Electric Motors

**Background:** The operation of an electric motor depends upon the special relationship between electricity and magnetic fields. The aspects of this relationship that we’re going to examine can be summarized in two sentences. Firstly, magnetic fields are created by electric currents. Secondly, whenever an electric current (or any moving charge, for that matter) passes through a magnetic field, there is a force exerted on the current.

Before we talk about these properties, we need to understand some facts about magnetic fields. Like many physical quantities, magnetic fields have a *magnitude* (how strong the field is) and a *direction* in space. Physical quantities that have both magnitude and direction are known as *vector* quantities, while physical quantities that have just a magnitude are known as *scalar* quantities (can you think of some examples of each?) The magnitude of a permanent magnet’s magnetic field is easy to detect. You can just see how well the magnet sticks to a piece of iron (like the refrigerator). The direction of the magnetic field around a permanent magnet is a little more difficult to detect. You need a *compass* to sense the direction. A compass needle simply lines itself up with the direction of the magnetic field around a permanent magnet. If there is no permanent magnet nearby, a compass needle lines itself up with the earth’s magnetic field, which is directed from South to North. This fact has long been used to help ships, airplanes, and people on foot figure out what direction they are traveling.

Now that we understand something about magnetic fields, we can talk about how they are created. All magnetic fields are created by electric currents. If you wrap wire around a nail and then hook up a battery to the wire to move the electrons through it, then the nail becomes an electromagnet. But what about permanent magnets? Where are the currents that make the magnetic field around a permanent magnet? To answer this question, we need to remember the structure of atoms. The atoms of all materials basically consist of a nucleus with electrons orbiting around them. The orbiting electrons are like tiny current loops, and since currents make magnetic fields, each atom has a tiny magnetic field associated with it. In most materials, these tiny atomic magnetic fields are in all directions, and they cancel one another out so that the material as a whole is not magnetic. In *ferromagnetic* materials (iron, cobalt, and nickel are the main three), however, the atomic magnetic fields can line themselves up to make a big magnetic field.

Whenever an electric current passes through a magnetic field, there is a force exerted on the current. The equation that tells us how to find this force is known as the *Lorentz Force Law*, after the scientist who discovered it. This law is often written like this: \( \mathbf{F} = q (\mathbf{v} \times \mathbf{B}) \). The \( \mathbf{F} \) is the force, which is a vector quantity. The \( q \) is the amount of charge that is passing through the field (scalar quantity). The \( \mathbf{v} \) is the velocity with which the charge is passing through the field (vector quantity). The \( \mathbf{B} \) is the magnetic field that the charge is passing through (also a vector quantity). The \( \times \) symbol stands for “cross product”. Figuring out exactly how this equation works is a little tricky, but we’ll go some examples of how it works on the board. The Lorentz Force law can be used to build a very simple motor. The trick is figuring out how to use this law to make the motor spin.