2. Mutual Interaction Effects

Reaction Effects

It has been shown in the previous chapter that an electric charge in motion has three dynamic energy components. These are its kinetic energy, its dynamic electric field energy and its magnetic energy. Further, these are all equal in magnitude for observations in the electromagnetic reference frame and when the velocity is small relative to the velocity of electromagnetic wave propagation. Also, and most important, the magnetic energy is a negative quantity because it is energy supplied *from* the field medium. Thus, the total self-dynamic energy of an electric charge in motion under the conditions just specified is, for normal observations, simply its kinetic energy.

The same principles apply to any reacting charge in motion in the magnetic field set up by the above charge, but when additional charges are present there are mutual interaction effects to consider. It is of importance to consider the mutual interaction energy components present when a group of interacting electric charges is in a dynamic state. The basic principles of magnetism are founded in the physical understanding of these interactions.

By way of definition, it will be assumed that a discrete charge in the sense to be used in this study of mutual interaction effects is a unit which, if not spinning in the inertial reference frame, has all its constituents moving together at the same velocity. Such a charge might comprise a close-compacted aggregate of charged particles of both polarities. For example, if a proton consists of three quarks as already mentioned, we still regard this as a single unit of charge. The physical reason for this distinction will become evident below.

Discrete units of charge in a general interacting system may be classified as primary or reacting. By this is meant that any charge which forms part of the system and has a controlled motion is termed primary charge. Other charge present is merely disturbed and reacts to the motion of the primary charge so that it may be termed reacting charge. An example of this is the flow of current in a circuit. The electrons carrying the circuit current comprise the primary charges. Electrons in any surrounding conducting medium comprise a reacting system. Even though the circuit current is steady, the conduction electrons in adjacent conductive media provide a system of charge capable of reacting in the sense intended here.

The three dynamic energy components will be denoted K, E and H respectively applying to kinetic energy, electric energy and magnetic energy. Also, a suffix P, R or M will denote primary charge, reacting charge and mutual interaction between charge, respectively. Thus, the total dynamic energy of the system under study is given by:

$$K_P + E_P + H_P + K_R + E_R + H_R + K_M + E_M + H_M \tag{2.1}$$

Now, we have already established that the self-electric and magnetic energies of the charges are equal. Further, the magnetic energy quantity is negative. Thus E_P and H_P in (2.1) sum to zero and E_R and H_R sum to zero. Physically, this is because the disturbance of the field medium which we term magnetism involves a redeployment of energy in the field itself. In fact, the terms in (2.1) are energy changes and the requirement that E_P and H_P sum to zero is merely a mathematical account of a situation in which the phenomenon of magnetism causes energy to be released from one form in the field medium and used to generate the dynamic electric field present where this energy is released. The mutual interaction between the charge causes a magnetic interaction energy term H_M which also must combine with E_M to sum to zero. The result is that the energy given by (2.1) can be simplified as:

$$K_P + K_R + K_M \tag{2.2}$$

The term K_M has been introduced for generality and denotes what we could term mutual kinetic energy. It is of interest to examine what is meant by mutual kinetic energy.

Mutual Kinetic Energy

Kinetic energy can be said to be the intrinsic energy of motion which we associate with a particle. It has been shown in the previous chapter that the mass property of a particle is related to its intrinsic electric field energy. The law $E = Mc^2$ was derived. The rest mass of the particle is found by dividing the electric field energy of the particle by c^2. In the sense of (2.1) we have precluded consideration of effects internal to composite charge aggregations. These have self-balancing mutual dynamic interactions and the kinetic energy is that of the composite mass of the aggregations. We need only consider the mass effect of the mutual electric interactions in our open system. This has to take account of the implications in the analysis that mutual magnetic interaction involves field energy redeployment to produce dynamic mutual electric energy states. However, such energy can give no mass property to the system since the mutual dynamic *field* energy (electric and magnetic) sums to zero anyway. There are mutual non-dynamic electrostatic interaction energy components not included in (2.1) and these could be said to give rise to a mutual kinetic energy effect for a system in motion. However, in analysing interaction effects in a complete system, which is just what we are doing, effects are being analysed relative to the common inertial frame of the system. The total momentum of the system relative to its own inertial reference frame cannot vary if we consider only the effects of interaction and the self-action effects of the system itself. This is a well accepted fundamental rule of physics. Thus, if the electrostatic interaction energy is taken to be at rest in the inertial reference frame under study, simply because it is taken to define this frame by its very position, we cannot attribute kinetic energy to the motion of the interaction electrostatic energy with the system as a whole. In other words, we expect that there is no such thing as mutual kinetic energy in the context used above.

To relate this to the orthodox teachings in physics, consider two electric charges of opposite polarity but identical mass moving towards one another at equal speeds, the motions being in a common straight line. By accepted principles there are no magnetic forces between these two charges because there is no field along this line. This leaves us to accept that the mutual electrostatic attraction between the charges causes electrostatic energy to decrease as it is converted into the kinetic energy added by the accelerated motions of the charges. The analysis is simple and the reasoning quite straightforward. However, let us ask where the mutual electrostatic energy is located. Surely, it is in the field, that is, it is spread over the space surrounding the charges. As the charges come closer together, this field energy is released and converted to kinetic energy. Where is this kinetic energy located? As the charges come closer together, the mutual electrostatic field energy which is not yet released and converted to kinetic energy has nevertheless been compacted into a region closer to the charges. The energy distributed in the field has moved to new positions. Does this involve any kinetic energy effects itself? Accepted physics does not answer these questions. They are not formulated so bluntly. Yet, the questions must be asked and answered if our understanding of physics is to develop.

Let us try to formulate some rules. Every fundamental electric particle has an associated electric field and an intrinsic electric field energy. This gives the particle a rest mass, found by dividing the energy by c^2. Kinetic energy is then the energy of motion of this intrinsic electric field energy. The velocity of such motion has to be measured in an inertial reference frame which we take to be a non-rotating frame in which the "centre of gravity" of the mutual electrostatic energy of the complete system of electric charge including the particle is at rest. There is no such thing as mutual kinetic energy on this definition. Mutual electrostatic energy can be redeployed in its distribution in space without involving any additional dynamic energy effects not summing to zero. Mutual electrostatic energy can be released to augment the kinetic energy of the charges in the system.

These rules cater for the simple example of the two approaching oppositely charged particles. They do not cater for the increase in mass of an electric charge as its speed increases. The rules will therefore be extended as follows. The intrinsic electric field energy of the particle moves with the particle. This energy accounts for the mass of the particle. In the field surrounding the particle there is a dynamic disturbance of the electric field which involves an increase in electric field energy. This added field energy moves with the particle and augments its mass. There is a deficit in the intrinsic energy of the field medium termed magnetic energy and there is kinetic energy in equal measure. Both of these move with the particle but they compensate one another and have no mass effect. The dynamic electric field energy remains to add increased mass to the system. Since it could be replaced in analysis by the equal valued kinetic energy, we may then speak as if kinetic energy is the sole dynamic energy quantity.

It is a conclusion at this stage that there is no such thing as mutual kinetic energy. Thus, K_M in (2.2) is zero. This leaves us with the interesting result that the total energy in any system of electric charge in motion, apart from the rest electrostatic energy, is the kinetic energy of the charges. In particular, we can ignore magnetic energy which is somehow cancelled out by the properties of the system.

The Nature of Induced EMF

Consistent with the above analysis we can say that (2.1) and (2.2) can be written as:

$$K_P + K_R + E_M + H_M \tag{2.3}$$

where:

$$E_M + H_M = 0 \tag{2.4}$$

To give a physical interpretation of this expression as applied to an electric current in a solenoid, we can say that the energy K_P is the energy needed to establish current flow merely to get the electrons moving to form the current circuit. In such a case, this energy is small compared with the mutual energy components. The energy E_M is the energy needed to overcome the back EMF, the induced electromotive force in the system. It is energy supplied and stored in the mutual interaction of the dynamic electric states of the system. It remains available to return energy when the current is stopped. This energy is known to equal the conventional magnetic field energy supplied to the system. It is numerically equal, but that is all. In fact, magnetic energy is not supplied to the solenoid when it is magnetized. The energy E_M is supplied and by this action the negative energy H_M of equal numerical magnitude is made available in the field to provide energy K_R. The energy supplied to the solenoid is thus merely:

$$K_P + E_M \tag{2.5}$$

and we find that:

$$K_R + H_M = 0 \tag{2.6}$$

The result arrived at now means that we can extend the rules we have formulated still further. Although for a discrete electric charge in motion we could say that the magnetic energy released in the field was deployed to provide the dynamic electric energy component in the field, we now find that where significant mutual interactions between charges occur, the release of mutual magnetic energy is applied to augment the kinetic energy of the reacting system of electric charge present. In other words, we find that when a solenoid is magnetized, the core of the solenoid as the seat of the reacting charge should be heated to acquire a thermal energy exactly equal to the magnetic energy associated with the magnetization. This means that thermal energy is available to be radiated away from the core once it is magnetized, so that if the magnetic field is switched off after it is cooled down, we expect the solenoid energy to come from the term E_M right away, whilst the kinetic energy of the reacting charge in the system has to struggle to return the magnetic energy H_M to the field. The result should be a cooling of the solenoid core when it is demagnetized.

Magnetocaloric Effects

It has been deduced that the process of magnetization and demagnetization must be associated with thermal effects in such a way that magnetization develops heat whereas demagnetization produces cooling. This is, of course, found to be supported by experiment. If a paramagnetic material is magnetized it is found that its temperature increases. The phenomenon is used in the process of cooling by adiabatic demagnetization. When magnetized, it seems that energy has been added to the conduction electrons in kinetic form which is shared with the kinetic energy of the atoms to increase the temperature of the body. When a ferromagnetic is magnetized, the intrinsic magnetic state of domains in the substance is being brought into alignment. This does not cause thermal change related to the apparent magnetic energy involved. However, the thermal effects are manifested in the change in specific heat near the Curie Point. Due to intrinsic magnetism being destroyed as the temperature is increased, the specific heat of a ferromagnetic is greater than that which would be exhibited by a normal metal under the same physical conditions. These are well known phenomena. Less known, perhaps, is what happens even to a ferromagnetic material when it is suddenly magnetized to a very high field strength which far outweighs its intrinsic ferromagnetic field. H. P. Furth (1961) has described a test procedure attributed to F. C. Ford in which a number of $\frac{3}{4}$-inch diameter rods were transiently subjected to fields of the order of 600 kilogauss. Some test samples showed signs of thermal damage as if they had melted and solidified again. Others were ruptured as if they had been broken in a tensile testing machine and also showed signs of thermal damage. Furth demonstrates how these effects can be explained by relating the melting temperature in ergs per cc. with the energy density $B_m^2/8\pi$ and the tensile stress in dynes per square cm. with the energy density $B_s^2/8\pi$. For hard copper, for example, he found B_m to be 500 kilogauss and B_s to be 300 kilogauss. Appropriately, the copper sample showed both mechanical deformation and surface melting in the 600 kilogauss field. For hard steel, with B_s and B_m both 700 kilogauss there is no damage at all in the 600 kilogauss field. For mild steel which has a lower B_s there is some deformation. Thus, the magnetocaloric effect imposes a limit on the fields which can be developed at least transiently in any material. There is ample evidence to show that when a magnetic field is produced in any substance, a thermal effect of energy equal to the change of magnetic field energy is developed. Since magnetic energy cannot be simply identified as thermal energy owing to the dispersal property of thermal energy not being contained like magnetic energy by the inducing current, we must recognize that magnetic energy and the related thermal energy are of separate character. If we do this we are forced to answer the problem posed by the mysterious source of the thermal energy. If we still have the magnetic energy in the inductive storage of the magnetized system, where has the thermal energy come from? The answer to this problem has been presented above. It is not a hypothesis. It is an inevitable conclusion to be drawn from the facts of experiment.

One question which inevitably emerges from the above analysis is whether the field medium can be caused to supply energy for practical application. For example, imagine a solenoid containing a movable non-ferromagnetic core to be magnetized. The core receives heat energy. The field medium releases magnetic energy. The induced EMF action requires retention of energy in the inductive system. What if we then withdraw the core before demagnetizing the solenoid? Do we not then find that we have a surplus of heat energy in the core and can get back the inductive energy put into the solenoid, leaving the vacuous field medium itself in a cooler state (whatever that means)? The answer to this is that as the core is withdrawn from the field it will cool down, thus thwarting the attempt to get energy from nowhere. Then one might say, why not wait for the thermal energy to be conducted away from or radiated by the core. Then, using this energy to perform a useful function, we can later demagnetize the solenoid to end up with a process in which temperature can be cycled to do useful work without the expenditure of energy save to sustain copper loss in the solenoid. This should be possible. It is analogous to the heat pump in which energy comes from the ambient thermal source. What then if we add more thermal energy to the core in this cycle than is needed to cool the specimen down to absolute zero of temperature in the reverse process? If the core is at room temperature and then magnetized to a very high field which will raise its temperature to 500°C, say, what will happen if we then allow it to cool in this field back to room temperature and then demagnetize it? This is a most interesting question which experiment will one day answer. The best answer the author can give is that the field medium itself will be cooled down, meaning our energy balance problem can then show experimentally that there is an aether medium which acts as a source as well as a store of energy.

Evidence of Magnetic Reaction Effects

As just explained, there is abundant evidence to support the expression in (2.6), the equality of kinetic energy in the reacting system and the negative measure of the magnetic field energy due to mutual interaction effects. However, it is of interest to enquire into the other evidence which should be available to demonstrate that there are kinetic properties linked with mass in motion and associated with the magnetic field. To proceed, imagine a magnetic field H to exist in the reacting system under study. We are, for example, considering the state of uniform magnetization within a ferromagnetic domain. Consider then each element of reacting charge as, for example, a conduction element in a ferromagnetic. Let its charge be q in electromagnetic units, and denote its mass M and its velocity v. In the field H it will move to provide maximum opposition to the field. Then, balancing centrifugal force against magnetic force:

$$Hqv = Mv^2/r$$

where r is the radius of the charge orbit. Now, $qvr/2$ is, on classical theory, the magnetic moment of the reacting charge. Thus, the total reaction magnetic moment per unit volume becomes, from the above equation, the total kinetic energy of the reacting charge system per unit volume divided by H. Since this reaction field is not observed in experiment, it follows that the primary charge is really developing the field H plus a component to cancel this reaction effect. If the primary action develops the field kH, where k is a mere numerical factor, we note that $4\pi k$ becomes the factor relating the current moment to the induced field. Thus, we deduce:

$$H = kH - 4\pi k(K_R)/H \tag{2.7}$$

For maximum reaction kinetic energy, that is, the maximum energy transfer induced by the primary charge system, it may be shown by differentiating (2.7) with the primary field constant that k is 2. When k is 2, K_R becomes $H^2/8\pi$. Then, from (2.6), we find that:

$$H_M = -H^2/8\pi \tag{2.8}$$

This is a wholly consistent result. We have arrived at the usual expression for magnetic energy density. The magnetic energy has had to be taken as a negative quantity as we have predicted. Further, we have deduced that the magnetic field induced by any charge in motion is really invariably double that expected on conventional theory. However, as has been shown, reaction effects invariably halve this field to leave us with the value found in experiments.

For maximum reaction kinetic effect, reacting charges of larger mass will be favoured as those to provide the energy term K_R. Thus, when a magnetic field is induced in a metal, the heavier of any free electric charges will move to set up K_R. If there is free charge in the aether medium in quantum units of the electron charge e, then, whether or not these react, or the conduction electrons in the metal react, will depend upon which have the greater mass. If the conduction electrons have the greater mass they will provide the energy K_R. Then, the angular momentum of the reacting charge will manifest itself in magnetization changes. It follows that an experiment which can respond to the relation between magnetic moment and angular momentum of both the primary charge and the reacting charge will allow a direct measurement of the factor k. On the other hand, if there is *free* charge in the aether medium which *may* fill the voids between the atomic substance in the magnetized material and this charge has greater mass than electrons, this medium will itself provide the reaction effects and, although the magnetic field will be attenuated as the theory requires, the mechanical effects will not occur and the observation that k is 2 cannot be expected. This assumes the well known fact that the elusive aether does not provide any mechanical resistance to the motion of matter and so cannot communicate any angular momentum.*

* There are interesting exceptions to this rule discussed in Chapters 4 and 5.

In the latter event it will be difficult to explain how the magneto-caloric effects can occur. If the reaction kinetic energy is not provided by matter, it must occur in the aether medium and it cannot then cause thermal effects in matter. It must, therefore, be expected that if the aether has migrant charge free to move to react to magnetic fields, these charges must be of smaller mass than the electron. Further, the experimental derivation of the factor k from observation on magnetomechanical effects must then be possible.*

Before discussing the evidence supporting this proposal, we note that the energy K_R has to be sustained in a steady magnetic field because (2.7) is applicable to the steady state. Thus the physical meaning of the equation is that K_R has to be maintained by the reacting electric charge system. This is assured if the thermal energy of the conduction electrons is adequate, that is, if the temperature is sufficiently high. If the temperature is too low because there has been cooling after magnetization occurred, it may well be that free charge in the aether takes over the role of K_R in (2.7). This means that at magnetic fields and temperatures low enough to permit the super-conductive state in materials exhibiting this property, it could be that the charge in the aether takes over the role of reacting to cancel half of the magnetic field. Thus the magnetomechanical ratio should not be anomalous under these circumstances. Kikoin and Goobar (1938) have measured the gyromagnetic ratio, as it is called, for super-conducting lead. They found k to be unity. In referring to this result, Bates (1951, b) said, "We conclude that the large diamagnetism of superconductors is due to electrons moving in orbits in the crystal lattice as if they were free in the sense of having ordinary values of e and m." However, as will now be explained, k is greater than unity under normal circumstances.

The Gyromagnetic Ratio

Richardson (1908) suggested that when the magnetism in a pivotally mounted ferromagnetic rod is reversed, the rod should sustain an angular momentum change. It was predicted that the gyromagnetic ratio, the ratio of the change of angular momentum to the change of magnetic moment, should be $2mc/e$, the quantity applicable to the electron in free orbital motion, where e is the electron charge, m is its mass and c is the velocity of light. Einstein and Haas (1915) first

* The analysis was presented also by the author in ref. Aspden (1966, b).

observed the effect. Sucksmith and Bates (1923) then found that the effect was only one half of that predicted. The gyromagnetic ratio was only slightly greater than mc/e. Meanwhile, Compton (1921) had suggested that the electron possesses an intrinsic angular momentum or spin and a magnetic moment. Uhlenbeck and Goudsmit (1925) proposed an angular momentum of $h/4\pi$, and a magnetic moment of $eh/4\pi mc$, corresponding to the gyromagnetic ratio of mc/e. This spin property of the electron was found to help resolve problems in spectral theory, and the use of this concept is now firmly established in atomic theory. Later, Sucksmith (1930) took the experimental observations on ferromagnetic specimens as an indication that ferromagnetism is, in the main, due to electrons spinning on their own diameters. This conjecture has, however, not really been substantiated and is likely to be in error, while the spin concept remains to define a primary property of elementary particles having no clear physical interpretation.*

When the direction of magnetism is reversed in a ferromagnetic rod, the electrons generating the magnetic flux undergo a change in angular momentum. However, the magnetic flux traverses the ferromagnetic medium and this contains free electrons in a state of agitation. Similarly, magnetic flux in vacuo may also traverse an aether medium in which (for all we know) there could be free electric charge in a state of agitation. Free conduction electrons satisfying Fermi–Dirac statistics are so numerous in a ferromagnetic conductive material that, as a little analysis shows, they should react to cancel any magnetic flux traversing the substance. The magnetic field deflects the electrons into orbital motion between collisions and, regardless of their velocity or direction, the arcuate motion invariably develops a reaction field component and a reaction angular momentum.

The field attenuation problem thus predicted does not show itself in our experiments and its absence, or apparent absence, requires explanation. In the above analysis it was shown that the magnetic field to be expected from orbital electrons in motion in a ferromagnetic is really double that normally predicted. There is then an attenuation in that reaction effects due to conduction electrons halve the field. Curiously, the analysis points to this halving effect as a

* In a textbook on magnetism, Professor W. F. Brown (1962) wrote: "If later theoretical research succeeds in reinterpreting the 'spinning electron' as an actual system of spinning charge or as a system of poles, this . . ." His book was written without reliance on either interpretation, clearly having in mind the uncertainty surrounding the subject.

universal effect but leaves scope for variations in the magnetomechanical ratios involved in different circumstances. However, the analysis does show that the parameter k must be 2 and this means a gyromagnetic ratio of mc/e and not $2mc/e$. The predictions of the previous analysis are clearly supported by the gyromagnetic ratio. Also, it is then possible to say that ferromagnetism is due to the orbital motions of electrons in atoms and not to the mysterious spin property which is so much in dispute. What remains a mystery is the way in which the electron reaction effect in metals subject to magnetization has been overlooked in the researches on the subject. It is true that there is a magnetic anomaly facing researchers who try to compare theoretical eddy currents and those observed. This anomaly, termed the "eddy current anomaly" involves the study of reaction currents when there is changing magnetic flux. Its explanation is bound up with the behaviour of magnetic domains, as the author has demonstrated experimentally (1956). The mystery we are concerned with is how electrons can move about in a metal to set up a reaction effect without this having been recognized. The simple answer, given by the informed physicist, is that it has been recognized, but a correct analysis shows that the reaction sums to zero. However, it should be noted that such analysis was performed when it was expected that the result should sum to zero. It was later that the gyromagnetic anomaly was observed. If we examine how one can obtain the zero reaction result we find that the argument is somewhat equivalent to what is portrayed in Fig. 2.1. In this figure electrons are shown describing circular paths to develop the magnetic reaction effect opposing an applied magnetic field. Electrons at the boundaries are caused by collision with the boundaries to migrate around the whole magnetized region and so develop an opposite magnetic effect. They

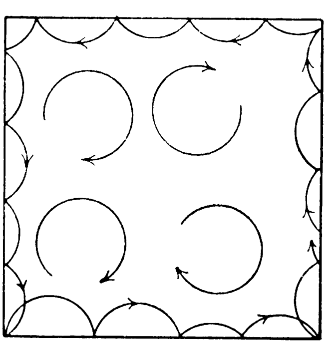

Fig. 2.1

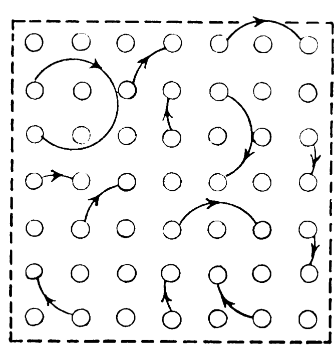

Fig. 2.2

migrate, as can be seen, in the opposite sense to the orbital reaction motion of the electrons in the body of the magnetized material. Of course, collisions are occurring between electrons and atoms and there is no clear boundary as indicated, but the effect is the same. Mathematical analysis shows that there is complete cancellation. It is a matter of statistics. Now, if we accept this explanation we have to dismiss the gyromagnetic explanation offered in the previous pages. But if we accept the explanation of this reaction cancellation we must accept that electrons bounce like billiard balls in their collisions with atoms. Furthermore, there is no boundary at the surface of any real substance. All there is to keep the electrons from going into space or into another material is an electric field or perhaps a magnetic field which deflects the electron back again. It suffices, then, to talk of collisions with atoms. Do electrons bounce back like billiard balls, recoiling from the heavy atoms as the billiard ball recoils from the edge of a billiard table? Alternatively, do electrons strike the electrons in an atom and transfer their momentum to these electrons just like a billiard ball exchanges momentum with another billiard ball in its collisions on the table? When superconductivity was discussed in Chapter 1, it was this latter argument that was followed. If electrons merely transfer momentum to other electrons and there is continuous electron exchange between atoms we get the situation depicted in Fig. 2.2.* There is no countermotion of electrons to develop the cancelling effect. Is not this an important question? It is simply a question of whether, when an electron collides with an atom, it collides with a rigid body having the mass of the whole atom or collides with an electron having a mass like itself. In one case we have no field reaction effects and in the other we have those offered to explain the gyromagnetic ratio. The reader has his choice. On the conventional path he is led to the intricacies of quantum electrodynamics to seek his answers to the problems posed. On the other path, the one which assumes that an electron certainly must collide with one of the electrons acting as outer guard in the atom, he is led with the author along a virgin and unconventional path. However, this is a path well worth exploration, particularly in view of some of the uncertainties which now beset physical theory.

* Clarricoats (1961) in discussing loss mechanisms in ferrites states. "In ferrite materials which contain iron in two valence states, certain electrons can move quite readily through the crystal lattice." The fact that the gyromagnetic ratio is still 2 in such non-conductive materials does not invalidate the argument that the gyromagnetic anomaly is due to electron exchange between atoms.

In this quest it has to be assumed that the magnetic field produced by any electric charge in motion relative to the electromagnetic frame will be exactly double that measured in experiment but that, invariably, there is something which reacts to halve the true field, whether in free space or in matter. This assumption is in line with the finding that magnetic field energy is a deficit of energy equivalent to the kinetic energy of reacting charge. There has to be a reacting charge in free space and it has to have a priming of energy to be able to assert a reaction. Having said this, the reader must understand that the double magnetic field can be ignored in further analysis. The gyromagnetic factor of 2 has to be used in certain magnetomechanical analyses but this is in line with normal physics. Furthermore, when we come to explain the anomalous magnetic moment of the electron, the gyromagnetic factor is merely assumed on the strength of the above explanation and the anomaly is explained by regular analysis.

The Aether

Before going on to show how the above principles have immediate application to the derivation of the true law of electrodynamic force between charges in motion, it is appropriate to comment on the concept of the aether. It is usual to ignore this medium in modern physics. This is more a matter of convenience than anything else. Its existence is a matter for intuition. Electromagnetic waves travel through free space at a certain finite velocity. There must be a medium to sustain such waves. Hence, from time immemorial when the aether was a matter of philosophical hypothesis to today when it is more a question of logic, the aether has been ever present. To recognize its existence in any specific form causes the difficulties. If we have preconceived notions about the aether as a medium which provides an absolute frame of reference for light propagation, then the physicist rightly will reject such aether. There is experimental evidence to the contrary, notably the famous Michelson–Morley experiment. However, we do not intend to make such assumptions. The aether under review in this work is the one indicated by experiment, not an imaginary one conceived by hypothesis. The aether is the medium permeating space and having the property that it can store a magnetic field. Seemingly, from the foregoing analysis, it contains free electric charge in motion and able to react to the action of electric charge in matter. If we are not then to be led immediately into the trap of thinking that this reacting charge determines the frame of reference for electromagnetic wave propagation, we must think in terms of wave *disturbance*. Something is disturbed. There must be something other than the reacting charge. Without the reacting charge the aether can be said to be unable to sustain a magnetic field, but it may still contain electric charge provided this can be regarded as primary in the sense used above. Such charge would have a *controlled* motion. With no reacting charge K_R in (2.3) is zero, and then from (2.4) it is seen that the only energy in the aether is K_P, the kinetic energy of its controlled primary charge. Adding what must be a relatively small energy in the form of the reacting system gives an energy priming of ψ, say, equal to the kinetic energy K_R of the reacting system. Then, since ψ fixes the limit on the energy which can be stored by a magnetic field we have to expect there to be a limit on the maximum magnetic field which can exist in space. In addition it can be said that since ψ is much less than K_P we have to think in terms of the probability that the intrinsic energy density of the aether is significant.

Is there any evidence of a limit of magnetic field strength? Already in this chapter there has been reference to fields of 700 kilogauss used in practice. Probably the highest magnetic fields are produced in thermonuclear reactor experiments in which a self-pinching electric discharge is used to focus the magnetic energy of an electric current. The object is to develop very high temperatures in an almost infinitesimal volume disposed along the current filament. Evidence of a limit on the temperature which can be obtained in practice would be evidence of a limit on magnetic field. However, the problem confronting such research is that of keeping the discharge stable during the collapse. Yet, even if the discharge can ever be stabilized sufficiently, there might be a limit on the maximum temperature which can ever be reached and this limit might be set by a *saturation effect in the aether*. This is speculation, it is true, but it might be worthwhile speculation in view of the cost of thermonuclear research. Later, in Chapter 6, it will be shown how evidence is forthcoming indirectly from the theory and experiment to indicate that there might well be such a limiting effect and to afford an estimate of the magnitude of ψ.

Thermonuclear Reactor Problems

The research into the development of the thermonuclear reactor gave prominence to plasma physics. Electric and magnetic phenomena in a plasma of ions and electrons need thorough analysis to study the behaviour of the processes being applied to induce high temperatures by thermonuclear reaction. As mentioned above, a strong current arc contracts under its self-pinch action to produce high temperatures. With a high energy concentration around atoms of heavy hydrogen, having the deuteron as nucleus, it is sought to produce a temperature of the order of 300,000,000°K for long enough to cause fusion into tritium and helium. Nuclear energy will then be released in excess of the energy supplied to stimulate this action.

As was announced in 1958, trouble was being encountered in stabilizing the electric arcs, with the result that they snaked around within the reaction chamber and were destroyed by contact with the walls. Using the accepted teachings of electrodynamics it was possible to devise systems which could, at least theoretically, overcome the stability problem. One simple proposal offered by the author (1958, b) was to induce the arc along the central axis of a hollow primary conductor, the arc being, in effect, the secondary circuit of a transformer. However, what has seemed a theoretical possibility has remained a practical impossibility. The attempts to stabilize the discharge have gone on without success, or at least without sufficient success to induce the high temperatures expected. It is not difficult to begin to wonder whether the laws of electrodynamics applied with such success in other fields have their limitations in this area. One is dealing with a closed electric arc which is not held in place by a conductor of solid material. The rigidity of the usual current conductor is not present. Further, there is scope for the arc to act on itself. Electrodynamic theory is usually applied to actions between currents where, invariably, one current is a closed circuit. Our simple formulations in electrodynamics depend upon this assumption. However, it does not apply if we can have one part of a current circuit acting on another and we have nothing to restrain the interaction. This introduces the next topic in this work, the law of electrodynamic force between two isolated charged particles in motion. It is an academic problem of classical importance. The practical motivation could be the problems of the thermonuclear reactor discharge. The encouragement available is the foregoing new approach to magnetic theory and a desire to see how far we can proceed without invoking Einstein's theory as a pillar in the analysis. Again, we will come to a seemingly heretical suggestion. It will be suggested that there was failure to realize the full implications of the

Trouton–Noble experiment. The result of the experiment was not surprising in the light of Einstein's theory. However, had there been no Einstein's theory the result of the experiment might have been used to provide the missing piece in the jigsaw posed by the electrodynamic problem.

The Law of Electrodynamics

A summary of the early development of the law of electrodynamic action between current elements has been presented by Tricker (1965). He recites the basic paper of Ampère on this subject, and the criticisms sustained by Ampère's law and alternative formulations by Biot and Savart and by Grassmann. Also mentioned is the general empirical formulation by Whittaker (1951, a) in which he proposes a simplified new law based upon new assumptions. The common problem is that none of these laws is fully consistent with Newton's Third Law when applied to interactions between individual elements of current. Yet, all the formulations appear to give the correct answers when used in integrated form to apply to interactions involving a closed circuit. Tricker then reaches the seemingly inevitable conclusion that an isolated element of steady current is a contradiction in terms, and thus he leaves open the question of how two electrons in motion really react owing to their electrodynamic interaction. This question is important in any attempt to understand the physical behaviour of electric charge on a fundamental basis. Electrical measurements are based upon electric current flow in solid conductors. Forces can possibly be absorbed by such conductors. As explained above, there is unusual behaviour in the case of electrical discharges which are not constrained by a solid conducting path. Hence, it is the basic action between isolated charges in motion which has to be understood if the true physics of electrodynamic phenomena are to be discovered. It may well be that when we consider the interaction between two isolated current elements, the proper application of Newton's Third Law requires us to consider a complete system. Then, if the facts of experiment do not match the results of applying this law to the two current elements, the inevitable conclusion is that the system is incomplete. In other words, perhaps the field or the aether medium has to be brought into the analysis. Here, it is proposed to apply Newtonian principles to the problem of two interacting electrical particles. From very simple considerations a formulation of the law of interaction is deduced which is fully consistent with the empirically derived general formula of electrodynamics. It has a specific form which is identical with that which can be derived empirically if we introduce the experimental result afforded by the experiment of Trouton and Noble (1903). Curiously this latter experiment does not appear to have been applied in previous analyses of this problem. The specific law of electrodynamics deduced is different from the laws deduced, by assumption, by Ampère, Biot and Savart, Grassmann, and Whittaker. The new law of electrodynamics has a most valuable feature. It indicates that there should be an inverse square law of attraction operative between like current vectors, the force acting directly along the line joining the currents. This feature is not shared by the other laws and it is exactly such a feature which is needed to contemplate the eventual explanation of gravitation in terms of electromagnetic effects. Apart from this, the law has another very significant feature when applied to the study of interaction effects between electric particles of different charge-mass ratios. This may have value in explaining certain hitherto unexplained anomalies in electric discharge phenomena.

Four basic empirical facts were relied upon by Ampère in deriving his law:

(a) The effect of a current is reversed when the direction of the current is reversed.
(b) The effect of a current flowing in a circuit twisted into small sinuosities is the same as if the current were smoothed out.
(c) The force exerted by a closed circuit on an element of another circuit is at right angles to the latter.
(d) The force between two elements of circuits is unaffected when all linear dimensions are increased proportionately, the current strengths remaining unaltered.

Ampère combined with the above the assumption that the force between two current elements acts along the line joining them, and thus he obtained his law:*

$$F=kii'\left\{\frac{3(ds.r)\,(ds'.r)}{r^5}-\frac{2(ds.ds')}{r^3}\right\}r \tag{2.9}$$

In the equation F denotes the force acting upon an element ds' of a circuit of current strength i' and due to a current i in an element ds.

* Note that expressions in r are vectors, whereas r^3, r^5 etc. are scalar.

The line from ds to ds' is the vector distance r; k is arbitrary and depends upon the limits chosen, although its polarity may be determined by using the law to verify the observation:

(e) Two extended parallel circuit elements in close proximity mutually repel one another when carrying current in opposite directions, or attract when carrying current in the same direction.

From the analysis by Whittaker, disregarding Ampère's assumption, the general formulation consistent with observations (a) to (d) is found to be:

$$F = kii' \left\{ \frac{3(ds\,.\,r)(ds'\,.\,r)r}{r^5} - \frac{2(ds\,.\,ds')r}{r^3} + \frac{A(ds\,.\,r)ds'}{r^3} - \right.$$

$$\left. \frac{B(ds'\,.\,r)ds}{r^3} - \frac{B(ds\,.\,ds')r}{r^3} + \frac{3B(ds\,.\,r)(ds'\,.\,r)r}{r^5} \right\} \qquad (2.10)$$

Here, A and B denote arbitrary constants. Whittaker then assumed linear force balance as represented by symmetry in ds and ds'. This involves equating A and $-B$. In its simplest form, with k and A both equal to unity, the law becomes:

$$F = \frac{ii'}{r^3} \{(ds\,.\,r)ds' + (ds'\,.\,r)ds - (ds\,.\,ds')r\} \qquad (2.11)$$

Inspection shows that this formulation satisfies observation (e). However, Whittaker made no mention of the all-important experimental discovery of Trouton and Noble. Their experiment demonstrated that separated charges in a capacitor do not cause the capacitor to turn when in uniform linear motion transverse to its suspension. Put another way:

(f) There is no out-of-balance interaction torque between anti-parallel current elements.

This balance of torque action is not assured by the simple formulation of Whittaker in (2.11). To satisfy observation (f), terms other than those in r must cancel when ds is equal to $-ds'$. This applies to the general formulation when $A = B$. Using the general formulation (2.10) and putting $A = B = -1$, and $k = 1$ to obtain the simplest version using all the empirical data, we find:

$$F=\frac{ii'}{r^3}\{(ds'.r)ds-(ds.r)ds'-(ds.ds')r\} \tag{2.12}$$

According to this law, when $ds=ds'$, meaning that the current elements are mutually parallel, the last term only remains to indicate a mutual force of attraction, inversely proportional to the square of the separation distance, and directed along the line joining the two elements. Now, it will be shown how this can be explained from Newtonian principles without knowledge of any electromagnetic phenomena, but assuming that there is a fully-balanced interaction force of some kind acting directly along the line joining the elements. This force will then be explained in terms of magnetic field theory, so combining with the Newtonian argument to provide a truly basic explanation of the empirical law in (2.12).

Consider two particles of mass m and m'. They are separated by the distance vector r. The centre of inertia of this two-particle system is taken to be distant x and y respectively from m and m'. Then,

$$m'y=mx \tag{2.13}$$

Let v, the velocity of m, tend to change, decreasing by dv. This must arise from a force $-m(dv/dt)$ acting on m in the direction v. Let v', the velocity of m', tend to change, decreasing by dv'. This must arise from a force $-m(dv'/dt)$ acting on m′ in the direction v'.

These two forces on m and m' will, in the general case, produce a turning moment in the system. Since there is no evidence that any system can begin to turn merely by its own internal interactions, the forces in the system must be such as to prevent out-of-balance couple from asserting itself. Accordingly, there are restrictions on the proper relationship between the two forces just specified. These restrictions can be allowed for analytically by adding force components to the two particles to compensate, as it were, for any turning effects. On m we add the force:

$$-m'\frac{dv'}{dt}\frac{y}{x}=-m\frac{dv'}{dt}$$

from (2.13). On m' we add the force:

$$-m\frac{dv}{dt}\frac{x}{y}=-m'\frac{dv}{dt}$$

The total force on m' now becomes:

$$-m'\frac{dv'}{dt} \text{ in } v' \text{ direction,}$$

$$-m'\frac{dv}{dt} \text{ in } v \text{ direction,}$$

$$-F' \text{ in } r \text{ direction,}$$

where $-F'$ is the force we now assume to act directly on m' as a result of its electromagnetic field interaction with m. This force is a fully balanced interaction force. It will be discussed in detail later. In summary, we now have three force components acting on each particle. One is the prime direct electromagnetic force which induces acceleration in a particle and therefore inertial reaction. The other two are components of force representing this inertial reaction, but, notwithstanding initial generally-directed motion of the particles, subject to the condition that the system cannot develop any out-of-balance couple about its centre of inertia.

Consider the rate of energy change at m', that is:

$$-m'\left(\frac{dv'}{dt}.v'\right)-m'\left(\frac{dv}{dt}.v'\right)-\frac{F'}{r}(r.v') \tag{2.14}$$

We then remove the kinetic energy term and equate the remainder to zero. Thus,

$$m'\frac{dv}{dt}=-\frac{F'}{r}\,\frac{(v'.r)v}{(v.v')} \tag{2.15}$$

Similarly for m,

$$m\frac{dv'}{dt}=\frac{F'}{r}\,\frac{(v.r)v'}{(v.v')} \tag{2.16}$$

We can now evaluate the resultant force acting on each particle. For the particle of mass m', equations (2.15) and (2.16) may be used to derive the general force expression:

$$F=\frac{F'}{(v.v')r}\left\{(v'.r)v-\frac{m'}{m}(v.r)v'-(v.v')r\right\} \tag{2.17}$$

If it is now assumed that the particles are electrons, the masses m and m' become equal, and since the effective current elements ev and ev' may be written ids and ids', respectively, where e denotes the electron charge in the appropriate units, (2.17) becomes:

$$F = \frac{F'}{(ds\,.\,ds')r}\{(ds'\,.\,r)ds - (ds\,.\,r)ds' - (ds\,.\,ds')r\} \tag{2.18}$$

Comparison with (2.12) shows this to be of the same form as that found empirically. It is identical if:

$$F' = \frac{kii'(ds\,.\,ds')}{r^2} \tag{2.19}$$

From observation (*e*), with $ds = ds'$, (2.18) shows that k in (2.19) is positive and unity with the right choice of dimensions. Of interest then, is the fact that the force given by (2.19) is exactly the force deduced theoretically by evaluating the interaction component of the integrated magnetic field energy due to the two current elements.

Whittaker (1951, b) explains how Neumann published in 1845 a memoir showing how the laws of induction of currents were deduced by the help of Ampère's analysis. Neumann proposed to take a potential function as the foundation of his theory, the nature of which was expressed by Whittaker in the form:

$$ii'\iint\frac{(ds\,.\,ds')}{r} \tag{2.20}$$

where the integrations are performed over closed current circuits. This expression represents the amount of mechanical work which must be performed against the electrodynamic ponderomotive force in order to separate the two circuits to an infinite distance apart, when the current strengths are maintained unaltered. It therefore accounts for the force *component* between current elements, as presented in (2.19). Then, later in his book at page 233, Whittaker refers to a series of memoirs published between 1870 and 1874 by Helmholtz and refers to Helmholtz's observations that for two current elements ds, ds', carrying currents i, i', the electrodynamic energy is:

$$\frac{ii'(ds\,.\,ds')}{r} \tag{2.21}$$

according to Neumann, but different according to other writers, as, for example, Weber. Again, it is noted that all formulations meriting attention give the same result when applied to entire circuits. The failing seems to be that, although it was recognized long ago by Neumann that the true electrodynamic effect is that given by (2.19), the mechanical effects of inertial reactions in discrete charge systems have not been appreciated. It is wrong to assume that current strength remains constant when we talk of discrete charges in motion and subject to forces. There has been heavy reliance upon hypothetical formulations, without true appreciation of the simple mechanical implications of the problem.*

One of these implications, the key difference between the Whittaker formulation in (2.11) and the author's formulation in (2.12), is that Whittaker forbids out-of-balance linear force. The author forbids out-of-balance torque, with experimental backing, but allows out-of-balance linear force. This is seen by the lack of symmetry in ds and ds' in (2.12). Interchanging ds and ds' gives different results for the total force. Then the force on m does not balance the force on m'. Now, this does not mean that we have argued against Newton's Third Law. Action and reaction still have to balance in a complete system. It merely means that the system of two particles is incomplete unless, perchance, they move mutually parallel or anti-parallel, a circumstance which does eliminate the first two terms in (2.12) and thereby leaves the equation symmetrical. This tells us that the field medium itself, or space–time, has to be regarded as a part of the system separate from the particles under study. It also tells us that, if space–time contains electrical particles in motion, then, being collectively a complete system, they must have a motion which is always mutually parallel or anti-parallel as, for example, a harmonious circular motion.

The thought that space–time can exert an out-of-balance linear force is feasible. It is well known that photons convey linear momentum. Photons are disturbances of space–time and they exert linear forces on matter in their creation and absorption. The thought that space–time cannot exert out-of-balance torque is feasible. If space–time has the force transmission characteristic similar to that of a solid body it can be understood how a part of it can be caused to turn within the whole without steady restraint, once the slip action is developed and the inertial action overcome. This does not mean that we are precluded from acknowledging that space–time can accept some angular momentum. This is needed to sustain inertial action.

This type of argument may seem to be fanciful, but, be that as it may, a law of electrodynamic force applicable to actions between

* Note that (2.14) declares that a free electric charge can only store its own kinetic energy, as shown on page 26.

isolated charges in relatively steady motion has been developed and has empirical support. It remains for us to use the law to prove its value. It has already been indicated that the law may have value in gravitational theory. This is deferred until Chapter 5. It will be shown in Chapter 3 that the law has application to the understanding of the nature of ferromagnetism. To conclude this chapter, since it has been suggested that the law might have value in understanding electrical discharges, it is appropriate to draw attention to the significance of the middle term in (2.17). This middle term represents a force component along the direction of current flow, and we may predict that in a discharge circuit, where electrons carry current in a cathode and positive ions contribute to the current to the cathode, there will be an electrodynamic force manifested along the discharge. Similarly, some manifestation of the predicted anomalous forces should appear in plasma work.

Many authors have found anomalous cathode reaction forces in discharge studies. For example, Kobel (1930) found an anomalous cathode reaction force of 250 dynes at 16 amps and 1,400 dynes at 35 amps. This is of the order of $100i^2$, where i is the current in absolute units. This quadrature current phenomenon has defied explanation. Mere reaction momentum considerations lead to a relatively small cathode reaction force which is linearly dependent upon current. Even using equation (2.9), for example, any element of current in a continuous filament is subjected to balancing forces from the filament current on either side. There is no force action along the filament. This also applies to the classical formulations of the electrodynamic law. However, bearing in mind that in a discharge at least some of the current at the electrodes suddenly is transported by ions and not electrons, the m'/m factor to be used with the middle term of equation (2.12) assumes importance. On one side of this current junction, at the cathode, electrons act upon ions in the discharge, and on the other side ions act on ions. It works out that there is an out-of-balance force productive of a cathode reaction by impact from the ions. This force is the product of the constituent ion current component squared and the ratio of the ion mass to the electron mass. Forces of the order of $100i^2$, as found by Kobel, are therefore readily explained.

It may be concluded that the resolution of this long-standing problem of the true nature of this basic electrodynamic law is not a mere academic topic. Some deeper understanding of the law will have practical consequences in discharge and plasma control. For comment on this see Aspden (1965). Also note that the law was first suggested by the author some years previously (Aspden, 1960) in connection with gravitational theory. The analysis in this chapter is substantially the same as that in a paper published by the *Journal of the Franklin Institute* (Aspden, 1969).

Summary

In this chapter the principles developed in Chapter 1 have been extended to a study of mutual interaction effects rather than effects only concerned with isolated charge. It has been shown that the idea that there are three separate energy components to consider in field calculations is wholly compatible with more general phenomena. The concept that magnetic energy is a deficit of an energy level throughout space is, no doubt, a step which the conservative physicist will hesitate to take. Even so, there are rewards in accepting this and there are many avenues opened for further advances. The gyromagnetic ratio ceases to be a problem needing specialist treatment in the analysis of the spinning electron. The electron has a spin property but it need not have this property to account for the factor of 2 found in gyromagnetic ratio measurements. Spin will be discussed later in Chapter 7. Also, the law of electrodynamic force between two isolated charges has been formulated from empirical experimental data and verified by separate analysis using the theory thus developed. The law is simple but different from previous proposals. It has features which may have practical importance and its form is such that it gives new hope for explaining gravitation by an electrodynamic approach, our quest in Chapter 5. The inevitable conclusion, however, is that attention has to be paid to the aether medium. It would be folly to continue efforts to try to cancel it out of our theoretical studies, because, though many would say that it has cancelled itself out, the fact remains that there are four basic discoveries in the last two chapters which owe their origin to the fact that omissions in existing theory have eliminated the need to recognize the aether. This is a reference to the omission of the accelerating field in calculating the energy radiated by an electron, the failure to recognize the existence of a dynamic electric field induced by charge in motion, the failure to give weight to the potential reaction effect of free electrons in a magnetized substance, and even the alleged misinterpretation of the Trouton–Noble experiment.