Magnetic Coupling

HOME: The Physics of Bruce Harvey

We have shown that inductance depends on magnetic intensity $\vec{H}$ and that the old concepts of flux linkage and of flux cutting conductors must be modified. Magnetic flux as described by its flux density $\vec{B}$ only cuts conductors on rare occasions because under most circumstances the the magnetic intensity as described by $\vec{H}$ induces a current in the conductor generating its own flux as described by $\vec{B}$. It is useful to define the terms B-flux and H-flux.

- B-flux is the real stuff with flux density $\vec{B}$.
- H-flux is the mathematical artefact with flux density $\mu_0 \vec{H}$.

When we have two circuits P and Q carrying currents, each has its distinct H-flux field, but there is only one B-flux field:

$$\mu_0 \vec{H}_p = \mu_0 \sum_{i \in p} \vec{v}_i \wedge \vec{D}_i \qquad \mu_0 \vec{H}_q = \mu_0 \sum_{i \in q} \vec{v}_i \wedge \vec{D}_i$$

$$\vec{B} = \mu_0 \vec{H}_p + \mu_0 \vec{H}_q$$

Where p is the set of conduction band electrons in circuit P, $\vec{v}_i$ the velocity of each measured relative to the circuit and $\vec{D}_i$ the electric flux of each. Similarly for circuit Q. The B-flux and the electric flux are real. The flux densities $\vec{B}$ and and the trillions of individual $\vec{D}_i$ are real. The H-flux and its flux densities $\vec{H}_p$ and $\vec{H}_q$ are mathematical artefacts. This truth lay hidden in classical electromagnetic theory because it used units in which magnetic flux density and magnetic intensity had the same dimensions.

When we consider the electromagnetics of atoms, magnetic flux is quantised and the phenomena of classical electromagnetism in which there is a change in the flux linkage between two circuits cannot happen. We can only understand what actually happens when we are clear about the nature of magnetic flux and magnetic intensity. The current loops of orbiting electrons are cut by each other's H-flux and the electrons orbit in each others H-flux fields.

We have also shown that the force on a charge moving through a magnetic field depends on its H-flux because the moving charge generates its own H-flux field and that if we could see the B-flux it would appear to us as if the charge had its own B-flux which moved with it pushing its way through the B-flux of the background magnetic field. We can explain the force on the moving charge q when we consider the way in which the magnetic intensity $\vec{H}_q = \vec{v}_q \wedge \vec{D}_q$ interacts with the whole of the magnetic field. We find its contribution to the local energy density throughout the field requires energy to move to and from the charge and that this energy is either generated or adsorbed by the surface of the charge. But summing the energy exchange and then the force, we end up with the deceptively simple result that the force $\vec{F}$ on the charge q moving with velocity $\vec{v}$ though the magnetic field $\vec{H}_0$ is:

$$\vec{F} = \mu_0 \, q \, \vec{v} \wedge \vec{H}_0$$

We have to grasp these conceptual niceties if we are to understand what is actually happening within atoms.

We have also shown that the effect of a magnetic field on an electron orbit is quite different from that of a magnetic field on a current loop because both orbital mechanics and the quantisation of magnetic flux dictate what happens. Whereas the force between two current loops tries to turn them into parallel alignment and attract them towards each other, this is not necessarily true for atoms.

It is customary in electromagnetism to describe the strength of a magnet or current loop in terms of its magnetic moment. In the case of a simple (in one plane) current loop, this gives a beautifully simple result:

$$\mu = I A \qquad \vec{\mu} = I \vec{A}$$

The torque $\vec{\tau}$ and force $\vec{F}$ on a current loop in a background field of magnetic intensity $\vec{H}_0$ are:

$$\vec{\tau} = \mu_0 \left(I \vec{A}\right) \wedge \vec{H}_0 \qquad \Rightarrow \vec{\tau} = \mu_0 I \int \hat{n} \wedge \vec{H}_0 \, dA; \qquad \text{where } \hat{n} \text{ is unit vector normal to } dA$$

$$F = \mu_0 \left(I \vec{A}\right) \cdot \nabla \vec{H}_0 \, \hat{h} \qquad \Rightarrow \vec{F} = \mu_0 I \int \hat{n} \cdot \nabla \vec{H}_0 \, dA \qquad \text{where } \hat{h} \text{ is unit vector} \parallel \text{to } \nabla \vec{H}_0$$

The Stern-Gerlach experiment gives the first clue that the magnetic moment of an atom is different from that of a current loop or magnet. Current lops and magnets will only align parallel to the magnetic field, a fact which lead to the invention of the compass. Atoms line up either parallel or anti-parallel with equal probability. This is because the action of the magnetic field upon the orbiting electron is not inductance but the force $\vec{F} = \mu_0 q \vec{v} \wedge \vec{H}_0$ acting on the electron to modify its orbit. Parallel alignment causes the orbit to increase in radius reducing the energy in the magnetic field threading the orbit, but increasing the energy of the orbital system making it less negative. Anti-parallel alignment causes the radius of the orbit to contract increasing the energy in the magnetic field threading it, but reducing the energy of the orbital system making it more negative.

When two hydrogen atoms meet with parallel alignment, the effect is to increase the energy of each other's orbital system. Work must be done to increase the energy content and that work must be done against a resisting force. Therefore the atoms repel one another.

When they meet in anti-parallel alignment, the effect is to decrease the energy of each other's orbital system and the energy released is able to do work pulling the atoms together producing a force of attraction.

That is why atoms with magnetic moments couple in pairs to cancel each other out instead of forming long chains in the way in which the toy magnetic plastic balls behave.

We conclude that the concept of magnetic moment is applicable to atoms in calculating their magnetic far field, but not with regard to their interaction with magnetic fields. We will explore this in more detail in Quantum Theory chapters.

We speculate that the three quarks of a nucleon also form a stable orbital system with angular momentum and magnetic moment. As such, they would behave like hydrogen atoms with their magnetic moments coupling in pairs to cancel each other out. As the strength of magnetic dipole attraction obeys an inverse fourth power law, the much smaller size of the nucleons allows the dipole attraction to overcome the electric force.