Homopolar Motor
Theory of Operation

A Homopolar motor is an electric motor typically comprising a magnet, battery, and a solid copper wire formed into an armature.

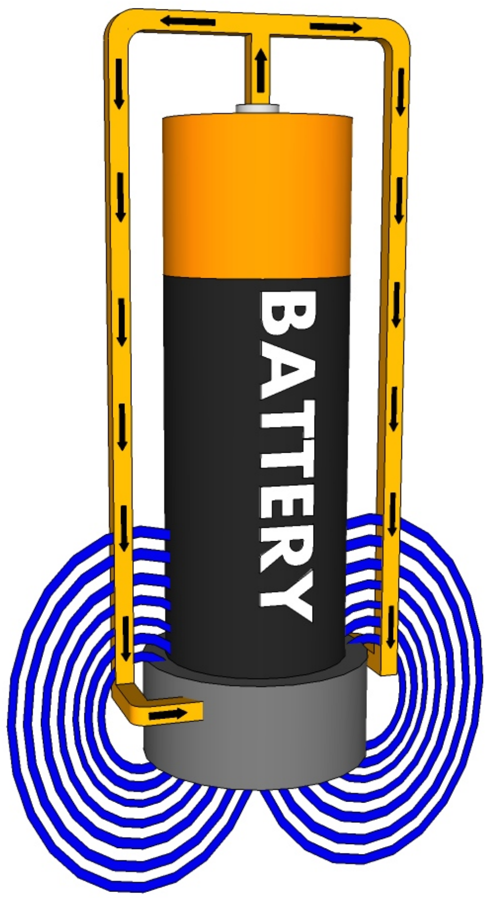


Fig 1. Homopolar motor model.

Magnetic field lines (in blue) leave the top of the magnet and re-enter at the bottom. Electric current (black arrows) leaves the top of the battery travels down both sides and enters the magnet through contact with the wire and then completes its circuit by re-entering the bottom of the battery. This is one example of a homopolar motor, there are others. The magnetic field from the permanent magnet interacts with the current-carrying wire to produce a torque on the armature (wire), causing it to turn. This interaction is through the **Lorentz Force**. The Lorentz force describes the force on a charged particle in an electromagnetic field. In vector calculus notation, it is written

$$\vec{F} = q\left(\vec{E} + \vec{v} \times \vec{B}\right) \qquad (1)$$

where q is the electric charge of the particle in coulombs, $\vec{E}$ is the external electric field (not created by the particle), $\vec{v}$ is the velocity vector of the particle, and $\vec{B}$ is the external magnetic flux density. The electric field is internal to the battery and causes the current to flow. The magnetic field is of interest for motor rotation so we may neglect the electric field term in Eq. 1 and our equation reduces to

$$\vec{F} = q\left(\vec{v} \times \vec{B}\right) \qquad (2)$$

It will now be required to find out how to express the charge and velocity of our current. We can see what the force on a single electron in the wire will be if we know the velocity, since the charge is well known and it is confined to travel in the wire. For now though, let's simply call the velocity v and think of this as the average magnitude of all the particles' velocities. Next, let's call the cross sectional area of the wire A and a unit length of the wire l. The product Al is thus the volume of a unit length of the wire. Finally, if we call the number density of the particles that participate in conduction *n*, then the total number of particles in a unit volume is this density times the volume: *nAl*. If we multiply that by the charge of a single particle, we get the total charge of conduction particles in a unit volume:

$$q_{tot} = qnAl$$

If we now put this equation for total charge in the Lorentz force law, Eq. (2), we get

$$\vec{F} = qnAl(\vec{v} \times \vec{B})$$

Note that there is a **cross product** between the velocity and magnetic field. If they are perpendicular (which, looking at the figure 1 they are approximately so) we can forego the cross product and just multiply the two vectors' magnitudes and remember that the resultant vector (the force) is perpendicular to the plane created by the two vectors and points along the direction a screw would *advance* if it were turned in the direction of rotation corresponding to rotating the *v* vector toward the *B* vector. This will become clearer in diagrams later, but for now let us consider only the magnitude of the force and write

$$F = qnAlvB$$

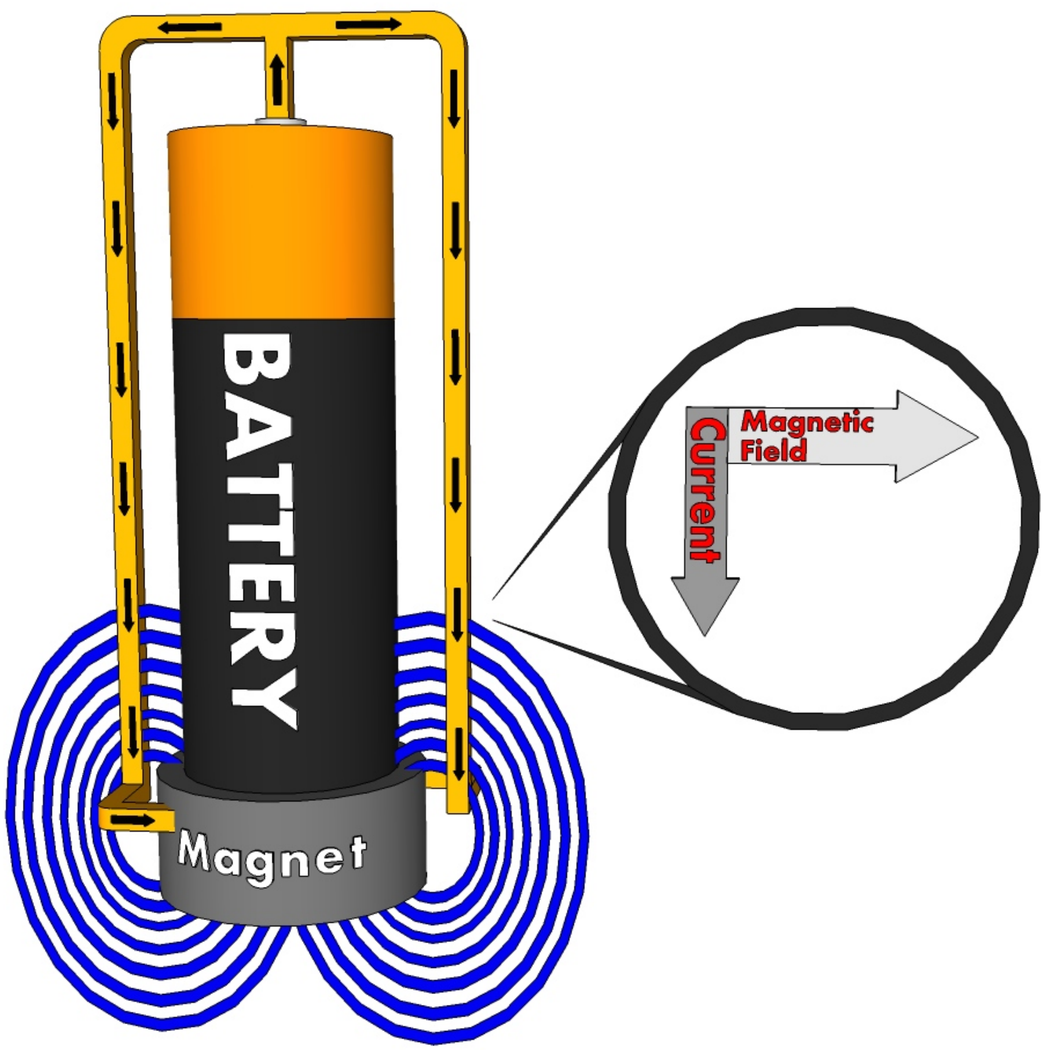
Rearranging gives,

$$F = qnvAlB \qquad (3)$$

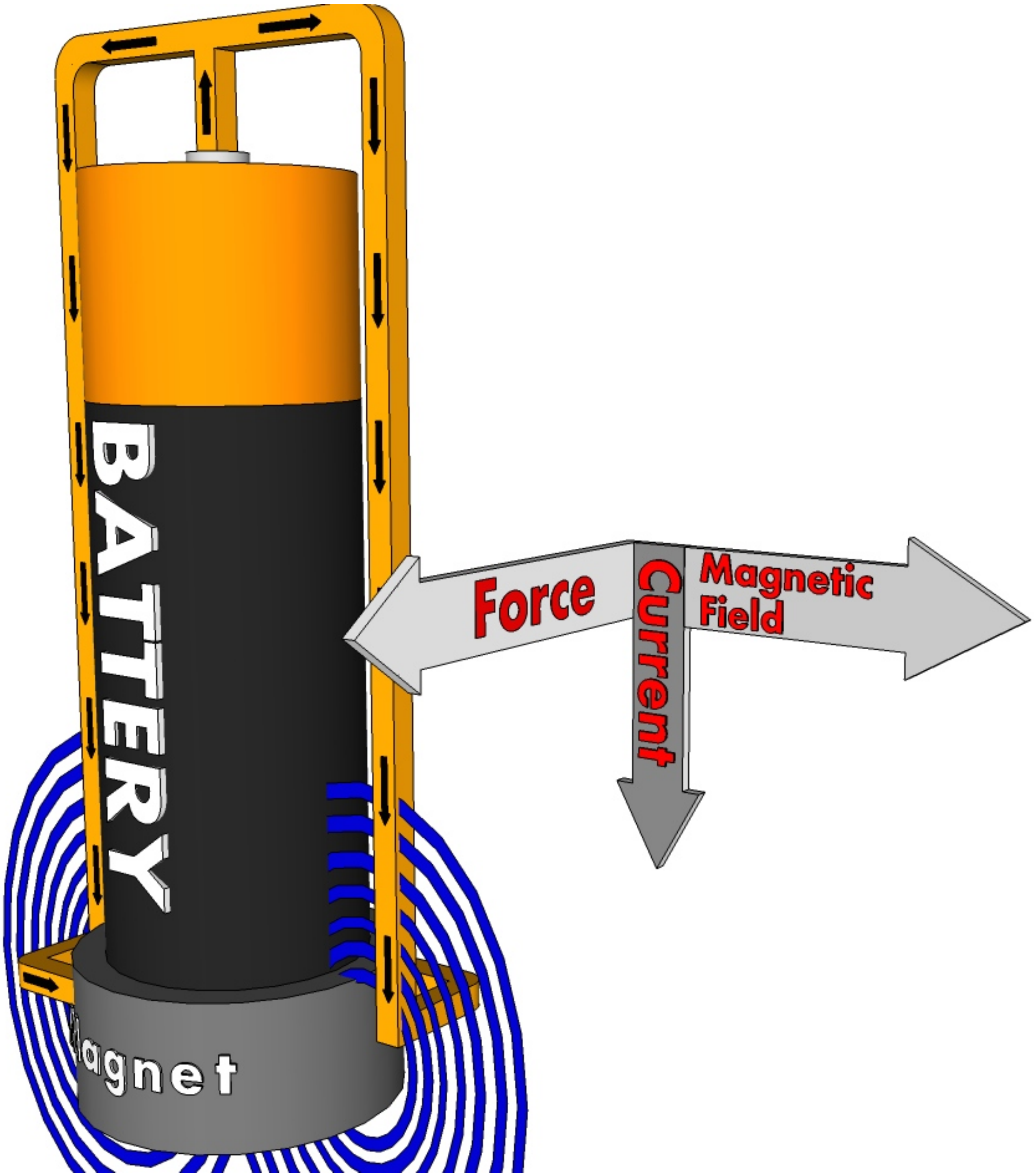
The factors qnv are the charge density times the velocity and represents the *current density* in amps per square meter. It is the total current passing through a slice of the cross section at any point in time. The current density times the cross sectional area of the wire is *the electric current, **i***. Thus we can rewrite Eq. (3) as

$$F = ilB \qquad (4)$$

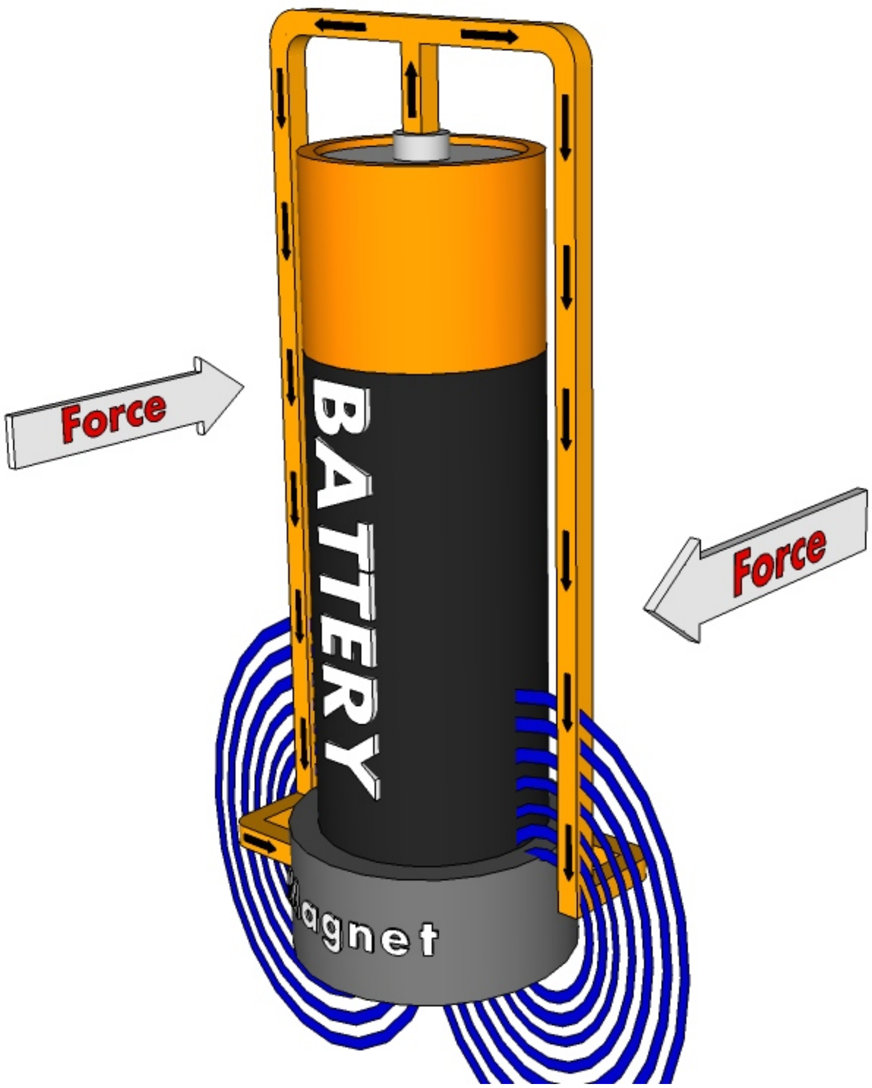
This is the well-known equation of the ***force*** on a wire of length ***l***, carrying a current ***i***, in a magnetic field, ***B***. We can use it to see why the homopolar motor works. Look at the magnetic field vector and the current. **Note that the current itself is not a vector**, but the direction it travels along the wire, *l*, is. Thus Eq. 4 would have the cross product between *l* and *B*.



Now consider the direction of the resultant force from the equation. This comes back to the cross product discussed earlier.



Note that the magnetic field drawn here is only partially represented. It actually emanates further from the magnet and fills all of the surrounding space in the shape of a donut. We are seeing only a limited cross section. This force effect applies to both sides of the wire.



These opposing forces result in a torque on the wire and cause it to turn. Since the wire will always be perpendicular to the magnetic field, and the current is constrained to travel in it, the charges will be moving perpendicular to the field and the Lorentz force will continue to act, keeping the motor spinning.