Magnetic Fields

The magnetic field is similar to an electric field. The space around a magnet is filled with the magnetic field of the magnet. A magnetic field exists in a region of space if a north or south magnetic pole experiences a force when placed in this region of space. The strength of the magnetic field is calculated from the magnitude of the force the field exerts on a test north pole. The direction of the field is the direction in which the field pushes the test north pole. We can create a uniform magnetic field in the space between two opposite magnetic poles with the same strength.

N

S

The magnetic field between the two poles is uniform. A magnetic pole placed anywhere in this space will feel the same size force and in the same direction. A north pole placed in the field would be pushed right and a south pole would be pushed left.

The symbol for magnetic field strength is *B* and has the unit teslas, T. Magnetic fields are often referred to as “*B* fields.”

A synonym for “magnetic field strength” is magnetic flux density or just **flux density**.

For what we do in this physics class the direction of a magnetic field will usually be perpendicular to the plane of the paper. The field will be directed out of the plane of the paper or into the plane of the paper. We show these directions this way:

 ● means a field pointing out of the plane X means a field pointing into the plane

 of the paper of the paper

Think of the arrow that we use to indicate direction. The ● represents the tip or point of the arrow coming toward you. The X represents the feathers of the arrow as it goes away from you.

 a uniform *B* field directed a uniform *B* field directed

 out of the plane of the paper: into the plane of the paper:

 ● ● ● ● ● ● X X X X X X

 ● ● ● ● ● ● X X X X X X

 ● ● ● ● ● ● X X X X X X

 ● ● ● ● ● ● X X X X X X

 ● ● ● ● ● ● X X X X X X

Each atom in a material can be viewed as a magnet. Each electron in an atom is accelerating and therefore produces a magnetic field around it. The magnetic fields of all the electrons in an atom combine to make a magnetic field around an atom. Any bit of matter contains many atoms. The atoms of a substance tend to congregate into areas within the matter that we call ***magnetic domains***. The magnetic fields of the atoms in the magnetic domain tend to be randomly oriented so they tend to cancel each other. So under normal conditions, the magnetic domains of the matter are randomly oriented and the bit of matter is ***not magnetic***. Under the right conditions the magnetic domains of the matter can be made to mostly orient in the same direction. The magnetic fields of the atoms combine making the domain magnetic. The magnetic fields of the domains will combine and make the bit of matter magnetic. Certain materials, typically metals or metal alloys, have domains that will “line up” like this. These metals and metal alloys can be magnetized. Other bits of matter cannot be magnetized.

Page 2

**movement of a charged particle in a magnetic field**

A moving charged particle creates a magnetic around itself. ***The particle must be moving and the particle*** ***must have an electric charge***. The particles at which we usually look are subatomic particles;

|  |  |  |  |
| --- | --- | --- | --- |
| ***particle*** | ***mass in kg*** | ***electric charge in C*** | ***relative electric charge*** |
| electron | 9 X 10-31 | - 1.6 X 10-19 | -1 |
| proton | 1.67 X 10-27 | + 1.6 X 10-19 | +1 |
| neutron | 1.67 X 10-27 | zero | zero |
| antielectron or positron | 9 X 10-31 | + 1.6 X 10-19 | +1 |
| alpha particle | 6.64 X 10-27 | + 3.2 X 10-19 | +2 |

When a charged particle moves through a magnetic field, the external magnetic field interacts with the magnetic field of the moving charged particle. The interaction produces a force on the charged particle that will change the path of the particle as it moves through the field. ***The path the particle follows will be*** ***circular, either a complete circle or an arc of a circle***. If the is a complete circle, the magnetic field captures the particle and the particle does not leave the field. If the particle leaves the magnetic field then the path of the particle through the field will be an arc of a circle.

If the particle moves perpendicular to the magnetic field we can calculate the size of the force the field

exerts on the moving charged particle with the following equation:

 $F = qvB$

***F*** – the force the field exerts on the moving charged particle in newtons

***q*** – the size of the charge on the moving particle in coulombs

***v*** – the speed of the particle in m/s

***B*** – strength of the magnetic field in teslas

The direction of the force on the charged particle will be perpendicular to both the velocity vector of the particle and the direction of the magnetic field. We determine the direction by a ***right-hand rule***. Open your **right** hand and point the thumb perpendicular to the fingers. Point the fingers of your **right** hand in the direction in which the particle is moving when it enters the magnetic field. Point the palm of your hand in the direction of the magnetic field. If the field is directed out of the plane of the paper (dots) then point your palm toward you. If the field is directed into the plane of the paper (X’s) then point your palm away from you. The direction in which your thumb points is the direction of the force on a moving **positive** charge. A moving negative charge would feel a force in the opposite direction.

**moving wire in a magnetic field**

When a conductor moves in a magnetic field an electric potential difference or voltage is induced in the wire. This is the principle of the electric generator. The voltage induced is given by the following equation:

 $V = Blv$

***V*** – voltage induced by the movement of the wire in volts

***B*** – strength of the magnetic field in teslas

$l$– length of the moving wire in meters

**v** – speed of the moving wire in m/s

To induce a large voltage a generator should have strong magnets, a long coil of wire, and the coil should spin very fast.

Page 3

**transformers**

A transformer is one of the few electrical devices that will operate on AC but not on DC. This property is why we use AC to transmit electricity today. A transformer consists of two coils of wire that are not physically connected to each other but oriented so one coil is in the magnetic field produced by the other coil. A changing magnetic field in one coil induces a potential difference in the second coil. The potential difference in the second coil may not be the same as the potential difference in the first coil. The two coils of the transformer are referred to as the primary coil and the secondary coil. You create a voltage across the primary coil and send current through this coil. The magnetic field produced induces a potential difference in the secondary coil which causes a current to flow in the wire of the secondary coil. The currents and voltages of the two coils are related to the number of turns of wire in the two coils. The voltage across a coil is directly proportional to the number of turns in the coil. The current in the coil is inversely proportional to the number of turns. The equations are:

  AND ($Iprimary)(Nprimary) = (Isecondary)(Nsecondary)$

*V*primary – voltage across the primary coil in volts

*V*secondary – voltage across the secondary coil in volts

Nprimary – number of turns of wire in the primary coil

Nsecondary – number of turns of wire in the secondary coil

Iprimary – current in the primary coil in amperes

Isecondary – current in the secondary coil in amperes

A transformer is called a **step-up** transformer if the transformer has a higher voltage in the secondary coil than in the primary coil. A **step-down** transformer has a lower voltage in the secondary coil than in the primary coil.

Transformers allow us to step up the voltage so that long-distance transmission of electric current occurs with little loss of energy. Other transformers step down the voltage for use in your house. If you have a device that will work on batteries or wall current the box-like object that your plug into the wall outlet is a transformer. It steps down the voltage from the 110 V of the outlet to the voltage your device requires. The transformer has another element in it that converts the AC from the wall outlet into DC for your device.

Since energy cannot be created or destroyed the power input to an ideal transformer will equal the power output.

 Pprimary = Psecondary OR (Iprimary)(*V*primary) = (Isecondary)(*V*secondary)

***A step-up transformer increase the voltage but reduces the current. A step-down transformer decreases voltage but increases current.***