Laws of Electromagnetism

There are four laws of electromagnetism:

- The law of Biot-Savart — magnetic field generated by currents in wires
- Ampere's law — the effect of a current on a loop of flux which it threads
- Force law — the force on an electron moving through a magnetic field
- Faraday's law — the voltage induced in a circuit by magnetic flux cutting it

Our unified theory deduces each of these from its basic assumption that magnetic fields exist to give elementary charged particles the property of inertial mass. Classical Physics calls these "empirical laws" meaning that they have been formed from observation. That is to say that they have no theoretical justification; they just work. Our derivation of these laws raises their status, but also raises questions about their physical meaning.

What nature does

Directions are important in electromagnetism and nature usually does things at right angles. Any proper description must involve vectors and the vector cross product described in the section on fields.

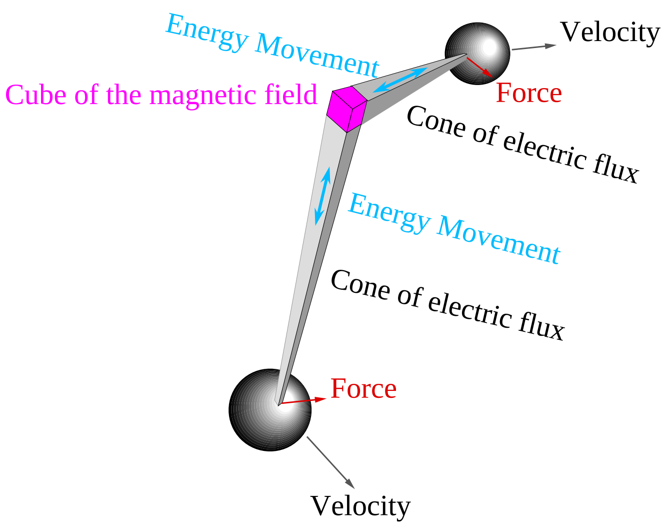
Magnetic fields contain energy. That is their function in nature. The factor which determines their interaction with moving charges is their energy density. There is no universally agreed symbol for energy density so we have chosen to use Q_m for the energy density of magnetic fields.

$$Q_m = \tfrac{1}{2} B H \qquad \text{or} \qquad Q_m = \tfrac{1}{2} \vec{B} \cdot \vec{H} \qquad \text{where} \qquad \vec{H} = \sum_i \vec{v}_i \wedge \vec{D}_i$$

If we use the properties of permeability μ_0 and our definition of magnetic intensity as the sum of the actions of the moving electric fields, we can write:

$$Q_m = \tfrac{1}{2}\mu_0 H^2 \qquad \text{which expands to} \qquad Q_m = \tfrac{1}{2}\mu_0 \left(\sum_i \vec{v}_i \wedge \vec{D}_i \right) \cdot \left(\sum_i \vec{v}_i \wedge \vec{D}_i \right)$$

This absolutely ghastly bit of university maths is the key to how everything works. Since there is no way that we can ever work it out because it involves more sums than there are atoms in the earth, it should be possible to talk about it without getting too worried about how horrible it looks. The thing to understand is that the moving electric flux of every electron is interacting with the moving flux of itself and every other electron and quark. Each one of these adds or subtracts a littler bit to the energy density at each point in space.



Let us consider just two electrons.

We can draw the two cones of electric flux which come from the two electrons and meet in the tiny volume of magnetic flux. We have made the drawing so that they meet at right angles in a cube, but they could meet at any angle and the cube could be any shape.

The contribution to the energy density of each electron depends on its velocity and all the angles between its velocity, the cone of electric flux and the magnetic flux. Any change in one of these results in a change to its contribution to the energy in that tiny cube. This requires energy to move back and forth along the tube of electric flux. Now a considerable length of the tube of electric flux passes through similar tiny miss-shaped cubes and the change in energy in each these adds to the energy which needs to flow up or down the cone.

The cone ends in a little square of the surface of the electron and that is where net amount of this energy which moves up and down the cone has to be either generated or adsorbed. This results in a force. The force could be doing work or adsorbing energy; it all depends on the relative direction of the force and the velocity. One thing we can be certain of: each of these forces is tangential to the surface. What happens is that the whole of the surface lies at the end of its own cone of electric flux and each is resonsible for a tiny force. All these tiny contributions add up to give a net force on the electron.

But the universe is not quite that simple. If the magnetic field is trying to dump energy, the electron has to be free to move allowing the force to do work. If we stop the electron from moving, the magnetic field has to find another electron which is free to move. This action can be seen in transformers and switch mode power supplies. If the universe did not work this way, none of our televisions, computers or mobile phones would work.

If we could look closely at a moving electron and could see the magnetic field generated by its motion, we would see energy densities millions and billions of times greater than any found in the magnetic field of a magnet. The interaction we have described is completely dominated by the electrons own contribution. The magnetic field contains its kinetic energy and the force generated is the inertial force which resists its acceleration. The maths even gives us Newton's law $F = m\,a$.

As we build machines which exploit this interaction, the geometry and action of each results in a special law to fit the circumstances. Traditional TV sets contain a tube in which a beam of electrons scans the screen generating the picture. The beam is deflected by a powerful magnetic field generated by currents in the field coils. The law of Biot-Savart enables us to calculated the magnetic field and the force law allows us to calculate how it bends the beam. Ampere's law allows us to calculate the energy contained in a magnetic field and together with Faraday's induction law is used in the design of the transformer or switch mode power supply which powers the TV from the mains.

The law of Biot-Savart

This gives the magnetic field generated by a current I flowing through a small length of wire $\delta\vec{l}$. The law is heavily dependent on directions and can only be described by a vector equation. The flux density $\vec{B}$ is:

$$\vec{B} = \frac{\mu_0\, I\, \delta\vec{l} \wedge \hat{r}}{4\pi\, r^2}$$

The basic assumption of our unified theory is that moving electric flux generates a magnetic intensity $\vec{H} = \vec{v} \wedge \vec{D}$. We consider a short section of wire and all of the electrons and quarks in it. The magnetic intensity generated by their motion is given by the sum of all of their individual contributions $\vec{H}_i = \vec{v}_i \wedge \vec{D}_i$. At first the velocities $\vec{v}_i$ are measured relative to the background formed by the electric fields of all the electrons and quarks in the universe. But if we group together all the electrons and quarks of an atom, the sum of their magnetic intensities is equal to $\vec{H}_i = \vec{u}_i \wedge \vec{D}_i$ where $\vec{u}_i$ is now the velocity of a conduction band electron relative to its parent atom. Thus the magnetic intensity due to all the conduction band electrons in the length δl of wire is:

$$\delta H = \sum_i \vec{u}_i \wedge \vec{D}_i$$

Then with a bit more maths, we can show that the sum depends on the current I and the length δl of the bit of wire. We need to include the direction of the current along the wire for the vector cross product and the end result is the law of Biot-Savart:

$$\vec{B} = \frac{\mu_0 I \,\delta\vec{l} \wedge \hat{r}}{4\pi r^2}$$

Force law

Classical Physics gives the empirical law that the force on a charge q moving at velocity $\vec{v}$ through a magnetic field of flux density $\vec{B}$ is given by the school and university maths formulae:

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

If the electron's velocity is perpendicular to the flux then the magnitude of the force is given by the school maths $F = B e v$ in which e is now the charge of the electron.

Classical physics makes no attempt to explain how the force is generated. Modern Physics attempts to explain it with relativity using a "Lorentz transform" to turn the magnetic field into an electric field, but in the author's opinion, this is a maths fudge.

In our unified theory, there is an interaction between the whole of the magnetic field and the whole of the electron's electric field. This interaction results in an energy transfer between the magnetic field and the electron generating a net force. When we look closely at the situation, we find that equal amounts of energy are flowing into and out of the electron with resulting forces spread over its surface. Because they are not all in the same direction, when we add them, we find that there is a net force. This is perpendicular to the velocity, so does no work and the speed and kinetic energy remain unchanged.

In our unified theory, the electron is surrounded by its own magnetic flux generated by its velocity, so the flux of the magnetic field through which it is passing must be pushed aside. This means that it does not "feel" any local presence of the magnetic flux. This does not matter because in our unified theory, the force is not generated by a local action. The maths is difficult university stuff, but amazingly it all simplifies to give:

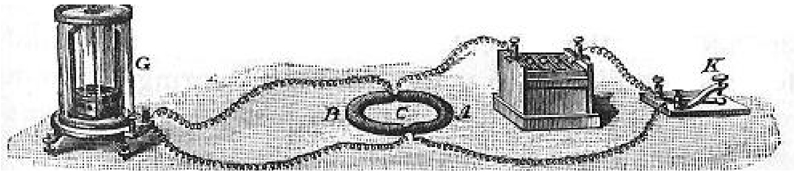
$$\vec{F} = \mu_0 q \vec{v} \wedge \vec{H}$$

We should not talk of the "bev" force, but of the "mu-hev" force because it is this mathematical artefact $\vec{H}$ which comes out of the maths. Because $\vec{H}$ is a mathematical artefact, it is not subject to the limitation imposed on the flux density $\vec{B}$ by the fact that the flux is real and singular.

That having been said, it is obvious that the force on the electron is perpendicular to its velocity. This being so, the acceleration it imparts always causes the electron to follow a circular or a spiral path.

Faraday's Law

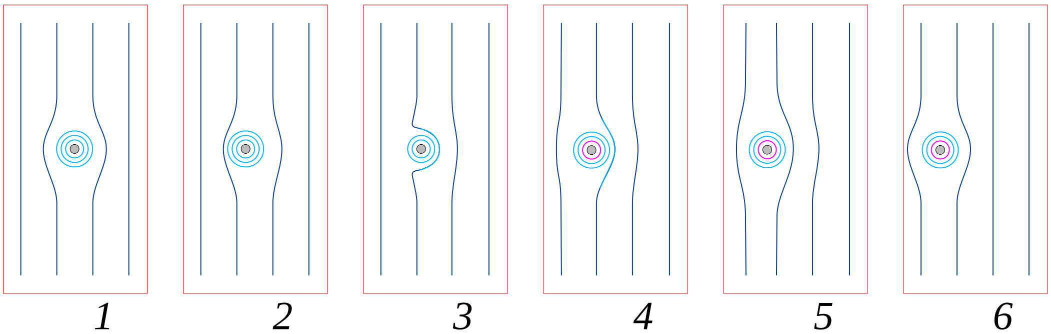
This is the most important law. Without it, we would only have batteries. There would be no mains electricity, no electric motors. This is the law which once understood allowed us to generate electricity.



The diagram shows a sketch of Faraday's original apparatus which consisted of a ring of soft iron with two coils of wire wrapped around it. It is in fact the world's first transformer.

In our unified theory, we try to describe how nature works at the most fundamental level and identify the actual physical processes through which she acts. Classical Physics as taught in the university Electrical and Electronics Engineering Departments has the very simple idea that the iron ring contains magnetic flux and that any change in the flux content envolves flux cutting through each turn of the wire. Modern Physics should if it is honest to itself follow Einstein's doctrine that magnetic flux does not really exist. The truth lies somewhere between these. Magnetic flux is real stuff, but it does not cut the wires.

Faraday's law follows on from the force law. We saw how the moving electron does not actually pass through the magnetic flux, because it is surrounded by its own magnetic field and this pushes the flux of the background field aside. Once a current starts to flow, the turns of wire are each surrounded by their own magnetic field. A loop of flux can only move past the wire by joining with one of the flux loops around the wire, then breaking from it on the other side as shown in the sequence below.



Light blue represents the flux strands encircling the wire and dark blue the strands of the background flux. As the wire moves two flux strands each break and rejoin with each other so that the strand now passes on the other side. As the wire passes further away from this strand, an new strand of flux shown in magenta emerges from the wire to replace the lost encircling light blue strand.

The reverse process occures when the wire moves the right so from 6 to 1, a point is reached where the magenta loop of flux is adsorbed into the wire 4→3 and then splits in two places rejoining with itself 3→2 to allow the adsorbed encircling loop to be replaced.

So there is no direct action between the loop of flux and the wire or the conduction band electrons within it. It is an indirect action involving the interaction of the electric field of each conduction band electron with the whole the background magnetic field. This interaction involves energy transfers between the magnetic field and each conduction band electron resulting in net force $\vec{F} = \mu_0 \, q \, \vec{v} \wedge \vec{H}_0$ on each one. It is only when we try to add up these forces that Faraday's law emerges.

The "trick" is to express the velocity $\vec{v}$ of an electron relative to the magnetic flux as the sum of the the velocity $\vec{w}$ of the electron relative to the wire and the velocity of the wire relative to the flux.

$$\vec{F} = \mu_0 \, q \, \vec{v} \wedge \vec{H}_0 \qquad \text{becomes} \qquad \vec{F} = \mu_0 \, q \, (\vec{w} + \vec{u}) \wedge \vec{H}_0$$

Now, we can split the force into two parts $\vec{F}_1 = \mu_0 \, q \, \vec{w} \wedge \vec{H}_0$ and $\vec{F}_2 = \mu_0 \, q \, \vec{u} \wedge \vec{H}_0$. When we add up the all the $\vec{F}_1$ forces for a short length of wire, we get a force acting on the wire at right angles to it. When we add up all the $\vec{F}_2$ forces, we get a force along the length of the short bit of wire. If we now add up the forces on the short lengths, the $\vec{F}_1$ forces all add to zero and the $\vec{F}_2$ forces add up to give the induced voltage.

We need to understand how the equation $\vec{F}_2 = \mu_0 \, q \, \vec{u} \wedge \vec{H}_0$ relates to natures' actions. The actual magnetic flux does not pass through the wire, but the mathematical artefact $\vec{H}_0$ which is the magnetic intensity of the background magnetic field can be described in exactly the same way as if it were a flux and its flux passes through the wire. We have to use a suffix 0 to distinguish it from the magnetic intensity $\vec{H}_w$ generated by any current in the wire. The actual magnetic flux threading the circuit formed by the wire results form the sum of the two magnetic intensities. We need some college maths to describe how we calculate the amount of flux threading the circuit by integrating $\mu_0 \left(\vec{H}_0 + \vec{H}_w \right)$ over the area enclosed by the circuit. Nature is busy breaking and joining, then breaking flux strand that they move form one side of the wire to the other, so along the length of the circuit flux is being lost or gained resulting a net rate of change of the amount Φ of flux threading the circuit. When all the maths is worked out, we find that the voltage induced in the circuit is:

$$V = -\frac{d\Phi}{dt}$$

Where the term $\frac{d\Phi}{dt}$ describes the rate at which the flux threading the circuit is changing with time.

Ampere's law

Ampere's law is important when we consider magnetic fields in transformers and inductances. It involves the concept of magnetomotive force (*mmf*) which is given by an integral around a closed path. Ampere's law states that the *mmf* is equal to the current threading the path:

$$mmf = \oint \vec{H} \cdot d\vec{l} = I$$

The initial assumption of our unified theory is that moving electric flux generates a magnetic field. This leads to the description of magnetic intensity generated by the motion of an electron $\vec{H}_i = \vec{v}_i \wedge \vec{D}_i$. We saw how this could be summed for a current I in a short length δl of wire to give the law of Biot-Savart. For a particular circuit, it is possible to calculate the magnetic field produced by the current. It is then possible to integrate $\oint \vec{H} \cdot d\vec{l}$ around a particular path and show it is equal to the current. However, it only simple enough to do in the case of some very special geometries. It does not constitute a general proof.

We can derive the law when we consider the interaction between a single electron and a loop of flux. It then becomes quite easy to sum the actions of all the conduction band electrons in a circuit and deduce the law. But there is a lot of geometry in it, so we have refer the reader to the derivation at physicist level.