Lesson 18: Applying Concepts of Magnetic Fields

What we've been looking at lets us explain a lot of things, as well as come up with new ways of studying the world and building new devices.

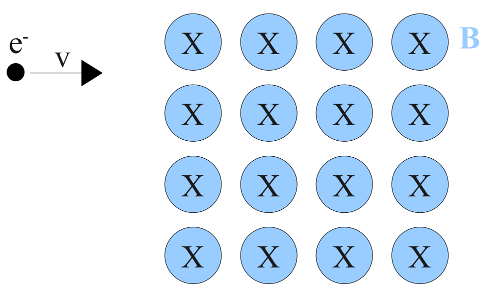
- This lesson will look at some of the more advanced problems that can be solved by applying the concepts of magnetic fields, moving charges, and current carrying wires.

Charges Trapped in Magnetic Fields

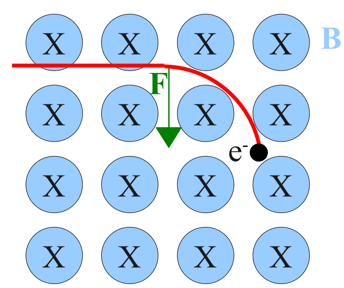
If you've ever watched the Northern Lights (Aurora Borealis) then you've seen the effect of capturing a moving charged particle in a magnetic field.

- The Sun is constantly shooting off charged particles whenever a solar flare erupts on its surface.
  - Some of these charged particles, moving at about 0.10c (*10% the speed of light*) come flying right towards Earth.
  - As they get near, they begin to interact with the magnetic field that surrounds the Earth, causing them to change their path.
  - If the conditions are just right, some of these particles are funneled in at either the North or South poles and start to spiral in towards the ground.
  - As the particles bump into air particles they can transfer energy that causes electrons to jump up energy levels. Since the electrons don't stay there long, they release energy as they fall back down, which we see as light.

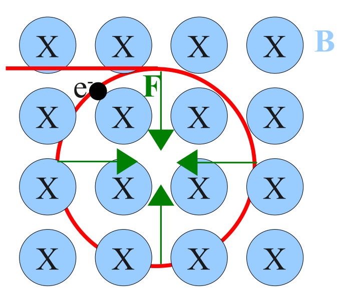
To see how this spiraling can happen, look at the following simplified diagram of an electron shot into a magnetic field...



(i) The electron is initially moving to the right as it approaches the magnetic field.



(ii) Using the third hand rule, we can see that when the electron is traveling to the right it will experience a force pushing it down, so its path starts to curve down.



(iii) At each new position, the electron is traveling a different direction. This means that at each new position we need to figure out a new direction for the force acting on it.

(iv) If we keep following the electron around, we will see that the direction of the force changes so that it always points in towards the centre of the circular path it ends up following.
We know that this force is F_m , but we can also see that it is causing circular motion which means it is F_c.

$$\mathbf{F_m = F_c}$$

Example 1: An electron is moving towards a 1.13T magnetic field at a speed of 2.38e3m/s. **Determine** the radius of the electron's path if it enters perpendicular to the field.

$$F_m = F_c$$
$$qvB = \frac{mv^2}{r}$$
$$r = \frac{mv}{qB}$$
$$r = \frac{9.11\text{e-}31(2.38\text{e}5)}{1.60\text{e-}19(1.13)}$$
$$r = 1.20\text{e-}8\, m$$

Did you know?
The cyclotron, which accelerates charged particles while trapping them in a magnetic field, was invented by Ernest Lawrence. The first one he built was small enough to fit in the palm of your hand.

Warning!
In questions involving particles spinning around inside a magnetic field, make sure you are answering the question being asked. If it is quantitative, solve for the one variable you need. If it is qualitative, watch out for the difference between the direction of the path (shown as the continuous RED vector in the diagrams above) and the direction of the force acting on the particle (shown as individual GREEN arrows in the diagrams).

Magnetic Forces Balanced by Gravitational Forces

The magnetic force does not always have to be equal to a centripetal force. We often need to look at questions involving gravitational forces.

- This could still involve single charges (as shown in **Example 2**), but can also involve current carrying wires (**Example 3**).

Example 2: An alpha particle is shot into a 4.9e-7 T magnetic field at 90 degrees. The magnetic force on the alpha particle is acting upwards. **Determine** the speed at which it must be traveling so that the magnetic force balances out the force of gravity pulling it down so that the particle travels in a straight line.

$$F_m = F_g$$
$$qvB = mg$$
$$v = \frac{mg}{qB}$$
$$v = \frac{6.65\text{e-}27(9.81)}{3.20\text{e-}19(4.9\text{e-}7)}$$
$$v = 0.42\, m/s$$

Example 3: An electric balance (an electric scale) can be made by having a length of current carrying wire sitting in a magnetic field. If no mass is on the scale, the wire will be at an equilibrium position. When a mass is placed on the scale, the wire is pushed down. A certain amount of current is needed to force the wire back up to its equilibrium position. A particular electric balance has a length of wire 0.298 m long placed perpendicular inside a 3.75e-3 T magnetic field. If a current of 7.81e-2 A is required to balance the scale after an object is placed on it, **determine** the mass of the object.

$$F_m = F_g$$
$$IlB = mg$$
$$m = \frac{IlB}{g}$$
$$m = \frac{7.81\text{e-}2(0.298)(3.75\text{e-}3)}{9.81}$$
$$m = 8.90\text{e-}6\ kg$$

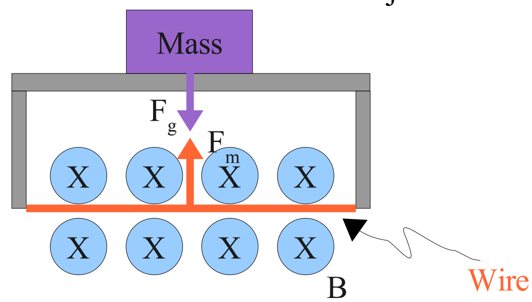


Illustration 1: Electric Balance with a mass sitting on the platform pushing down, and the wire underneath with a force pushing up.

If you were asked, the electron flow current in the wire must be towards the left.

Magnetic Forces Between Two Wires

We can also look at situations involving the forces between two or more current carrying wires.

- This is a very real concern when designing modern equipment, such as airplanes.
  - There are thousands of metres of current carrying wires bundled together running around different parts of an airplane.
    - Sometimes the current in two wires might run in the same direction, sometimes opposite directions.
  - Since each wire is inducing its own magnetic field around itself, it's natural to say that sometimes wires will attract or repel each other.

Andre Ampere did research into the force between current carrying wires. He identified three factors that influence the strength of the force between the wires:

1. the length of the wires that run beside each other
2. the distance between the wires
3. the current flowing in the wires

Although he came up with **Ampere's Law** to calculate the amount of force based on the strength of the magnetic fields the wires created, you are only required to say if there is attraction or repulsion.

Currents Running in Same Direction Results in Attraction

Let's draw a simple diagram to figure out what the magnetic fields of the two wires will look like side by side.

- Remember that the magnetic fields induced around the wires act like any other magnetic field. Although the loop endlessly around the wire, they still have a magnetic North and South.

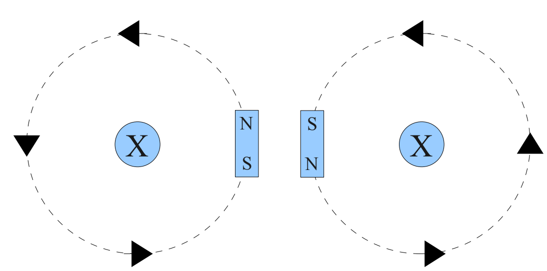


Illustration 2: Current flowing in same direction, showing induced magnetic field around each wire.

- Use the first hand rule to figure out the direction of the magnetic field around each wire.
- In the space between the two wires, the regular vector showing the direction of this magnetic field has been replaced with a magnet representing the direction.

- These magnets are arranged so that the north pole of one is near the south pole of the other. Therefore they will attract.

Currents Running in Opposite Directions Results in Repulsion

We can draw a similar diagram when the wires have current running in opposite directions.

- Again, use the first hand rule to identify the direction the direction of the induced magnetic fields around the wires.
  - This time the magnetic fields between the wires point in the same directions.
- Since north repels north, and south repels south, the two wire repel each other.

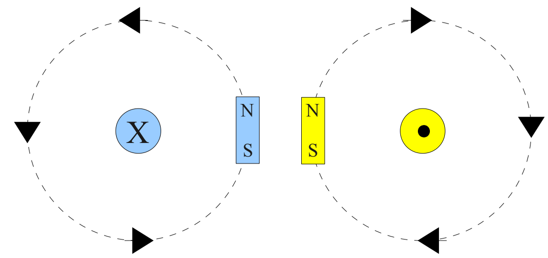


Illustration 3: Current flowing in opposite directions, showing induced magnetic field around each wire.