Grade 10 Physics Notes - Unit 4, Part II

Aaron G. Kebede

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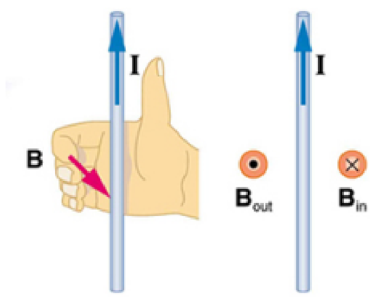
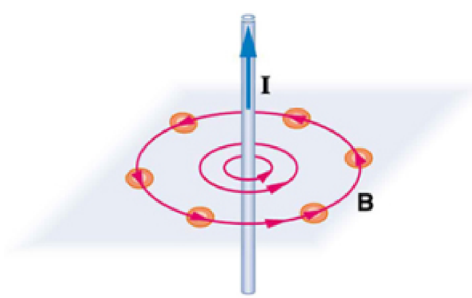
Magnetic Fields

There are multiple sources of magnetic field. A straight current carrying wire is one prime example of a source of magnetic field. The magnetic field generated by a straight current carrying wire is determined by the **Right Hand Rule**. The basic idea in this rule is to align your thumb with the direction of current(**I**). Then, the direction in which the rest of your fingers curl show the direction of the magnetic field(**B**).



Thus, for a straight current carrying wire, we have circular magnetic fields.



To represent magnetic field and show where it acts, we use magnetic field lines. These are hypothetical lines that show the line of action of magnetic force.

Here is a few things that make magnetic field lines and generally any force field lines especially.

- The direction of the magnetic field is tangent to the field line at any point in space. A small compass will point in the direction of the field line.
- The strength of the field is proportional to the closeness of the lines. It is exactly proportional to the number of lines per unit area perpendicular to the lines (called the areal density).
- Magnetic field lines can never cross, meaning that the field is unique at any point in space.
- Magnetic field lines are continuous, forming closed loops without beginning or end. They go from the north pole to the south pole.

The SI unit of magnetic field strength(**B**) is called **Tesla(T)**.
The magnitude of the magnetic field across a straight current carrying wire is affected by a few things.

1. Current - the larger the current, the stronger the magnetic field.
2. Distance from wire - as we get farther from the wire the magnetic field decreases in strength

Thus, we have the following relationship:

$\mathbf{B}\ \alpha \frac{I}{r}$, where **I** is the current and **r** is the distance from the wire.

The constant of proportionality for the above relationship is called permeability(μ). The permeability of a material is the tendency of a material to get magnetized.

$$B = \mu_0 \frac{I}{2\pi r}$$

μ_0 is called the permeability of free space(vacuum) and it is the tendency of vacuum to get magnetized.

J.C. Maxwell made a stunning discovery that light is indeed an electromagnetic wave and he came up with the following relationship to find the speed of light in vacuum(the maximum speed in the universe):

$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$, where μ_0 is permeability and ϵ_0 is permitivitty of free space respectively.

Magnetic Force of a Straight Current Carrying Wire

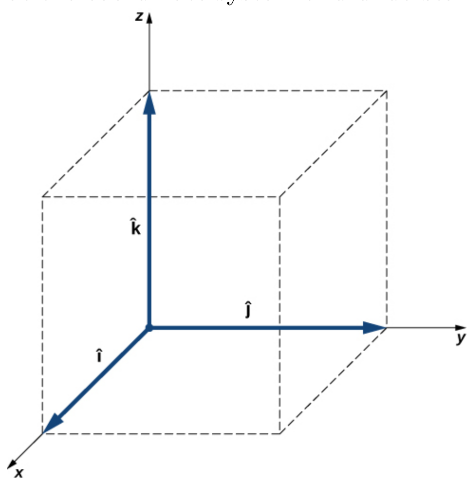
If a current carrying wire is subjected to an **external** magnetic field, a magnetic force will act on the wire. The magnitude of the force depends on the following:

- The strength of the magnetic field the wire is subjected to.
- The amount of current passing through the wire.
- The length of the wire(how much of it is in the magnetic field)

Thus, we have the following:

$$\mathbf{F} = \mathbf{IL} \times \mathbf{B}$$

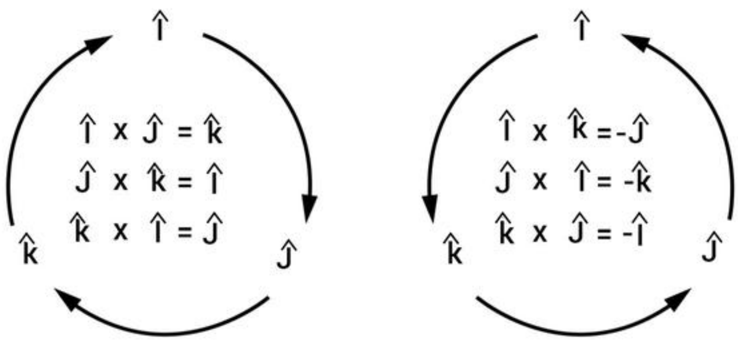
The above product is called a cross product. It is a type of product where two vectors are multiplied to give a vector. To understand how this works, let's look at the coordinate system and understand some conventions.



We know that vectors are physical quantities that need both **magnitude + unit** and **direction** to adequately be described. Thus, we use the coordinate system and unit vectors to describe the directions of a vector.

- A vector acting to the right (positive X-axis) can be described as acting in the $\hat{\boldsymbol{i}}$ direction. Consequently a vector acting to the left(negative X-axis) will have its direction be $-\hat{\boldsymbol{i}}$
- A vector acting upwards(positive Y-axis) can be described as acting in the $\hat{\boldsymbol{j}}$ direction, consequently, a vector acting downwards(negative Y-axis) will have its direction be -$\hat{\boldsymbol{j}}$
- A vector acting **out of the page**(positive Z-axis) can be described as acting in the $\hat{\boldsymbol{k}}$ direction. Consequently, we describe vectors acting **into the page**(negative Z-axis) to be in the -$\hat{\boldsymbol{k}}$ direction.

When these vectors are multiplied in their vector forms, they end up giving us vectors. Look at the following diagram to see how it is done:



Cross products of cyclic unit vectors are positive

Cross products of anticyclic unit vectors are negative

Thus, we can determine the direction of the magnetic force acting on the wire using vectors as shown above. To determine the magnitude of the force in this case, we use the following :

$F = ILBsin\theta$, where θ is the angle between the current and magnetic field

Force on Moving Charges

We have seen that when a current carrying wire is placed in an external magnetic field, a magnetic force acts on it. Another interesting concept is the force exerted on moving charges(not that surprising since current is moving charges anyway.) We have seen that:

$$\mathbf{F} = \mathbf{IL} \times \mathbf{B}$$

And that means

$$F = \mathbf{L}\frac{q}{T} \times \mathbf{B}$$

That simplifies to

$$F = q\mathbf{V} \times \mathbf{B}$$

It is a similar case here. It is a vector product and we can find the direction of a the force acting on the charge if we know where it is moving and if we know the magnetic field on it. The interesting case here is that whether the moving charge is negatively or positively charged matters.

Similarly to the situation above, the magnitude of the force acting on a moving charge is given by the following:

$F = qVBsin\theta$, where θ is the angle between the velocity and magnetic field

Force on a moving charge

When a charge goes through a magnetic field, it usually deflects about an arc. When an object is moving about a circle, the net force acting on the object is called centripetal force(F_c) and it is given by:

$$F_c = m\frac{V^2}{r}$$

When a charge is moving through a magnetic field, if the only force acting on it is magnetic force, we have the following:

$$F_c = \text{Magnetic force on the charge}$$

$$m\frac{V^2}{r} = qVBsin\theta$$

$$m\frac{V}{r} = qBsin\theta$$

Thus, if we know about the charge and the magnetic field it is passing through, we can predict the curvature and the radius of its trajectory.

$$r = \frac{qBsin\theta}{mV}$$