Nicholas Hender

Area Of Study 1, Electric Power, Study Notes 2

Electromagnetism

The two concepts fundamental to this topic:

1. **Current through a wire causes a magnetic field.**
   The wire does not need to be iron, nickel or cobalt. The current doesn't even need to be through a wire. Wherever an electron moves, a magnetic field is generated.

2. **Moving a wire in a magnetic field, or moving a magnetic field near a wire, causes current in the wire.**
   Again, the wire does not need to be iron, nickel or cobalt. In fact, relative motion between any conductor and a magnetic field causes electrons to move. This process is called "electromagnetic induction", and will be further explored later.

Right Hand Grip (RHG) Rule

This gives the **direction of a magnetic field** around a wire carrying current.
- Use your **right** hand.
- Stick your thumb out.
- Align your **thumb with the current** in the wire.
- Curl your fingers around the wire.

Your **fingers point in the direction of the magnetic field**:
- **From** North.
- Indicating the direction of the force that would be experienced by a North pole.

Current Carrying Wires In Magnetic Fields

A current carrying wire has a magnetic field. Because of this, the wire will experience **force** when in another magnetic field (as the two magnetic fields interact).

The magnetic field of a current carrying wire is perpendicular to the current, so the direction of force experienced by the wire when in another magnetic field is not attractive or repulsive (towards or away from the other magnetic field), but **sideways** (in relation to the other magnetic field.)

Right Hand Push (RHP) Rule

This gives the **direction of the force** experienced by a current carrying wire in a magnetic field (assuming an angle of 90° between the current in the wire and the magnetic field affecting it).
- Use your **right** hand.
- Stick your thumb out.
- Align your **thumb with the current** in the wire.
- Stick your fingers out.
- Align your **fingers with the magnetic field** affecting the wire (not the magnetic field **of** the wire).

Your **palm points in the direction of the force experienced by the wire**.

Magnitude Of The Force Experienced By A Current Carrying Wire In A Magnetic Field

$$F = BIl\sin\theta$$

Where
- F = force on the wire, in N
- B = magnetic flux density (magnetic field strength), in T
- I = current in the wire, in A
- l = length of the wire in the magnetic field, in m
- θ = angle between the direction of the magnetic field and the current in the wire, in degrees

When the direction of the magnetic field is perpendicular to the current in the wire, $\theta = 90$, and $\sin\theta = 1$, so the above formula can be simplified to:

$$F = BIl$$

Magnitude Of The Force Experienced By A Moving Charged Particle In A Magnetic Field

Current is the motion of charged particles. Current carrying wire experiences force in a magnetic field because the motion of charged particles in the wire gives it a magnetic field of its own. If charged particles are **not** part of a current carrying wire, they still experience force as they move in a magnetic field, because their motion causes them to also have a magnetic field.

$F = BIl\sin\theta$ .... as above

$I = \frac{q}{t}$ .... current equals amount of charge per unit of time (from electronics)

$v = \frac{l}{t} \rightarrow l = vt$ .... length equals velocity multiplied by time taken (from motion)

$F = B(\frac{q}{t})vt\sin\theta$ .... substituting I for $\frac{q}{t}$, and l for vt

$F = Bqv\sin\theta$ .... simplifying

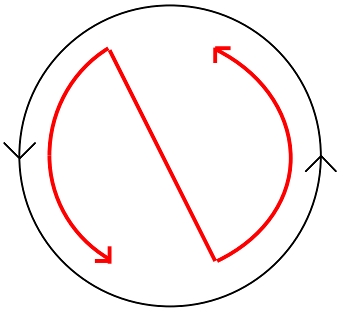
Where
- F = force on the wire, in N
- B = magnetic flux density (magnetic field strength), in T
- q = charge of moving particle, in C
- v = magnitude of velocity, in ms^{-1}
- θ = angle between the direction of the magnetic field, and the direction the of motion of the charged particle, in degrees

Again, when the direction of the magnetic field is perpendicular to the direction the of motion of the charged particle, $\theta = 90$, and $\sin\theta = 1$, so the above formula can be simplified to:

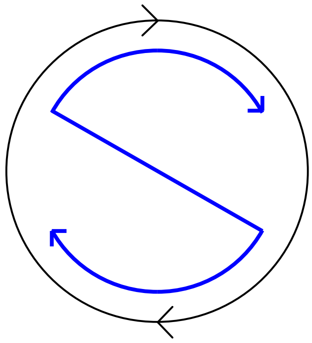
$$F = Bqv$$

Solenoids (Coils)

A high current is required to get a strong magnetic field. However, if long lengths of wire with even only low current are aligned, their magnetic fields cumulate. By wrapping wire into a spiral, strong magnetic fields can be generated. These spirals of wire are called "solenoids" or coils. A North pole is created at one end of a solenoid, and a South pole is created at the other. Considering the direction of the current through a wire in a solenoid, here's how to tell which end is North and which end is South.



Looking at end of solenoid, if current is **anticlockwise**, polarity is **North**. Other end therefore has South polarity.



Looking at end of solenoid, if current is **clockwise**, polarity is **South**. Other end therefore has North polarity.

Solenoids are often formed around a soft iron core. The soft iron experiences magnetic induction (easily becomes temporarily magnetised in the vicinity of a magnetic field). This greatly increases the flux density (the magnetic field strength) of the solenoid. Such a device is what's known as an "electromagnet". Electromagnets are very useful because:

- They can be switched on and off, as zero current = zero magnetic field.
- Their flux density (magnetic field strength) can be controlled by the amount of current flowing through the wire; high current = high flux density, and low current = low flux density.

Electric Meters

These are electromagnetic devices used for measuring things. They work like this:

- A needle (an indicator) is attached to a solenoid.
- The solenoid is attached to a pivot, so it can turn through part of a rotation.
- The solenoid is situated in a constant magnetic field.
- Current through the solenoid causes it to have a magnetic field, varying with the amount of current.
- Interaction between the magnetic fields causes force on the solenoid, making it (and the attached needle) move.
- The needle indicates a quantity by pointing to a calibrated scale.

Electric Motors

These are electromagnetic devices which operate similarly to electric meters, but the solenoid is able to complete full rotations. This cannot happen in an electric meter because the force on the solenoid reverses within a half rotation, causing it to either come to rest or rotate in reverse. This is overcome in electric motors by reversing the current in the solenoid every half turn. Parts of an electric motor allowing it to work like this:

- **Armature**: the axle that spins, and the soft iron around which the solenoid wires are wound.
- **Brushes**: usually made of carbon, because it conducts and is slippery, connect the current from a power supply to the commutator (explained below) on the armature.
- **Commutator** (also known as a "series commutator" or "split series commutator"): on one end of the armature, connecting the current from the brushes to the solenoid. The commutator has a "split", such that a different half is connected to each brush every half rotation. This reverses the current in the solenoid every half rotation, keeping the force on it always in the same direction and thereby making it spin, rather than only swing back and forth and come to rest.