Magnetic forces and magnetic fields

Chapter 5

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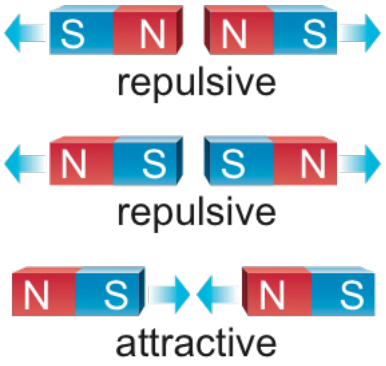
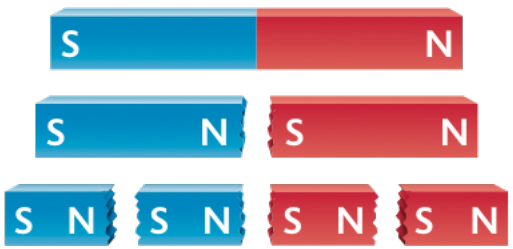
magnets and magnetic fields

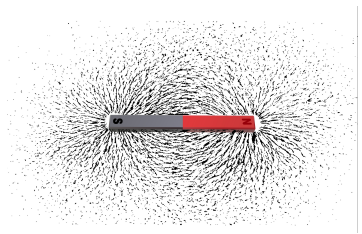
Magnets have two poles called north and south.
Like poles repel and unlike poles attract.
Materials with magnetic properties exist in nature, such as magnetite.
Magnets can also be manufactured

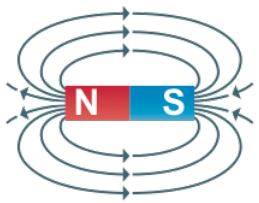


Cutting a magnet in half does not result in a north pole and a south pole, but the creation of two smaller magnets.



Magnetic fields can be visualised using magnetic field lines, which are always closed loops. By convention, they exit from the north pole and enter at the south pole.

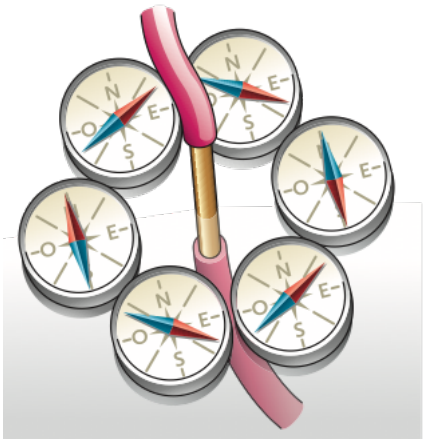


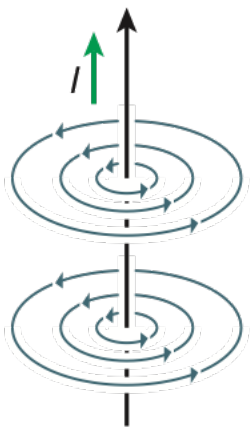


electric currents produce magnetic fields

Experiment shows that an electric current produces a magnetic field.

A compass needle is deflected when placed near a current-carrying wire as it is in the presence of a magnetic field.
The needle aligns with the magnetic field lines.





The direction of the magnetic field lines is given by the right-hand grip rule: when the thumb points in the direction of the conventional current, the fingers wrapped around the wire point in the direction of the magnetic field.
The magnetic field is given by:

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

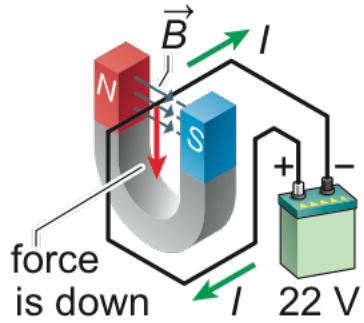
where μ_0 is the permeability of free space and r is the radial distance from the wire.

force on an electric current in a magnetic field

A magnet exerts a force on a current-carrying wire.

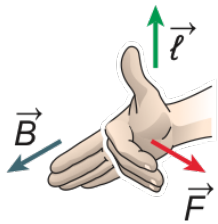
The force F on the wire depends on the current I,
the length ℓ of the wire,
the magnetic field B:

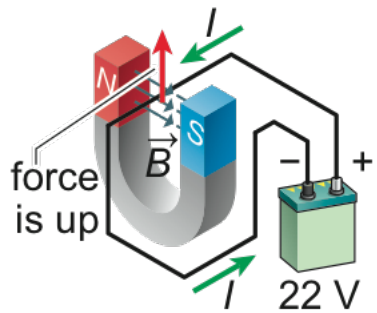
$$F = I\ell B \sin(\theta)$$



The direction of the force is given by the right-hand rule.
Its orientation is perpendicular both to $\vec{I}$ and to $\vec{B}$:

$$\vec{F} = I\,\vec{\ell} \times \vec{B}$$





The unit of B is the tesla, T: 1 T = 1 N/(A · m).
Another unit commonly used for B is the gauss (G): 1 G = 10^{-4} T.

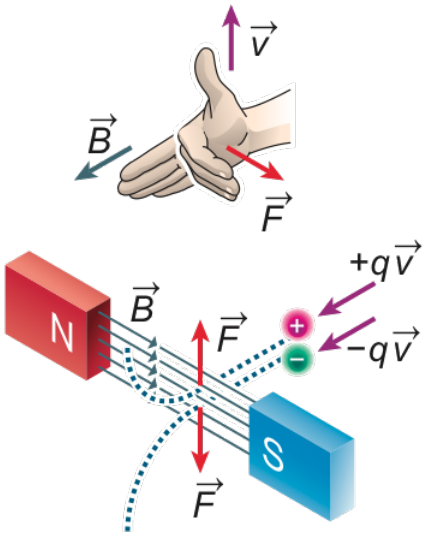
force on a moving electric charge in a magnetic field

The force on a moving charge, the Lorentz force,is related to the force on a current:

$$\vec{F} = q\vec{v} \times \vec{B}$$

where $\vec{F}$ is the magnetic force, q is the charge, $\vec{v}$ is the velocity of the moving charge, and $\vec{B}$ is the magnetic field.

The force on a charged particle due to a magnetic field is perpendicular to the direction of the magnetic field.



Problem

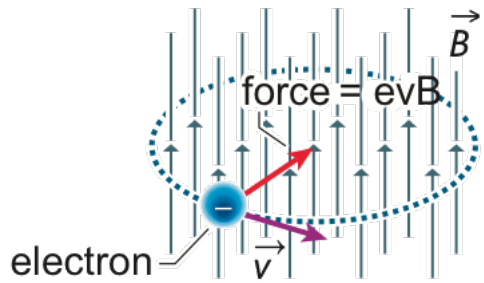
A negative charge $-q$ is placed at rest near a magnet. Will the charge begin to move? Will it feel a force? What if the charge were positive, $+q$?

Solution: There is no force as the charge is not in motion, be it either positiveor negative, so in neither case will it be subject to a force.

the path of an electron in a uniform magnetic field

An electron, with a velocity of 2.0×10^7 m/s, travels in a plane perpendicular to a uniform magnetic field with a magnitude of 0.01 T.

The magnetic force keeps the particle moving in a circle. Let's calculate the radius and the frequencyelectronof the rotational movement.



The particle is subject to the centripetal force, i.e. the Lorentz force. By applying the second law of dynamics:

$$qvB = \frac{mv^2}{r}$$

The radius is then given by:

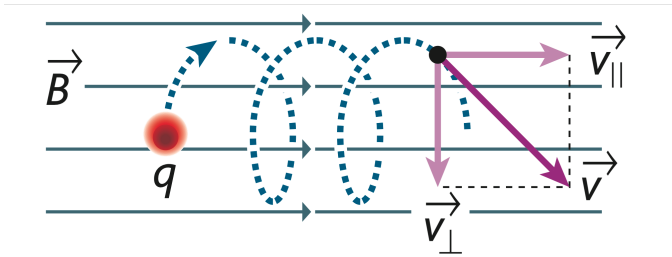
$$r = \frac{mv}{qB} = \frac{\left(9.1 \times 10^{-31}\,\text{kg}\right) \times \left(2.0 \times 10^{7}\,\text{m/s}\right)}{\left(1.6 \times 10^{-19}\,\text{C}\right) \times \left(0.010\,\text{T}\right)} = 1.1 \times 10^{-2}\,\text{m} = 1.1\,\text{cm}$$

and the frequency by:

$$f = \frac{1}{T} = \frac{v}{2\pi r} = \frac{qB}{2\pi m} = \frac{\left(1.6 \times 10^{-19}\,\text{C}\right) \times \left(0.010\,\text{T}\right)}{2 \times 3.1415 \times \left(9.1 \times 10^{-19}\,\text{kg}\right)} = 0.28 \times 10^{9}\,\text{Hz}$$

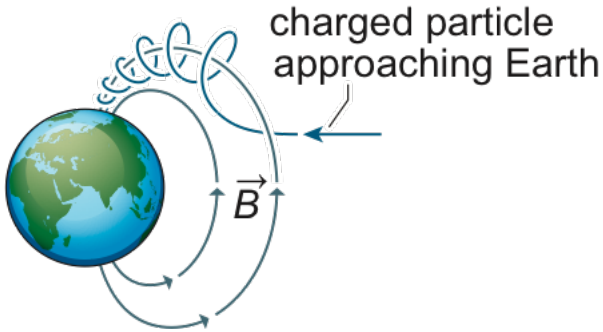
force on a moving electric charge in a magnetic field

What is the path of a charged particle in a uniform magnetic field if its velocity is not perpendicular to the magnetic field?



The path describes a helix – the component of velocity parallel to the magnetic field does not change, whilst the component of velocity in the plane perpendicular to the field describes a circle.

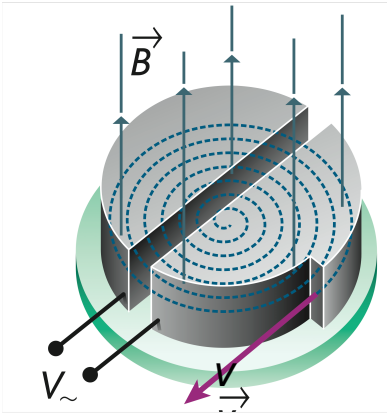
The northern lights (**aurora borealis**) are caused by charged particles from the solar wind spiraling along the Earth's magnetic field, and colliding with air molecules.



cyclotron

A **cyclotron** is a particle accelerator in which, due to the combination of a magnetic field and an electric field, a charged particle is accelerated from the centre to the outside along a spiral path.

The rapidly varying electric field accelerates the charged particle.
The magnetic field, perpendicular to the trajectory, keeps the particle on a spiral path.
With each cycle, the electric field increase the energy of the particle, and consequently its velocity.
This leads to an increase in the radius of the circular path of the particle due to the Lorentz force.



Frequency of a particle accelerated by a cyclotron:

$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

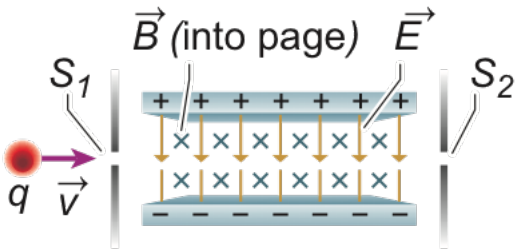
The energy of a particle accelerated by a cyclotron is a function of radius *r*:

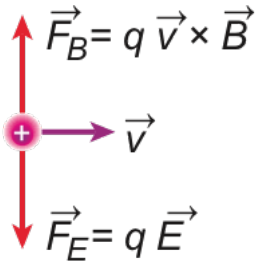
$$E = \frac{r^2 q^2 B^2}{2m}$$

The maximum energy is achieved when the path ofthe particle follows the perimeter of the cyclotron.

mass spectrometer

A velocity selector



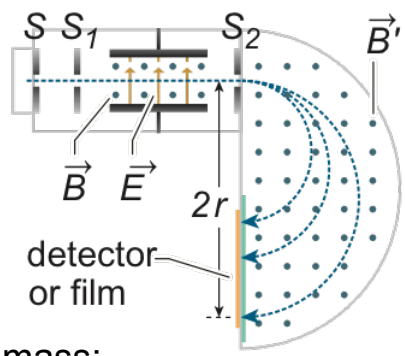


Only particles whose velocities are such that the magnetic and electric forces balance each other will pass through both slits:

$$qE = qvB \quad \rightarrow \quad v = \frac{E}{B}$$

Using a mass spectrometer, it is possible to measure the masses of atoms. If a charged particle is allowed to move through a velocity selector, there is a particular speed at which it will pass straight ahead (i.e. without any deflection), allowing its mass to be measured by a second magnetic field *B*'.

All atoms reaching the second magnetic field *B*' have the same speed.
The radius of curvature of deflection of a particle depends on its mass:

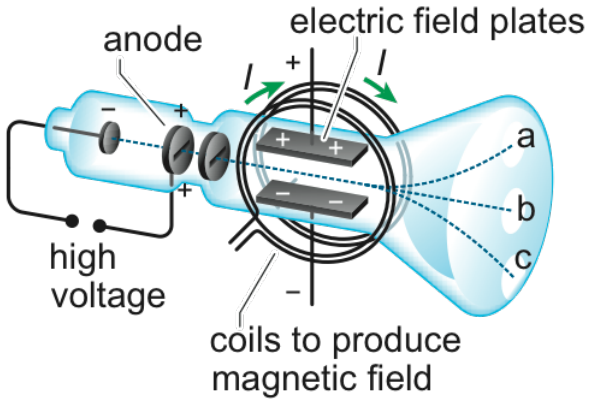


$$m = \frac{qB'r}{v} = \frac{qBB'r}{E}$$

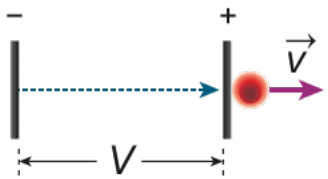
an application of electric and magnetic fields

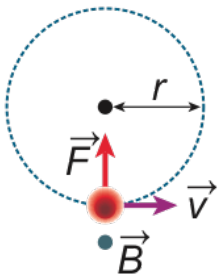
The discovery of the electron and its properties

Electrons were first observed during studies using cathode ray tubes. These tubes contain a very small amount of gas and have a high cathode voltage. It was observed that something – named "cathode rays" at the time – appeared to travelvoltage from the cathode to the anode.



In 1897, Thomson used an apparatus, which made use of electric and magnetic fields, to measure the value of *e/m* (charge/mass) for cathode rays.





The currently accepted values of the electron mass and charge are:

$m = 9.1 \times 10^{-31}$ kg
$e = 1.6 \times 10^{-19}$ C

$$E_{kin} = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2eV}{m}}$$

$$\frac{e}{m} = \frac{v}{Br} \Rightarrow \frac{e}{m} = \frac{2V}{B^2 r^2}$$

learning the basics

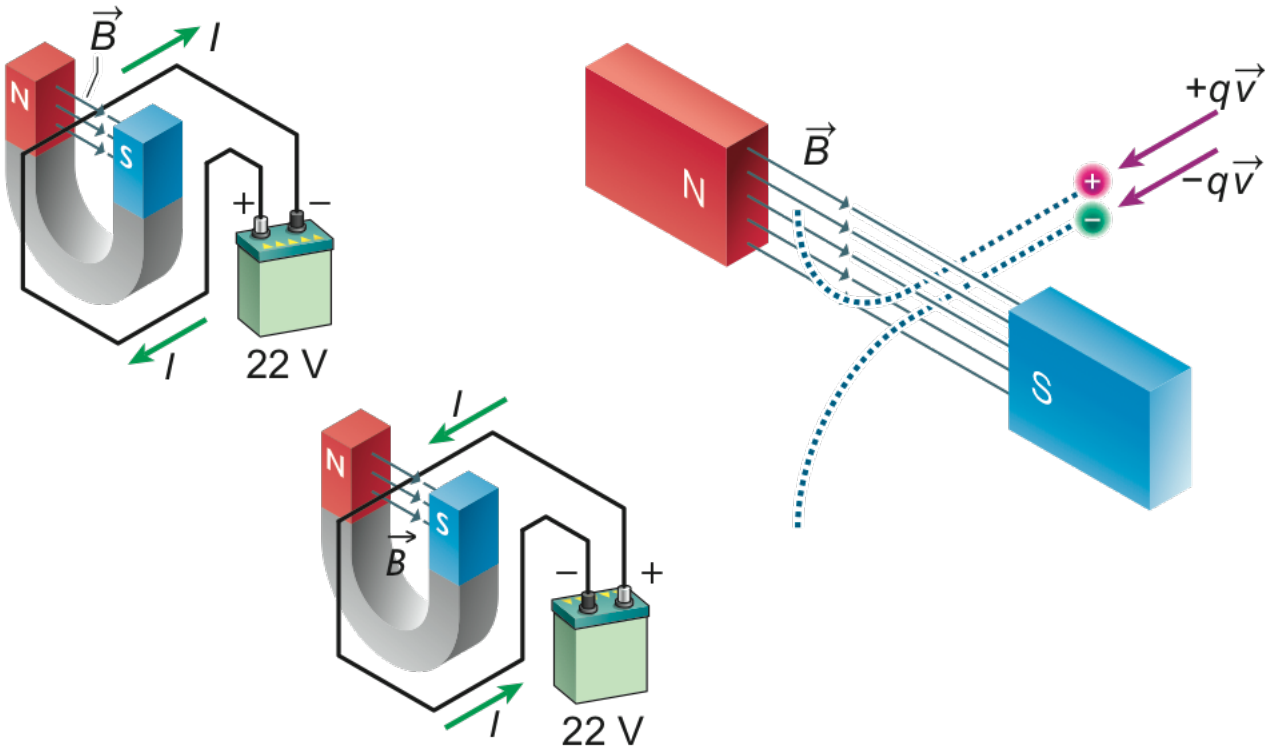
1. It is possible to isolate a magnetic pole. T F

2. If a particle with a velocity v passes through a uniform magnetic field, a force will act on it causing its deflection and its ultimate path will be circular. T F

3. If a current-carrying wire is placed in a uniform magnetic field, a force will act on it that is inversely proportional to the length of the wire. T F

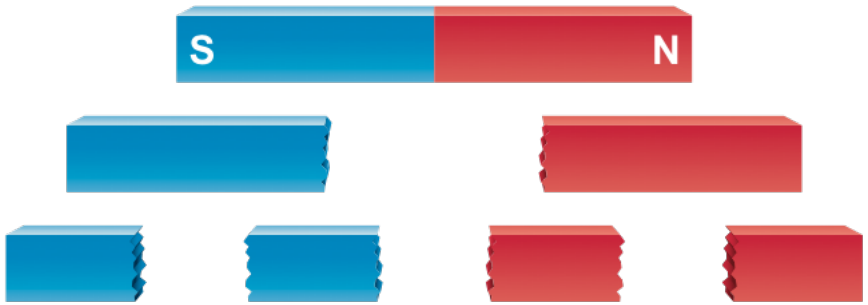
applying the concepts

1. Draw the directions of the forces acting on the wires and on the particles.



applying the concepts

2. Write on the edge of each magnet which pole is present.



3. Draw the direction of the force and indicate if the force is repulsive or attractive.