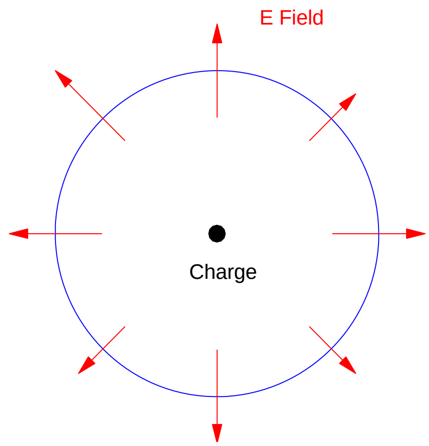
Maxwells Equations

Gauss's Law:

$$\oint E \cdot dS = \frac{1}{\varepsilon_0} \iiint \rho dV \qquad \nabla \cdot E = \frac{\rho}{\varepsilon_0}$$

Translation: There is such a thing as electical charge (electrons and protons). These electrical charges 'emit' electrical fields.

- The sum total of the electrical fields coming out of a closed surface is equal to the charge enclosed.
- If there is no net-charge enclosed, the net electrical field over a closed surface is zero.



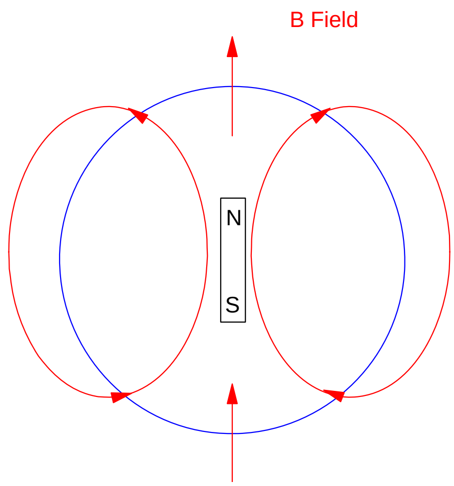
Gauss' Law: The net electrical field over a closed surface is proportional to the charge enclosed.

Gauss' Law for Magnetism:

$$\oint B \cdot dS = 0 \qquad \nabla \cdot B = 0$$

Translation: There is no such a thing as magnetic monopoles: magnetic fields form a closed-path

- The sum total of the magnetic fields coming out of a closed surface is equal to zero.
- There is no such thing as a magnetic mono-pole



Gauss' Law for Magnetism: The net magnetic field over a closed surface is zero.

Faraday's Law:

$$\Phi_B = \iint B \cdot dA$$

Translation: The induced electromotive force in any closed circuit is equal to the negative of the time rate of change of the magnetic flux through the circuit.[1]

Maxwell-Faraday Equation:

$$\oint E \cdot dl = -\frac{d}{dt} \iint B \cdot dS \qquad \nabla x E = -\frac{dB}{dt}$$

Translation: A time-varying magnetic field is always accompanied by a spatially-varying, non-conservative electric field, and vice-versa. (1).

1 www.Wikipedia.com

And let there be light.....

$$\nabla x E = -\frac{\partial B}{\partial t}$$

$$\nabla x B = \frac{1}{c^2}\frac{\partial E}{\partial t}$$

Taking the curl of the curl:

$$\frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} - \nabla^2 E = 0$$

$$\frac{1}{c^2}\frac{\partial^2 B}{\partial t^2} - \nabla^2 B = 0$$

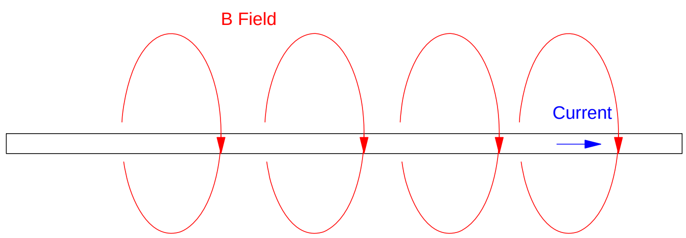
Leads to a self-sustaining electro-magnetic wave equation (a.k.a. light)

http://en.wikipedia.org/wiki/Electromagnetic_wave_equation

> It is known that Maxwell's electrodynamics—as usually understood at the present time—when applied to moving bodies, leads to asymmetries which do not appear to be inherent in the phenomena. Take, for example, the reciprocal electrodynamic action of a magnet and a conductor.
>
> The observable phenomenon here depends only on the relative motion of the conductor and the magnet, whereas the customary view draws a sharp distinction between the two cases in which either the one or the other of these bodies is in motion. For if the magnet is in motion and the conductor at rest, there arises in the neighbourhood of the magnet an electric field with a certain definite energy, producing a current at the places where parts of the conductor are situated.
>
> But if the magnet is stationary and the conductor in motion, no electric field arises in the neighbourhood of the magnet. In the conductor, however, we find an electromotive force, to which in itself there is no corresponding energy, but which gives rise—assuming equality of relative motion in the two cases discussed—to electric currents of the same path and intensity as those produced by the electric forces in the former case.
>
> Examples of this sort, together with unsuccessful attempts to discover any motion of the earth relative to the "light medium," suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest.
>
> — Albert Einstein, On the Electrodynamics of Moving Bodies

Wires and Current:

A wire carrying current produces a magnetic field. This field stores energy (creating an inductor) and attracts / repels other magnetic fields (creating motors).



The magnetic field strenth is

$$B = \frac{\mu I}{2\pi r}$$

Example 1: Find the magnetic field strength 1cm away from a wire carrying 1A. Assume a vacuum.

Solution:

$$B = \frac{\mu I}{2\pi r} = \frac{(4\pi \cdot 10^{-7})(1A)}{2\pi(0.01m)} = 20\mu \frac{Wb}{m^2}$$

You can strenthen the magnetic field by placing the wire in a coil with a large number of turns.

Example 2: Find the magnetic field strenth of 100 windings of wire in a loop 1cm in diameter. Assume a vacuum.

Soltion: Assuming unifirm field strentgh over the area

$$B = 100 \cdot \frac{\mu I}{area} = 100 \frac{(4\pi \cdot 10^{-7})(1A)}{2\pi(0.005m)^2} = 0.8 \frac{Wb}{m^2}$$

Magnetics attract when opposites. This means that two wires in parallel will attract with a force of:

$$F = \frac{\mu I_1 I_2 l}{2\pi r}$$

Example 3: Calculate the force exerted by two traces, 10cm long, 1mm apart, carrying 1 Amp.

Solution:

$$F = \frac{(4\pi \cdot 10^{-7})(1A)(1A)(0.1m)}{2\pi(0.001m)} = 2 \cdot 10^{-5} N \quad (0.0001 \text{ oz}).$$

You don't need to worry about this for designing circuit boards. Replace FR4 with iron/Supermalloy (x 800,000) and use 100 windings (x 100) and this becomes 1600N (350 lbf). This is what allows us to build motors.

Definitions:

B = magnetic flux density Webers / m2 = Teslas

$$B = \frac{\mu I}{2\pi r}$$

Φ = magnetic flux Webers

$$\Phi = B \cdot A$$

$$F = \Phi R$$

H = magnetic field intensity

$$H = \frac{B}{\mu}$$ Amps / meter

F = magnetomotive force

F = H l amp turns

R = Reluctance

$$R = \frac{l}{\mu A}$$

Quantity	Symbol	CGS	SI	Conversion
mmf	F	gilbert	amp-turns	1.257 Giltert = 1 Amp-Turn
Permiability	μ	$\mu_0 = 1$	$\mu_0 = 4\pi \cdot 10^{-7}$	
Reluctance	R	$R = \frac{L}{\mu_r A}$	$R = \frac{L}{4\pi \cdot 10^{-7} \cdot \mu_r A}$	
Flux	Φ	Maxwells	Webers	1 Weber = 1E8 Maxwells
Magnetic Field Intensity	H	Oersteds	Amp-Turns / Meter	1 Oersted = 79.6 AT/m
Flux Density	B	Gauss	Teslas	10,000 Gauss = 1 Tesla

Material	Permiability @ 20 Gauss	Maximum Permiability	Saturation Flux Density B (Tesla)	Hysteresis Loss ergs / cm3	Coercive Force Oersteds
Cold Rolled Steel	180	2,000	2.1		1.8
Iron	200	5,000	2.15	5,000	1
Purified Iron	5,000	180,000	2.15	300	0.05
4% Silicon Iron	500	7,000	1.97	3,500	0.5
78 Permalloy	8,000	100,000	1.07		0.05
Superalloy	100,000	800,000	0.8	12,000	0.002

(from CRC Handbook of Chemistry and Physics - 58th Edition)