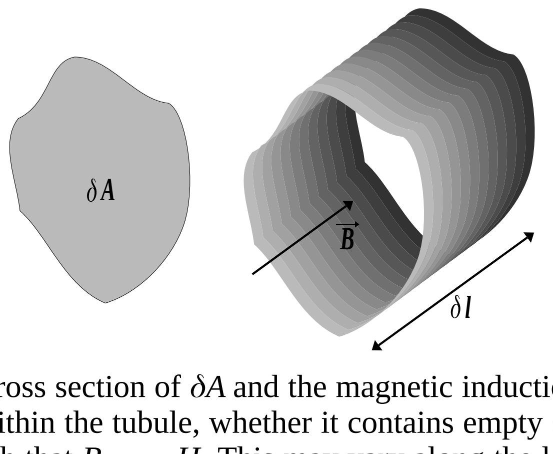
The units of electricity and magnetism have been adjusted so that they are equal to $N I$ where N is the number of turns of the coil and I the current passing through it.

Equating the two theories

Faraday's law is based on a mechanism which does not exist, but it does give the right answers. I have proposed an alternative mechanism which is conveniently too complex to put to the test mathematically because we would have to perform a complex numerical calculation for each of the nine million, four hundred thousand, billion billion conduction band electrons to be found per kilogram of copper wire. What we can do however is to use the principle of conservation of energy on the assumption that any change in an individual charge's contribution of energy to magnetic field is equal to work done to or by the charge. Thus a charge might be accelerated by an electric field increasing its contribution to a magnetic field. The flow of energy from the charge would generate a force opposing the accelerating force of the electric field with the effect that the work done by the electric field is equal to the gain in energy of the magnetic field from the charge. Thus all we have to do in proving that the new mechanism gives the same answer as calculations based on Faraday's law is to show that the calculations of the quantity of energy involved are the same.

There are traditionally two ways of calculating the e.m.f. with which an inductance will oppose a change in the current it carries. We can calculate the rate of change in magnetic flux which threads the coil and use Faraday's law to calculate the e.m.f. Alternatively we can use the concept of inductance. A perfect inductance has no electrical resistance and a steady current will flow through it forever requiring no work to be done. To increase the current, we find that we have to apply a voltage with the result that we are now doing work. The result of that work is to store energy in the inductance. We can thus calculate the e.m.f. with which the inductance opposes the change in current from the change in energy stored in it. Faraday's law gives the correct answer because of the relationship between the number of lines of force threading a coil and the energy stored in the magnetic field.

Let us first think in traditional terms. Consider a magnetic field. We can cut it with a surface such that every line of force passes through the surface once. We can now divide the surface into a very large number of elements of area. Then from each of these we can can construct a tube like structure everywhere parallel to the lines of force of the magnetic field. We might call these tubules in memory of the Faraday tubes of early electrostatic theory. These tubules are torus like structures and we can at any point along their length take a volume element and make some measurements.



The tubule has an area of cross section of δA and the magnetic induction is $\vec{B}$. This gives us a total flux within the tubule $\delta\Phi = B\,\delta A$. Within the tubule, whether it contains empty space or a magnetic material, we can measure a permeability μ such that $B = \mu H$. This may vary along the length of the tubule. We can treat the magnetic intensity and induction as scalars because they are everywhere parallel to the tubule. The energy stored within the tubule is:

$$\delta\mathcal{E} = \frac{1}{2} B H \ \delta A \, \delta l$$
$$= \frac{1}{2} \delta\Phi \, H \, \delta l$$

This is at once integrable because $\delta\Phi$ is constant over the length of the tubule and we can write:

$$\delta_{\oint} \mathcal{E} = \frac{1}{2} \delta\Phi \ \oint H \, dl$$

But $\oint \vec{H} \cdot dl$ around a path is known to be the current threading that path which in the case of a solenoid is $N I$. Therefore the energy stored in the magnetic field is:

$$\mathcal{E} = \frac{1}{2} N I \ \int d\Phi$$
$$= \frac{1}{2} \Phi \, N I = \frac{1}{2} \Phi \, m.m.f. = \frac{1}{2} \Phi \ \oint \vec{H} \cdot dl$$

The term $N I$ is the magneto motive force generated by the solenoid and we can write the result a number of ways. The last way best suits our purpose here.

Now let us go back to the equations we obtained for the equation we obtained earlier for the energy contribution to a magnetic field from the charges involved in the electric current which generated it:

$$\Delta Q_m = \frac{1}{2} \left(\mu_0 \sum_{k \in (M \cup I)} \vec{H}_k \right) \cdot \left(\sum_{j \in I} \vec{H}_j \right)$$
$$= \frac{1}{2} \vec{B} \cdot \vec{H}_I$$

The delta sign in front of Q_m denotes that we are aware that there are other contributions to the magnetic energy density at a point within the field. We originally had nine terms in our expansion and we disregarded seven and combined the remaining two. The magnetic induction has the traditional meaning, but the symbol $\vec{H}_I$ represents the component of the magnetic intensity generated by the electric current. We can use the same method to construct tubules and sum ΔQ_m over the volume of the magnetic field, but the component of magnetic intensity $\vec{H}_I$ is no longer parallel to $\vec{B}$ so we need to use vectors. The vector $\vec{B}$ is still parallel to the tubule, so we can equally well associate the unit vector with the element of length turning it into $\delta\vec{l}$ and perform the dot product with it instead.

$$\delta\mathcal{E} = \frac{1}{2} \vec{B} \cdot \vec{H}_I \ \delta A \, \delta l$$
$$= \frac{1}{2} \delta\Phi \, \vec{H}_I \cdot \delta\vec{l}$$

Again this is integrable and we can write:

$$\delta_{\oint} \mathcal{E} = \frac{1}{2} \delta\Phi \ \oint \vec{H}_I \cdot \delta\vec{l}$$

But $\oint \vec{H}_I \cdot \delta\vec{l}$ around a path is still constant and we get:

$$\mathcal{E} = \frac{1}{2} \Phi \ \oint \vec{H}_I \cdot \delta\vec{l}$$

We now have an almost identical expression. Only the meaning of the magnetic intensity is different. However the two line integrals are both equal to the m.m.f. and the equivalence of the two methods is proved.

Faraday's Law restated

We assume that any interaction between electricity and magnetism is primarily one of energy exchange and that energy is conserved. We then define a device in which an electric current and a magnetic field thread each other in order to provide a means of storing energy in the magnetic field. The word inductance is used both to name the device and to describe its ability to resist any change in the current flowing through it. It resists any change in the current flowing through it because it stores energy proportional to the square of the current. The reason for this becomes apparent when we differentiate. Any change in the energy content must be achieved by the passing of a current through a voltage.

$$\frac{d\mathcal{E}}{dt} = V\,I$$

$$\mathcal{E} = \frac{1}{2}L\,I^2$$

$$\therefore V\,I = \frac{d}{dt}\frac{1}{2}L\,I^2$$

$$= L\,I\frac{d\,I}{dt}$$

$$V = L\frac{d\,I}{dt}$$

We have applied a voltage V to the inductace increasing the current I. It is customary to concern ourselves not with the voltage which we must apply, but with an equal and opposite voltage which opposes Vproviding a condition of equilibrium. Thus we say that the inductance resists any change in the current with an e.m.f.

$$emf = -L\frac{d\,I}{dt}$$

The inductance is related to the total amount of magnetic flux Φ and the number N of times the electric circuit threads the magnetic circuit given by:

$$N\,\Phi = L\,I$$

Simply by differentiating this and substituting, we can obtain Faraday's law.

$$N\frac{d\,\Phi}{dt} = L\frac{d\,I}{dt}$$

$$emf = -N\frac{d\Phi}{dt}$$

Thus we have derived Faraday's law for this particular geometry from energy considerations without making any assumptions about the behaviour of magnetic flux. We conclude that in the geometrical situation where the magnetic and electric circuits thread one another, Faraday's law applies and is compatible with the fact that magnetic fields are primarily energy density fields and that the mechanism by which the e.m.f. is generated is one of transfer of energy.

Motion of a charge near a magnetic field

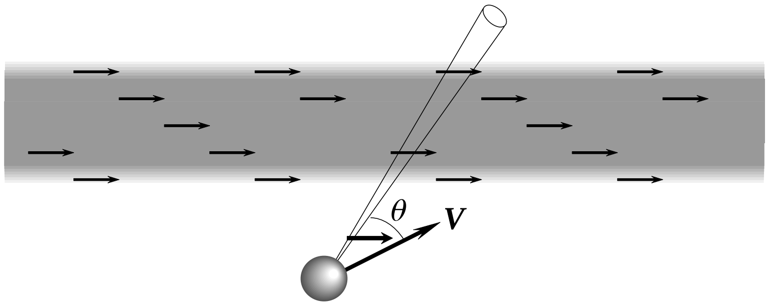
We now wish to look at situations where Faraday's law does not apply. Let us return to the expansion of the magnetic energy density at any point which is partitioned into the *i th* charge and the rest.

$$Q_m = \sum_{j\neq i}\frac{1}{2}\left(\mu_0\sum_{k\neq i}\vec{H}_k\right)\cdot\vec{H}_j + \sum_{k\neq i}\frac{1}{2}\left(\mu_0\vec{H}_k\right)\cdot\vec{H}_i + \sum_{j\neq i}\frac{1}{2}\left(\mu_0\vec{H}_i\right)\cdot\vec{H}_j + \frac{1}{2}\left(\mu_0\vec{H}_i\right)\cdot\vec{H}_i$$

Let us consider the second term. This is the contribution to the energy density by the *i th* charge due to the motion of all the other charges. Consider now a situation which might well apply to a conduction band electron in the coil of an inductance. The electron is bouncing around inside wire due to its thermal[1] motion and the body of the magnetic field is some distance from the charge. We consider a conic element of volume

1 The term is applied loosely to describe the random movements of conduction band electrons.

extending from the charge through the magnetic field parallel to the electric field of the charge.



To find any possible flow of magnetic energy density flux into or out of the surface of the charge due to it motion relative to the magnetic field, we must take the second term and integrate it over the length of the conic element and then differentiate with respect to time.

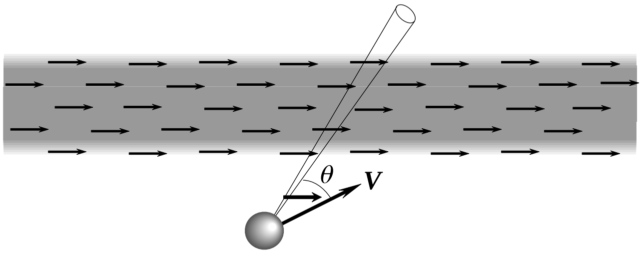
$$\frac{d}{dt}\,\delta\mathscr{E} = \frac{d}{dt}\int_r^\infty \sum_{k\neq i}\frac{1}{2}\left(\mu_0\,\vec{H}_k\right)\cdot\vec{H}_i\,d\tau$$

We are not actually going to perform the calculation, but content ourselves with speculating about how the result might be affected by the motion of the charge and changes in the magnetic field. Let us substitute for $\vec{H}_i$ and write the volume element in terms of an element of solid angle $d\omega$.

$$\frac{d}{dt}\,\delta\mathscr{E} = \frac{d}{dt}\int_r^\infty \sum_{k\neq i}\frac{1}{2}\left(\mu_0\,\vec{H}_k\right)\cdot\frac{q\,\vec{v}_i\wedge\hat{r}_i}{4\pi\,r_i^2}\,r_i^2\,d\omega\,dr$$

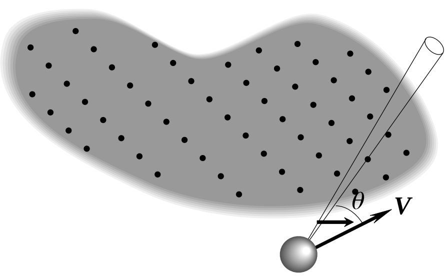
$$= \frac{d}{dt}\int_r^\infty \sum_{k\neq i}\frac{1}{2}\left(\mu_0\,\vec{H}_k\right)\cdot\frac{q\,\vec{v}_i\wedge\hat{r}_i}{4\pi}\,d\omega\,dr$$

The r_i^2 terms cancel and we see that the integral is unaffected by the distance of the charge from the region of magnetic field. So steady motion relative to a nearby uniform magnetic field has no effect. But any change in $\vec{v}_i$ does have an effect and magnetic energy will flow to or from the conic element into the surface of the charge generating a force. Thus there is the potential for every conduction band electron exchanges energy with the magnetic field at every change in its velocity.



Now imagine that the strength of the magnetic field is increased. The integral is changed depending on the velocity. So any change in the strength of a magnetic field near an electron results in an energy flow either into or out of the electron involving the action of a force on it.

The integral is also changed if the motion of the charge takes the conic element through boundary regions of the magnetic field which are not parallel. We might consider viewing this situation in the direction of the magnetic field.



As the charge moves, the conic element is moving out of the magnetic field and the magnitude of the integral is rapidly decreasing. Thus energy flowing into the charge generating a force on it.

These situations are dependent on the exact geometry of every situation and general mathematical solutions are impossible. What we can be sure of is that any change in the integral, due to a change in strength of the magnetic field or due to the movement of the conic element into or out of the magnetic field, results in the movement of magnetic energy density flux into or out of the surface of the charge generating forces upon it.

Motion of a charge within a uniform magnetic field

In most of the situations where we observe the action of magnetic field on a moving charge, the charge is moving through a large uniform magnetic field and we have a simple equation for the force produced.

$$\vec{F} = q\vec{v} \wedge \vec{B}$$

The problem is that the more we see the moving charge as surrounded by its own magnetic field, the harder it is to see how this equation works. As we approach the surface of the charge, its own magnetic field becomes millions then billions of times stronger than the background magnetic field $\vec{B}$ through which the charge is travelling. In view of what I have said about the behaviour of lines of magnetic induction, it seems inconceivable that lines of force are able to cut the surface of the charge and generate any force.

If we try to see the charge in the terms of the previous situations and look for boundary conditions, the problem arises that magnetic fields can be vast in size such as the earth's magnetic field which bends the paths of charged particles far into space, or such high symmetry as in the case of a cyclotron that the charge cannot experience any change in position relative to boundaries. We thus need some other form of explanation.

The simplest explanation lies in the equation:

$$Q_m = \frac{1}{2}\left(\mu_0 \sum_{k \neq i} \vec{H}_k\right) \cdot \left(\sum_{j \neq i} \vec{H}_j\right) + \frac{1}{2}\left(\sum_{k \neq i} \mu_0 \vec{H}_k\right) \cdot \vec{H}_i + \frac{1}{2}\mu_0 H_i \cdot \left(\sum_{j \neq i} \vec{H}_j\right) + \frac{1}{2}\left(\mu_0 \vec{H}_i\right) \cdot \vec{H}_i$$

The charge is moving through the background magnetic field and makes no non-local contribution to it. The energy density of the background field is given by the first term and we can write.

$$Q_m = \frac{1}{2\mu_0} B^2 = \frac{1}{2}\left(\mu_0 \sum_{k \neq i} \vec{H}_k\right) \cdot \left(\sum_{j \neq i} \vec{H}_j\right)$$

Thus firmly identifying the background magnetic field $\vec{B}$ with with energy owned by charges other than the *i th* charge which is moving through the magnetic field. If we now look at the surface of our charge, we find that it in relative motion to this magnetic energy which in in fact passing through the surface. So the force on each element of the surface is:

$$\delta\vec{F} = \delta q\vec{v} \wedge \vec{B}$$

Which upon integrating over the surface of the charge becomes:

$$\vec{F} = q\vec{v} \wedge \vec{B}$$

Thus it appears that the force is generated by the cutting of the lines of a magnetic field by the charge, but this is not the case. Because we tend to think of magnetic flux as being like a set of rubber bands, we fail to notice the way in which the behave thinning parting and re-linking with themselves or with other lines of force. The correct concept should be of an energy density flux which has a property of internal tension which has strength and direction described by the vector $\vec{B}$.

The thermal motion of conduction band electrons

If we construct a solenoid from 16 gauge copper wire, it can reasonably carry a current of 16 amps without too great a heating effect. Under such conditions, an average conduction band electron covers a distance of twenty to thirty thousand kilometres in an hour while only progressing some two metres along the wire. In view of the fact that thermal collisions occur so frequently, we might wonder how it every possible for magnetic fields to form. Based on the assumption that the velocities of conduction band electrons is governed by the quantum theory, Dirac ploted the velocities of electrons in a statistical diagram which is spherical in shape. When a current flows in the wire, the sphere is very slightly displaces and a set of electrons whose velocity vectors terminate in the region of the sphere outside of its original position take part in the formation of the magnetic field. Such a simplification seems to me to be rather naive.

The extension of the Pauli exclusion principle to the whole of the copper coil of a solenoid requires the electrons to know whether or not a particular velocoity is already taken before changing to it. When we realise that depending on the size of the solenoid we are talking about 10^{21} to 10^{29} electrons (~1 gram coil to a 10 tonne coil), the number of Bohr demons (quantum brothers of Maxwell's demon) required to do all the book keeping seems excessive. The reason for adopting the idea that the velocities of conduction band electrons are governed by the quantum theory is that thermodynamics predicts that a gas of free conduction band electrons would double the specific heat of a metal. This is however based on a misconception that electrons collide with atoms in the way that a ping pong ball might collide with ten pin bowling ball. What actually happens is that conduction band electrons collide with bound electrons an so acquire velocities of the same order of magnitude as those of the bound electrons. This is hardly affected by the thermal vibrations of the atom which are much slower.

We are left wondering just what the nature of the motion of a conduction band electron is like. My own belief is that they collide with each other more often than they collide with bound electrons. So far as I can tell, one of the basic tenants of the quantum thoery is that electrons cannot react directly with one another because neither know where it is let alone where the other one is. On this basis quantum theory is able to ignore the effect of the forces which electrons exert on each other constantly changing their velocity. My guess is that conduction band electrons meet each other as frequently as once ever 2, 3 or 4 units of lattice spacing, travelled. We can at best treat this as unknown but significant factor because whether a conduction band 1 or 100 lattice spaces before changing velocity, the distance which light can travel in that time is quite small. I would think that it would be of the order of 1μm, at best it might be 1mm. This has important implication for our theory of magnetism.

In order to understand the way in which an electric current interacts with the magnetic field, we need to refine our concepts a little more. Let us look again at the equation

$$\frac{d}{dt}\,\delta\mathscr{E} \;=\; \frac{d}{dt}\int_r^{\infty} \sum_{k \neq i} \frac{1}{2}\left(\mu_0 \vec{H}_k\right) \cdot \frac{q\,\vec{v}_i \wedge \hat{r}_i}{4\,\pi}\; d\omega\, dr$$

and ask ourselves how we imagine that magnetic energy might move to and from the charge as it experiences frequent changes in its velocity. This enquiry has to be made in the light of the fact that the electrons within the atoms of the core which contribute to its magnetic property are in rapid orbital motion and nevertheless provide energy to distant regions of the magnetic field. We must assume that there is some averaging process by which the magnetic field at a point draws its energy from individual charges according their average velocity over a time interval related to the time light takes from that point to the charge.

Thus we can say that in looking at electromagnetic phenomena on the scale of the devices we build, the velocity v_i to be used in evaluating this term is much more related to the average drift velocity of $2\ m\,/\,hr$ than to the actual velocity at any moment. However this term does form the mechanism by which an inductance resists any change in the current passing through it. Things become much more interesting when we look at really small magnetic fields generated by the motion of a small number of charges. Under these conditions, the process represented by this equation has the power to transfer energy from one charge to another via their interaction with the magnetic field. A future task is to determine the size of force which might be generted by this process.

In conclusion

We have here a new theory about the nature of magnetism which seeks to explain the basic mechanisms by which the interactions take place. At the scale on which we construct electromagnetic devices and within the restriction of the geometry of those devices, we can prove that Faraday's law applies even though it based on a misconception about the behaviour of magnetic fields.

As we turn our attention to smaller scales and consider systems of a small number of moving charges generating a magnetic field small compared to the distance light can travel in the time it takes a charge's velocity to change, this new understanding of the interaction between moving charges and magnetic fields opens up new possibilities for understanding the nature of the atom, nucleus and of nucleons and opens the door to the third phase of grand unification.