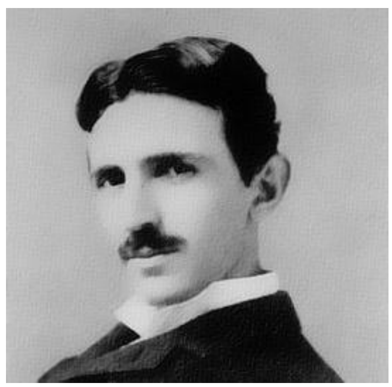
Homework 14

Magnetic force

As we remember the magnetic field applies the force to moving charges. As a charge particle which is moving perpendicularly to the magnetic field vector Bat a velocity V,the magnitude of the magnetic force applied to the particle is

$$F_m=qVB \quad (1)$$

where q is the charge of the particle, V is the particle's velocity, B is the parameter which is characterized the "strength" of the magnetic field. It is called magnetic induction. Magnetic induction is measured in teslas (international system of units). If the force applied to a charged particle with 1C of charge which is moving in a magnetic field at a velocity of 1m/s is 1N, then the magnetic induction is 1T (tesla). This unit is named after a famous Serbian inventor and physicist Nicola Tesla.

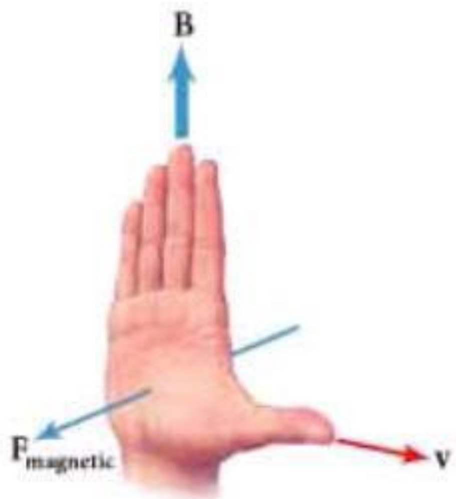


Tesla Nikola Tesla (1856-1943)

Magnetic force, described by formula 1, is also called Lorentz force. This name is given after a Dutch physicist Hendrik Antoon Lorentz..

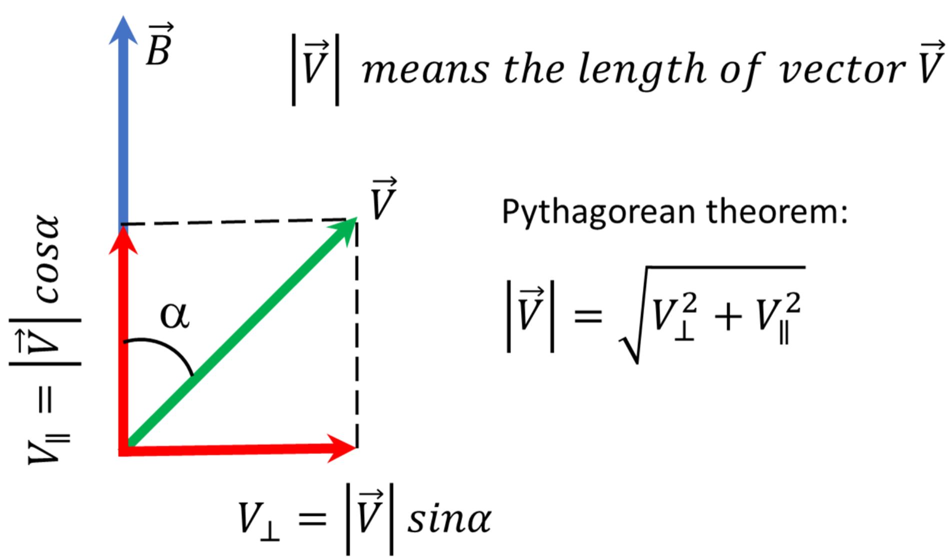
Hendrik Antoon Lorentz (1853-1928)

Magnetic force is directed ***perpendicularly*** to both the magnetic field and the velocity of the particle. The direction of the force can be found using "right hand rule".



Please remember that the picture above is for a positive charge. For a negative charge the direction of the force will be opposite.

Now, what happens when the velocity of the charge particle is directed at an arbitrary angle to the magnetic field? In this case we have to represent the velocity vector as a sum of two vectors. One is directed along the magnetic induction B, the other one is perpendicular to B. This is shown in the Figure below



If the velocity V is directed at the arbitrary angle to the magnetic induction B, instead of V we have to use in the formula (1) just $V_\perp$ - the perpendicular part of the velocity. This perpendicular part can be calculated as :

$$V_\perp = |\vec{V}| \cdot sin\alpha$$

Here α is the angle between B and V. Magnetic field does not affect at all the part of the velocity directed along the magnetic induction B.

We see that the magnetic force (Lorentz force) is directed perpendicular to both magnetic induction and velocity and its magnitude in a general case can be calculated as:

$$\left|\overrightarrow{F_L}\right| = q \cdot V_{\perp} \cdot B = q \cdot V \cdot B \cdot sin\alpha$$

It is possible to write a formula for the Lorentz force in an elegant way. For this we will use a special mathematical notation:

$$\vec{F}_L = q \cdot \left[\vec{V} \times \vec{B}\right]$$

The quantity $\left[\vec{V} \times \vec{B}\right]$ *in the square brackets is a vector which is directed perpendicular to both* $\vec{V}$ *and* $\vec{B}$ *and whose lengths is* $V \cdot B \cdot sin\alpha$. *In mathematics this vector is called "cross product" and its direction can be determined using right hand rule (your thumb directed along the velocity, the rest four fingers are directed along the magnetic induction then your palm is "pressing" along the direction of the cross product). In mathematics there are several ways of multiplication of two vectors and cross product is one of them. It is interesting that, in contrast to the regular multiplication, if you will change the order of vectors, the cross product will change the sign. Changing the sign for a vector means changing its direction to the opposite one. You can check this using the right hand rule. The cross product is widely used in physics and mathematics.*

Problems:

1. An electron enters the area with magnetic field; the velocity of the electron is perpendicular to the magnetic field lines. Do the speed and the velocity of the electron change as it enters into the magnetic field?

2. Same arrangement as in problem one, but now instead of electron we will use a particle the charge of the α-particle is positive, its magnitude is 2 times more than the electron charge and the mass of the α-particle is ~ 7300 times more than the mass of electron. Describe qualitatively the difference of the trajectories of the and the electron in a magnetic field if they have same velocity.

3. The wire made from nonmagnetic material can be attracted to or repelled from the magnet as there is the electrical current in the wire. Could you explain the effect?

4. Give an example of a physical situation where the force exerted on the object is perpendicular to the object's displacement.