
Electricity and Magnetism

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The Electric Force

Introduction: There are four known fundamental forces: gravity, electromagnetism, the nuclear strong force, and the nuclear weak force.

Electromagnetism is really a combination of two forces - the electric force and the magnetic force.

To understand the electric force we need to know a few basic things about atoms

1. Atoms are composed of a small, dense, positively charged nucleus surrounded by negatively charged electrons
2. All electrons are identical in mass and charge
3. Protons and neutrons reside in the nucleus and are almost 2,000 times more massive than electrons.

Neutrons are electrically neutral and have a "dab" more mass than protons.

4. Normal atoms have the same number of protons as electrons. If these are not the same we have an *ion*. Positive ions have more protons than electrons; negative ions have more electrons than protons.
5. Electrons close to the nucleus are held tightly; electrons far away from the nucleus are held more loosely.

Objects can become ionized by friction as electrons leave one material and are transferred to another. This gives a static charge on an object.

Examples: Rubbing a glass rod with silk, rubbing a balloon with your hair, walking across a carpet.

Big idea - Electrons are not created or destroyed, merely transferred from one place to another.

Coulomb's Law

The electric force is similar to the gravitational force in that the force is *inversely proportional to the square of the distance* between the charged particles. This gives the equation

$$F = k \frac{q_1 q_2}{d^2}$$

We see that if the charges have the same sign there is a positive (or repulsive) force. If the charges are of opposite sign then there is a negative (or attractive) force. Thus like charges repel and unlike charges attract.

k is a proportionality constant [$k = 9.00 \times 10^9 \text{ N m}^2/\text{C}^2$] , q_1 and q_2 represents the charges of the particles (in Coulombs) and d is the distance between the particles This large value of k means that the electric force is very large. The electric force holds the atom together!

Question: If a proton at a particular distance from a charged particle is repelled with a given force, by how much does the repelling force decrease when the proton is 3 times farther away from the particle?

Since electric forces can act without "touching" we say that there exists an electric field around every charged particle.

Electric Potential or Voltage

In the same way that we have to do work to overcome the gravitational force and move a mass we have to do work to overcome the electric force and move a charge. This leads to an electric potential energy and would be measured in joules. The ratio of the electric potential energy to the amount of charge moved is called the electric potential - more commonly called the voltage. The equation would be $V = W/Q$

$$1 \text{ volt} = 1 \text{ Joule/Coulomb}$$

Voltage can be thought of as a type of "electric pressure" similar to water pressure in a pipe.

Electric Current

Electric current is the *flow* of charged particles - electrons in a wire or perhaps ions in a water solution. The rate of electrical flow is measured in amperes (A). The equation would be $I = Q/t$.

$$1 \text{ Ampere} = 1 \text{ Coulomb/second}$$

Current may be direct (DC) or alternating (AC). Direct current has the charges flowing in one direction always. In alternating current the charges move back and forth. Most commercial use of electricity is AC and alternates back and forth 60 times a second. This is called 60 Hz AC power. AC current is easy to transport and change into whatever voltage and current combination we need.

Electrical Resistance

As a pipe offers resistance to the water flowing through it, a wire or water solution offers resistance to the charged particles moving through it. The unit of electrical resistance is the ohm and has the symbol Ω .

Ohm's Law

The ohm is defined by an equation that relates current, voltage, and resistance. This equation is known as Ohm's Law.

$$\text{Voltage} = (\text{Current}) (\text{Resistance})$$

$$V = IR$$

$$\text{volts} = (\text{amperes}) (\text{ohms})$$

Electric Circuits

Series - An electrical circuit in which the electrical devices are connected in such a way that the same current exists in all of them. See pages 197 and 198 in text (4th edition).

Parallel - An electrical circuit in which the electrical devices are connected in such a way that the same voltage acts across each one and any single one completes the circuit independently of all the others. See pages 198-200 in text.

(Our lab activity will demonstrate these circuits.)

Electrical Power

$$\begin{aligned} \text{Electrical power} &= \text{current} \times \text{voltage} \\ \text{power} &= (\text{charge}/\text{time}) (\text{energy}/\text{charge}) = \text{energy}/\text{time} \\ \text{Watts [=]} &= \text{amperes} \times \text{volts} \end{aligned}$$

Since power = energy /time then

$$\text{energy} = \text{power} \times \text{time}$$

Thus we buy electrical energy in kWh (kilowatt hours)

Questions - If you use a 100. W light bulb operating at 120. V, how much current is flowing through the bulb?

At 6.0 cents per kWh, what does it cost to operate a 1200. W hair dryer for 10. hours?

Magnetism

Magnetic forces attract and repel like electric forces.
Like poles repel; opposite poles attract.

Magnetic forces result from magnetic poles in a similar fashion to electric forces resulting from electric charges. *Important difference– magnetic poles cannot be isolated*. If you break a magnet each part behaves as a complete magnet.

Magnetic forces produce magnetic fields, similar to electric fields.

The nature of magnetism

Magnetic forces result from the motion of electric charge. In a bar magnet this movement of charge is the motion of the electrons of the material. In most materials the movement of all the electrons cancels out, but not always in the common materials iron, nickel, and cobalt – *ferromagnetic* materials.

In these materials, there are clusters of atoms (called domains) which can be aligned. When a magnetic material is brought close to one of these materials, the unaligned domains become aligned and the material becomes magnetic.

Currents and Magnetism

Moving charges produce magnetic fields so an electric current produces a magnetic field. The magnetism of a piece of iron can be increased by placing the material in a current carrying coil of wire. This produces an electromagnet.

The direction of the magnetic field is from north pole to south pole and can be deduced by pointing your left thumb in the direction of the electron flow. Your fingers will naturally curl in the direction of the field.

The earth's magnetism is due to the movement of electric currents that result from the thermal convection of the molten interior of the earth.

Magnetic forces and moving charges

A charged particle must be moving to “feel” a magnetic field. If it does move it feels a maximum force when it is moving in a direction perpendicular to the magnetic field lines and zero force when it is moving parallel to the field.

For a beam of electrons (current) perpendicular to a magnetic field, point the index finger of your left hand in the direction of the current and your other fingers in the direction of the field. Your thumb will point in the direction of the magnetic force. This force is very different from gravity and the forces between electric charges and magnetic poles since it acts perpendicular to the magnetic field and current.

Applications

Since current carrying wires experience a force when in a magnetic field this can be used to make a meter that detects a current. Loops of wire (a coil) is used to enhance the effect. This instrument is called a *galvanometer*. Voltmeters and ammeters are fancy galvanometers.

Electric motors also use this principle but in a devious and crafty way. After the coil has experienced its max deflection, the current is reversed (using brushes) and the coil continues to rotate. This reversal is continued in a cyclic fashion. Electric motors convert electrical energy to mechanical energy.

Electromagnetic Induction

If moving charges in a wire (an electric current) cause a wire to move in a magnetic field then it is reasonable to think that a moving wire in a magnetic field would cause charges to move in the wire (produce a current).

This can actually be accomplished by either moving the wire or changing the magnetic field. The larger the number of loops of wire around the magnet the larger the field.

This is the basis for *Faraday's Law of Electromagnetic Induction*: the induced voltage in a coil is proportional to the number of loops times the rate at which the magnetic field changes within those loops.

Examples of electromagnetic induction: electrical generators, car activated traffic lights, audio recording, metal detectors, electrical transformers. All of these devices convert mechanical energy into electrical energy.

Electrical transformers

When changes in a magnetic field of a current carrying coil of wire are intercepted by a second coil of wire, voltage is induced in the second coil. The relationship is simple:

$$\frac{\text{primary voltage}}{\text{\# of coil turns}} = \frac{\text{secondary voltage}}{\text{\# of coil turns}}$$

Since power in must equal power out for energy conservation

$$V_p I_p = V_s I_s$$