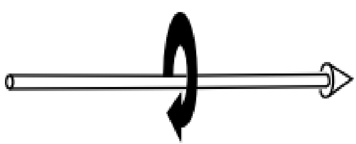
MAGNETISM

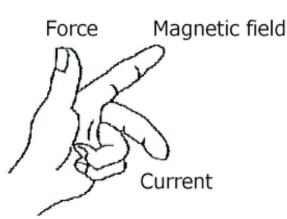
My aim is to provide a simpler way to understand magnetism. Magnetism refers to the forces on electrical charges due to their motion - as opposed to the simple electrostatic forces between charges at rest. Magnetism underpins modern life, from power stations to mobile phones, but it is not widely understood. The subject is complicated by the idea that a magnetic field circulates around a moving electric charge. This means we have to remember three-dimensional rules to describe which way the field circulates and how this field affects other moving charges.

The traditional magnetic field is described by what are called Maxwell's corkscrew rule and Fleming's left hand rule. These are illustrated below. Fleming's rule involves holding one's thumb and the first two fingers of one's left hand at right angles to each other. The thumb points in the direction of the magnetic force, the first finger points in the direction of the circulating magnetic field and the second finger points in the direction of the electrical current, i.e. the direction in which a positive charge moves. This rule describes the directions in an electric motor, e.g. when current from a battery is used to power a car. However, one uses one's right hand to describe an electrical generator. (This is not to be confused with the right hand rule used in the Lorentz force).

According to Maxwell's corkscrew rule, when looking in the direction of a current the magnetic field rotates clockwise. This means the traditional field has a rotational asymmetry.



The index finger is pointed in the direction of the asymmetric rotating field from the corkscrew rule.



Let us now consider a simple situation. Imagine two positively charged objects falling side by side through a vacuum. The motion of each charge is said to create a magnetic field that circulates clockwise. This means it is clockwise when looking in the direction that the charge is moving. But why is it clockwise instead of anticlockwise, and why is the field at right angles to the force it produces? I will return to these questions later. For now we can imagine the direction in which the field of each charge circulates through the other charge. By holding the thumb and fingers of our left hand in the correct directions we then see there are forces that push the charges together. In addition of course there is an electrostatic force of repulsion.

In this simple situation however there is a much simpler idea, i.e. 'like currents attract and unlike currents repel'. By like currents I mean the charges are both positive and they move in the same direction. Two negative charges would similarly attract each other. The electrons in a bar magnet form, in effect, a net circulation of charge in the same direction, e.g. clockwise, around its axis. Opposite poles of two magnets are obviously attracted together. Where such magnets touch, the circulating charges are moving in the same direction, a bit like cog wheels meshing together. If though the nearest parts of two magnets contain electrons that are rotating in opposite directions then there will be a force of repulsion. (Somewhat confusingly, the direction in which electrons move is the opposite direction to that of the resulting current. This is because electrons are defined as negative electrical charges whereas current is defined as positive.)

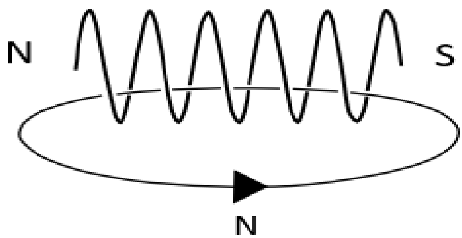
Similarly, if a magnetic compass is brought near to a conducting wire, magnetic forces will tend to rotate the compass needle. The circulating electrical charges in the compass that are nearest to the wire will be attracted toward the charges in the wire that are moving in the same direction. There will also be forces of repulsion between more distant charges that are moving in the opposite direction. These though will be weaker because the forces diminish with the square of the distance.

To recap, the traditional magnetic field involves an asymmetric rotation, i.e. a clockwise circulation. The field is also defined as being at right angles to the force it produces. This asymmetric field was invented by extremely clever people such as Faraday and Maxwell. It is regarded as the greatest achievement in physics of the 19th century. Unfortunately this early idea about a magnetic field predated a knowledge of the causes of magnetism. The magnetic spin of electrons and the circulation of electric charge around atoms were then unknown.

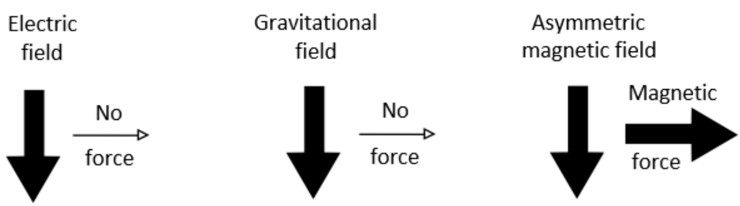
It is natural to assume that the proposed clockwise field has been confirmed by experiments, but the problem is that fields are only theoretical. Fields are ideas by which humans can better understand things, but one cannot directly measure a field. Instead, one measures forces. Magnetic forces are of course correctly predicted if one assumes the validity of a clockwise field and Fleming's left hand rule. Equally though, one can say these assumptions are disproved by experiments. The directions are instead correctly predicted using an *anti*-clockwise field and a *right* hand rule. These two theories are equivalent but they falsify each other. The field cannot be both clockwise and anticlockwise. The clockwise field is not really a proper scientific hypothesis - experiments cannot determine its superiority over the rival anti-clockwise hypothesis. So the traditional idea of a circulating magnetic field is inherently contradictory.

Faraday and Maxwell said the magnetic field contains "lines of force", each line pointing in the direction that a free north pole would move. But we now know magnetism arises from electrical circulation, not from poles. Magnetic force is defined by its effect on electric charges, and it is now usual to omit the misleading word "force" from "lines of force". The field lines are now just lines, or lines of magnetic flux. Yet flux is also misleading as it implies something flows along the lines. Remarkably, these lines are still defined as if the forces acted between poles - even though a pole is not a thing. A north pole is simultaneously a south pole when seen from the opposite direction.

It was natural to think magnetic lines arise from magnetic poles - not much else was known about magnets at the time - but the error of persisting with the old approach is easily demonstrated. Suppose a steady current flows through a wire coil, shown below. A free north pole, N, is repelled by the coil's N end and attracted to its south end, S. The field lines are continuous so inside the coil the free N pole would be repelled by the coil's S end and attracted to its N end. But this contradicts the rule about N poles repelling each other (even if free poles existed).



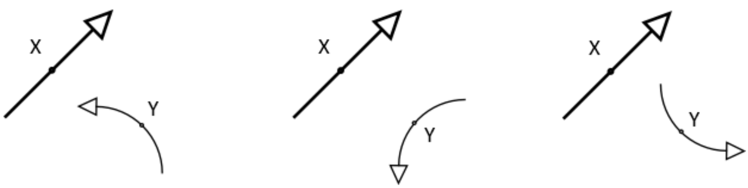
The traditional asymmetric magnetic field is defined as a vector field that is perpendicular to the force it produces. However, if a vector represents something that measurably exists, e.g. a mechanical force or an electrical or gravitational force, the vector has no effect in a perpendicular direction; see below. So there is no reason to suppose that a vector representing an asymmetric magnetic field has its maximum effect in a perpendicular direction. Yet this is how the asymmetric field is defined.



In fact there seems no reason to believe the universe has a major asymmetry that underlies magnetism. Nor would it make sense to say that electric or gravitational forces are explained by asymmetric fields at right angles to their forces. Experiments would similarly be unable to validate these assumed asymmetries in comparison with their conflicting asymmetries.

Magnetic forces arise from circulating electric charges, but an asymmetric circulating field is illogical. It requires an arbitrary (corkscrew) rule to change from the plane in which magnetic forces arise (the plane of current circulation) into a perpendicular asymmetric field. As a result a corresponding arbitrary rule (Fleming's) is needed to return to the plane where the forces can be measured (the plane of current circulation). Using Ockham's principle there is no reason to assume that space or matter involve a major asymmetry which cannot be experimentally verified. The magnetic field should stay in the obvious plane, i.e. the plane containing the current circulation.

It seems magnetism follows a simple counter circulation rule. Suppose two like charges, X and Y, are in motion. Imagine you are looking at the plane containing both the position of Y and the current path of X (i.e. the tangent to X's path). If from Y's position it seems X is moving clockwise, Y will be deflected anticlockwise within the plane. More simply, if X is moving to the right then the force in the plane will deflect Y's motion to the left, and vice versa. In three examples below, X has a clockwise rotation with respect to Y, i.e. it is moving to the right:

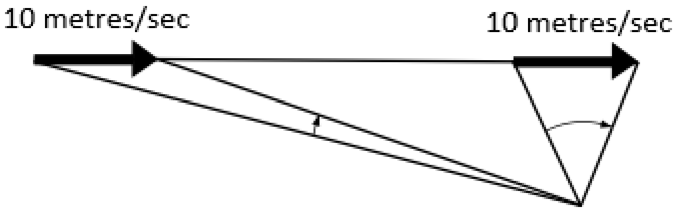


Whatever the direction of motion of Y in the plane containing X's path, Y is deflected anticlockwise, i.e. to its left.

So there is a principle of circulatory compensation. What matters is the component of Y's path in the plane containing both Y and X's path. If Y's path is entirely at right angles to this plane then no force applies. A sideways force on Y would not produce a compensatory circulation in this plane. It would produce a circulatory imbalance in a perpendicular plane.

The counter circulation principle is a much easier way to understand the directions of magnetic forces than the corkscrew rule and Fleming's left hand rule, but what about the strengths of the forces? Magnetic forces, just like electrostatic ones, reduce with the square of the distance between the charges. However, magnetic force is also proportional to the speed that charges move, i.e. to the current. This previously puzzled me but I now see that this dependency on speed simply indicates the rate of circulation of a moving charge with respect to other matter.

Suppose a train is moving past an observer. The faster its speed in metres per second, the faster its observed rate of circulation in degrees per second. However, for a given speed, its circulation rate will be a maximum when its distance is a minimum, i.e. when it is directly opposite the observer. This is shown below. When the angle to the train changes from this perpendicular position, the circulation rate reduces in accordance with the cosine of the angle (or the sine depending on the angle used).



Magnetic force reduces in the same way - as given by the important Biot-Savart law. Similarly, the faster an electric charge moves through a magnetic field, the greater the sideways force needed to achieve a given path curvature or counter circulation. This relation between speed and magnetic force is a striking aspect of magnetism. So again, the idea of counter circulation provides an intuitive basis for understanding a subject that is normally presented as a jumble of implausible ideas and, for most people, inscrutable equations.

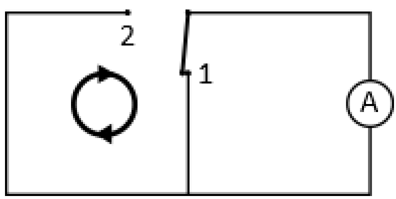
Hence the circulatory principle helps explain the strength of forces as well as their direction, but Fleming's left hand rule only applies to forces arising from existing currents, such as in an electric motor. If energy is being supplied to create a current, such as in a generator, Fleming's right hand rule applies instead. However, electrons do not need to know which device they are in before deciding which rule to follow. The circulatory rule applies in both situations.

The counter circulation rule describes the direction of the magnetic force when two charges are moving. A moving charge constitutes a current, so in practical terms the rule describes the force between short lengths of wires when they are both carrying a current. But electrons do not seem to care whether they are moving *through* a wire or the wire itself is moving and hence is carrying the electrons along with it. If one wire carries a current but the other does not, the rule still applies if the non-conducting wire is moving.

To summarise the arguments so far, early ideas about magnetic forces were naturally based on magnetic poles. This view would have been reinforced by the alignment of iron filings near a magnet. We now know poles are just artefacts of circulating electric charges. It is the motion of the electrons in the iron filings that is aligned with the electron motion in the magnets. The alignment of their poles is a misleading coincidence.

Retaining the original field lines means students need to grapple with needless irrational complications and the pantomime of poking their angled fingers in the air to arrive at the correct answers. Moreover a change in magnetic flux through a loop of wire is supposed to induce a current in the wire. Tilley's experiment though seems to contradict this. So the importance of a change in the hypothetical flux seems to be another misleading coincidence. Tilley's experiment is illustrated below.

The circular rotation shown on the left represents a magnetic field. The A on the right represents an ammeter to measure any current flowing in the circuit. The area enclosed by the electrical circuit depends on the switch near the middle. When the switch is moved from position 1 to 2, the flux through the area within the circuit containing the ammeter increases. An increasing flux is supposed to produce a current, but apparently it doesn't. A couple of other problems with the traditional flux can also be found in the literature (e.g. Feynman Volume II section 17-2).

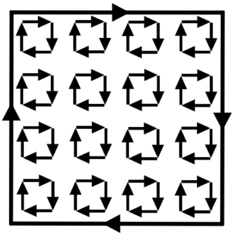
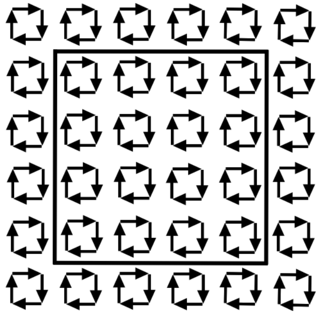


To avoid contradictions one can convert the asymmetric vector field into a simple scalar field. A vector is a number combined with a direction, but a scalar is just a number. So a moving charge is surrounded, in effect, by numbers indicating the strength of the counter circulatory effect at any point. The numbers come from Biot-Savart's law but are positive for a point in space where the charge's motion is seen to be clockwise, and negative where it is anti-clockwise. This then determines whether another moving charge is deflected to its left or right in the plane containing the charges.

It may seem a radical idea to abandon the asymmetric vector field in favour of a symmetric scalar field, but the traditional maths can still be applied to give the same answers. This would involve adding 'unit normal' vectors to the plane. These have a magnitude, or length, of one and are at right angles to the plane. Their only purpose would be to allow the use of the usual vector maths. It is important at this point to distinguish between a mathematical technique, e.g. cross multiplication, and a field. Both fields and techniques should make life easier. The problem comes from thinking a technique is a field. The use of unit vectors ensures that they are seen as a mathematical technique and not a field. We can then get rid of the asymmetric field that lies in a misleading direction.

When a current in one wire induce forces somewhere else, such as in a wire loop, they are called electromotive forces, or emfs. Emfs are supposed to arise from changes in the magnetic flux passing through the space enclosed by a loop, e.g. the flux from right to left through the middle of the coil shown on page 4. This is a very strange idea. One expects an object to experience forces where it is, not where it isn't, and the electrons are in the wire not in the space outside it. Putting magnetism aside for a moment, if a coil of wire is submerged in flowing water it is the forces of water on the actual wire that matter, not the flux of water passing through the middle of the coil.

Although an induced emf is meant to depend on the flux through the area enclosed by the wire, it is said this flux cancels out by virtue of Stokes' theorem. This theorem applies if an area of circulatory effects can be split into tiny polygons whose sides are touching, as shown on the next page. Suppose there is a clockwise circulation around the edge of each tiny polygon. For each shared edge, the circulations from adjoining polygons will be in opposite directions and so their effects will cancel out. This only leaves the circulatory effects from the edges of the polygons that lie on the edge of the overall area.

The diagram on the left illustrates the conventional view of a magnetic field through a square circuit. The asymmetric circulating field is indicated by tiny circulations inside the circuit and the conventional flux flows at right angles to the page. However, the asymmetric field is continuous and also exists outside the loop. In the diagram on the right I have shown a bit more of this traditional magnetic field. It can be seen that the circulatory effect from the polygons immediately outside the loop would cancel the effect from those immediately inside. So the traditional asymmetric field would not produce an emf in a loop because the field does not have an edge at the coil.

To recap, we started with a contradictory circulation. Electrons in a wire are also supposed to be affected by a flux through a surface where the electrons do not exist - except the electrons can ignore the flux inside a loop provided the person who uses Stokes' theorem only ignores the flux outside the loop. This supposedly converts a flux through a surface to a counter circulation in the wire where the electrons actually are. But this is what we should have started with in the first place.

It has taken the ingenuity of some brilliant people to arrive at the traditional ideas describing magnetism, yet to my simple mind the asymmetric field is irrational and should not be taught.

The traditional field lines are useful in so far as they indicate the direction in which there are no lines of counter circulatory force. They are the axes around which forces occur and a vector field "curls". The vector calculus that was developed to describe the traditional magnetic field is also neat and very useful. For me though the orthodox field doesn't exist. I view magnetism as an aspect of electric charges rather than as a different field. Physicists though say magnetism and electrostatics are united using special relativity, SR.

It is a pity children can be deterred from physics by SR and traditional magnetism as I was. It is a shock to find physics is not based on logic. Understanding electromagnetism at an advanced level requires quantum mechanics, QM, but school children ought to be given a simple and rational introduction. It's also a pity that so few adults understand the basics of the subject that underpins modern civilisation. In contrast many people probably retain a grasp of Rutherford's model of the atom. With hindsight we know there is quite a lot wrong with this model, but it's still a very useful step toward understanding some of the important scientific advances that were made up to the beginning of the 20^{th} century.

Similarly I think the idea of counter circulating charges is a useful way to describe the simpler aspects of electromagnetism. This principle is a bit like the conservation of angular momentum, but speed is multiplied by electrical charge rather than mass, and the counter circulating effect reduces with distance. When a current starts to flow in a circuit it induces a counter circulation in nearby circuits. It even creates counter forces in itself. When the flow of charges is constant there are counter circulatory forces on nearby moving charges. And if the current starts to reduce or increase then counter forces act to oppose the change (akin to conserving linear momentum). Any change to a current circulation meets with opposition. We don't normally think of charged particles as tending to preserve the status quo by going the opposite way to their peers, but this would be a memorable and even useful idea for children to take into adulthood.

Back to spacetime

I now want to link magnetism to some previous ideas. I spoke of the energy that binds an electric charge together, but at the time I had no idea how this might be explained. An electron's charge means it has an electrostatic repulsion which tends to explode the electron apart. If an electron is just a point, as many physics sources say, this repulsive force should be infinite.

The conventional view of electrons does not make sense to me. No internal structure has ever been detected in electrons, so what holds them together? Spin explains their magnetism, but we are told electrons cannot be spinning because they would need to spin faster than light, and nothing can disobey SR.

Physicists say electrons have angular momentum rather than spin. But angular momentum is what spinning tops have, so it seems impossible to avoid the idea that spin must somehow involve spinning. Moreover I think the conventional denial of spin involving spin is another example of the inadequacy of current physics. However I suspect the force that balances the electrostatic repulsion within an electric charge, and hence binds the electron together, may be regarded as a form of magnetism.

In Part One I suggested an extra time dimension, q-time, as a simple way to explain the electrostatic force of attraction. It seems that virtual photons may have negative momentum by moving in an opposite direction of time. A reversal of time changes a motion from X to Y to one from Y to X and reverses the momentum involved. So simplistically speaking, a positive charge involves a wave moving at the speed of light in one direction through q-time, but the same wave moving in the opposite direction (or having opposite phase) would be negative. This single type of charge in hidden time appears to us as two opposite charges, positive and negative, because they are not united in the single direction of r-time that we experience.

In q-time two of these charges moving in the same direction would repel each other, e.g. electrons repel, and charges moving in opposite directions would attract. This sounds similar to magnetism even though it involves a different rule of attraction. For want of a better term I will call this hidden magnetism. Presumably if the attraction between moving charges were the same in both dimensions of time, the charges would simply diverge or converge without forming stable entities. Such things might exist, but not in the rs^3 world we can see.

Opposite sides of a spinning body move in opposite directions, so this creates an attractive force in hidden magnetism which potentially provides the force to bind a spinning object together. So rather than spin just being a bewildering property of particles it may supply a mechanism whereby a particle's energy is localized, i.e. the reason that particles can exist.

In Part Two I talked about the angles of rotation of a magnetic axis, e.g. one having its north pole upwards. Whereas rotating a normal axis through 360 degrees brings it to its starting position, the magnetic axis of an electron for example needs 720 degrees in QM. Ordinary matter particles are described as having half spin. The only experimental evidence I have come across to substantiate this is as follows.

Neutrons that are known to have upward pointing spin axes are sent into a device that splits them into left and right pointing spin directions. These two diverging paths are then recombined (in phase) and the particles are all found to have up spin again. A magnet is then added that rotates spin axes. Suppose one of these devices is used to rotate all the axes in one of the two paths by 360 degrees. The resulting combined particles now have down spin, i.e. they've been rotated 180 degrees. It would take two of these devices to achieve a 720 degree rotation for the combined particles to recover their original up spin. Using the QM recipe of spinors (which includes the three Pauli matrices, one for each of the x, y and z directions) with a negative sign in the right place one obtains this result.

However in QM one needs to consider the experimental set-up as a whole. The magnet that changes the phases only affects half of the neutron paths. So it seems that changing half of the set-up by 360 degrees has a 180 degree effect, and affecting half of it by 720 degrees gives a 360 degree effect. I could be wrong about this but I'm not sure it needs a genius like Dirac to find a simpler way than QM's spinors to describe these results.

On the other hand, maybe a spin axis rotates through 360 degrees in q-time and 360 degrees through r-time. As I'm unable to picture anything rotating in five dimensions, I don't know. Nevertheless I come back to the point that a 360 degree rotation of a normal magnet achieves a full revolution, and I find it very hard to believe that geometry would radically change if a magnet were gradually shrunk down to an atomic size.

I will end with a thought on the earlier example of two charges that move downwards side by side in a vacuum at a speed of v. The magnetic attraction and its effect on the charges' acceleration varies with v. If a relativist moves down at the same speed as the charged objects then the objects will be seen to be at rest and so v = 0. Hence the magnetic force disappears for the relativist, but not for observers who are at rest. Mass is meant to increase with the Lorentz factor, but not linearly with v as required. So SR doesn't seem to unite electrostatic forces with magnetic ones for all inertial observers - which was a main aim of Einstein. Physicists have been unable to answer this point. So this seems another paradox that disproves SR's equivalence of inertial frames, which is approximately where I began.