
Action of the magnetic field

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The influence of the Earth's magnetic field on a compass needle, pigeons or solar charged particles is exerted through the magnetic force (Lorentz force). This force only affects moving objects carrying electric charges.

In general, everyday-life objects are electrically neutral and should not be sensitive to the magnetic force. However, we know that a magnet attracts objects such as steel nails. In this case, the magnetic force acts on the nail at the atomic level. Each atom consists of both a core (positively charged) and a cloud of electrons (negatively charged). The nail's sensitivity to the magnetic force originates from the movement of these charges (positive and negative). Generally, the magnetic forces exerted on the various atoms of an object neutralise each other: objects seem to be insensitive to the magnetic field. But for some materials like iron, these forces don't vanish and the object does experience the action of the magnetic field (like the nail).

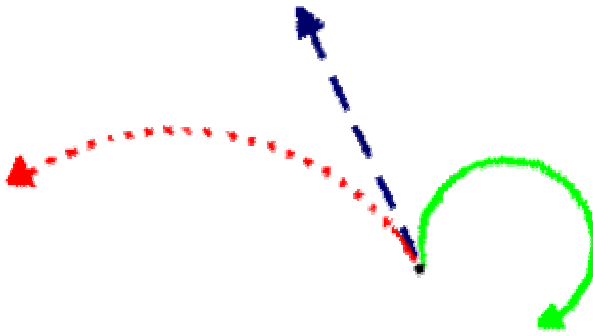
In some cases, part of the electrons of an atom is not any more bounded to the atom. These "free" electrons become sensitive to the influence of a magnetic field, as well as the remainder of the atom ("ionized" by the (partial) loss of its electrons). It is the case in a copper wire where 3% of the electrons are free (conductivity electrons). When the wire is moving near a magnet, the magnetic force tends to move the free electrons, which creates an electric current: it is the dynamo concept.

A similar situation arises in the upper layers of the atmosphere (the ionosphere) where, due to the Sun's UV and X radiations, most of atmospheric atoms and molecules are partially ionised, and where the Earth's magnetic field induces electrical currents. These electrical currents generate themselves a magnetic field (such as the current in the coil of a speaker), disturbing the Earth's magnetic field.

To be more precise, the magnetic force being exerted on a charged particle is proportional to the charge and the speed of the particle, and acts in a direction perpendicular to both the directions of the magnetic field and particle speed.



The action of this magnetic force is illustrated in the figure for a simple case where the magnetic field is static, uniform and perpendicular to the screen. The dashed line represents the trajectory of an electron when no field is present. When the magnetic field is active, the electron trajectory curves to follow the solid circle. The circle radius depends on the initial speed of the electron and the field intensity.



The dotted curve represents the trajectory of a proton with the same initial speed. Like the electron, the proton follows a circle but of larger radius and in the opposite direction. This is due to:

- the proton charged, the sign of which is opposed to the electron one ;
- the mass of the proton which is 2000 times larger.

This feature of the magnetic field is, for instance, applied in laboratory to confine protons and ions inside a cyclotron in order to accelerate them.

Some orders of magnitude:

The mass of a proton is $1.7 \cdot 10^{-27}$ kg (i.e. zero, dot, 21 zeros, one and seven milligrams!)

In a cyclotron with an extraction radius of one meter and a magnetic field of 1.5T, a proton can be accelerated up to an energy of 110MeV, which corresponds at a speed of 145000 km/s.

In the ambient magnetic field in Brussels (approximate value: 48000nT), a proton moving at 100 km/s (i.e. energy of 5eV) has a radius of gyration of 22m. In a magnetic field twice less intense, such as it exists at an altitude of about 800km, the same proton has a radius of gyration of 43m. An electron of the same speed has an energy of 0.03eV and a radius of gyration of 2.5 cm.

Protons as energetic as those produced in a cyclotron exist at an altitude of 800 km: a 110-MeV proton has there a radius of gyration of 60 km!

