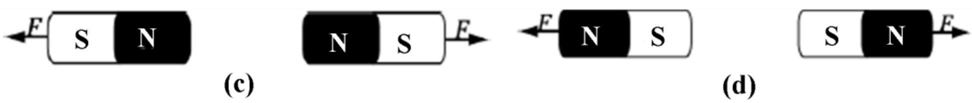
Chapter 1 Moving Charge in Magnetic Field

Day – 1

Introduction

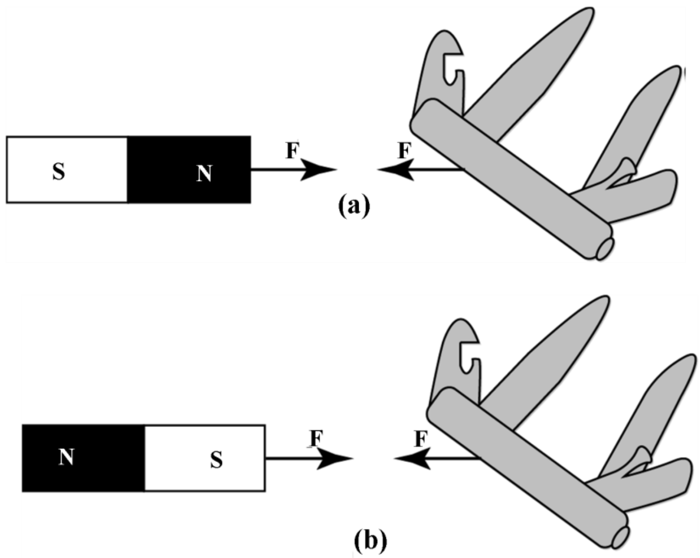
Two bar magnets attract when opposite poles (*N* and *S*, or and *N*) *are next to each other*



The bar magnets repel when like poles (*N and N, or S and S) are next to each other,*

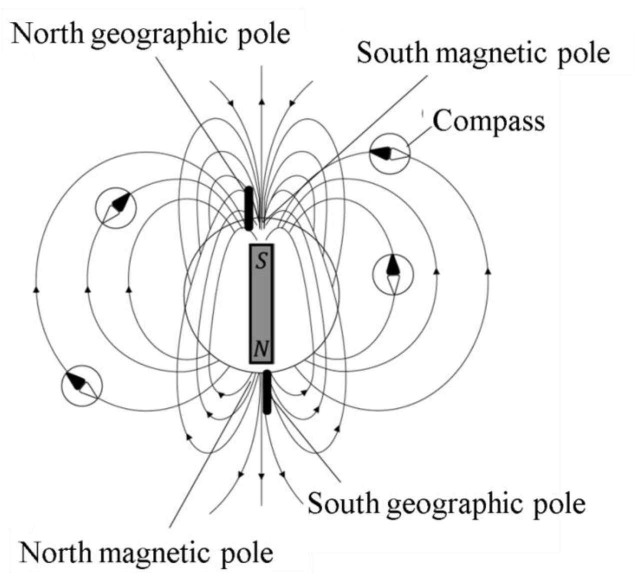
Magnetic phenomena were first observed at least 2500 years ago in fragments of magnetized iron ore found near the ancient city of Magnesia (now Manias, is western Turkey). These fragments were examples of what are now called permanent magnets

Before the relation of magnetic interactions to moving charges was understood, the interactions of permanent magnets and compass needles were described in terms of magnetic poles. If a bar-shaped permanent magnet, or bar magnet, is free to rotate, one end points north. This end is called a north pole or N-pole; the other end is a south pole or S-pole. Opposite pole attract each other, and like poles repel each other. An object that contains iron but is not itself magnetized (that is, it shows no tendency to point north or south) is attracted by either pole of a permanent magnet. The earth itself is a magnet. Its north geographical pole is close to a magnetic south pole, which is why the north pole of a compass needle points north. The earth's magnetic axis is not quite parallel to its geographical axis (the axis of rotation), so a compass reading deviates somewhat from geographic north. This deviation, which varies with location, is called magnetic declination or magnetic variation. Also, the magnetic field is not horizontal at most points on the earth's surface; its angle up or down is called magnetic inclination. At the magnetic poles the magnetic field is vertical

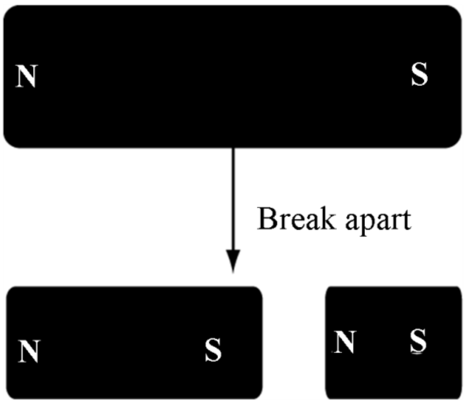


(a) , (b) Either pole of a bar magnet attracts an unmagnetized object that contains iron.

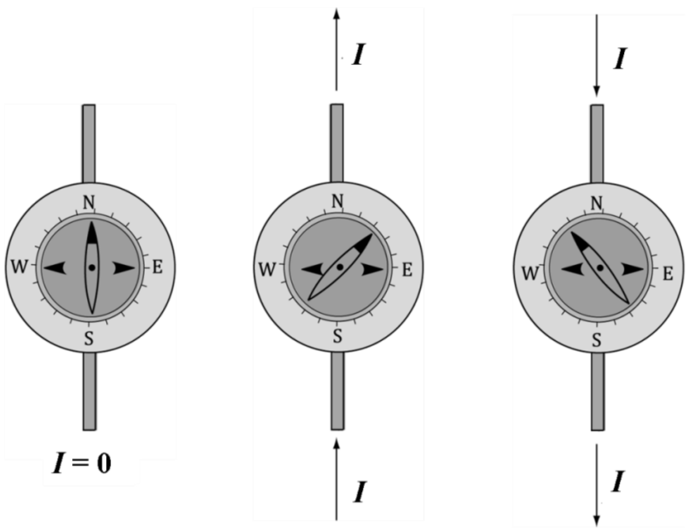
The concept of magnetic poles may appear similar to that of electric charge, and north and south poles may seem analogous to positive and negative charge. But the analogy can be misleading. While isolated positive and negative charges exist, there is no experimental evidence that a single isolated magnetic pole exists; poles always appear in pairs. If a bar magnet is broken in two, each broken end becomes a pole. The existence of an isolated magnetic pole, or magnetic monopole, would have a sweeping implication for theoretical physics. Extensive searches for magnetic monopoles have been carried out, but so far without success



A compass placed at any location in the earth's magnetic field points in the direction of the field line at that location. Representing the earth's field as that of a tilted bar magnet is only a crude approximation of its fairly complex configuration. The field, which is caused by currents in the earth's molten core, changes with time; geologic evidence shows that it reverses direction entirely at irregular intervals of about a half million years.



Breaking a bar magnet. Each piece has a north and south pole, even if the pieces are different sizes. (The smaller the piece, the weaker its magnetism)



(a)
No current in wire: needle points north

(b)
Current flows north: needle swings to the east

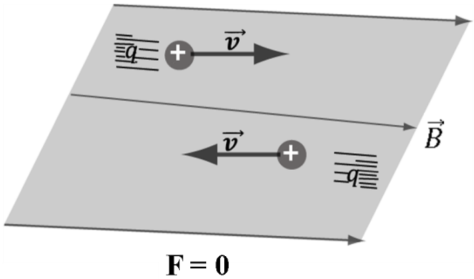
(c)
Current flows south: needle swings to the west

In Oersted's experiment, a compass is placed directly over a horizontal wire (hire viewed from above). When the compass is placed directly under the wire, the compass swings are reversed.

Magnetic Field

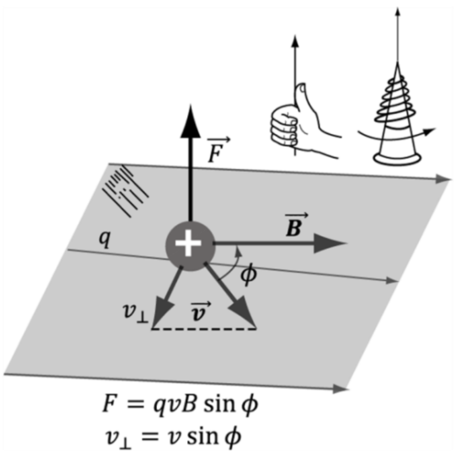
1- A moving charge or a current creates a magnetic field in the surrounding space (in addition to its electric field)

2- The magnetic field exerts a force $\vec{F}$ on any other moving charge or current that is present in the field



(a) *Velocity* $\vec{v}$ *parallel or antiparallel to magnetic field* $\vec{B}$ *magnetic force is zero*

Like electric field, magnetic field is a vector field-that is, a vector quantity associated with each point in space. We will use the symbol $\vec{B}$ for magnetic field. At any position the direction of $\vec{B}$ is defined as that in which the north pole of a compass needle tends to point. The arrows in suggest the direction of the earth's magnetic field; for any magnet, $\vec{B}$ points out of its north pole and into its south pole.



(b) $\vec{v}$ *at an angle* ϕ *to* $\vec{B}$ *magnetic force has magnitude* $F = qvB \sin\theta$

The direction of $\vec{F}$ is always perpendicular to the plane containing $\vec{v}$ and $\vec{B}$. Its magnitude is given by

$$F = |q|v_{\perp}B = |q|vB \sin\theta$$

Where $|q|$ is the magnitude of the charge and ϕ is the angle measured from the direction of $\vec{v}$ to the direction of $\vec{B}$, as shown in the figure

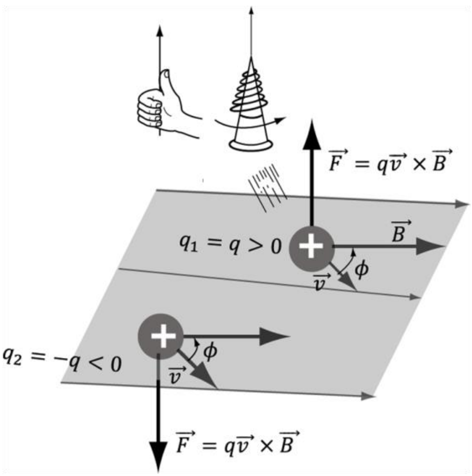
$$\vec{F} = q\vec{v} \times \vec{B}$$

(*magnetic force on a moving charged particle*)

The units of B must be the same as the units of F/qv. Therefore the SI unit of B is equivalent to 1N.s/C.m, or, since one ampere is one coulomb per second (1*A* = 1*C/s*), 1*N/A*, m. This unit is called the tesla (abbreviated T), in honor of Nikola Tesla (1857-1943), the prominent Serbian-American scientist and inventor

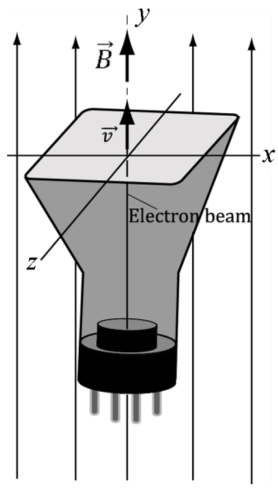
$$1\ tesla = 1T = 1N/A, m$$

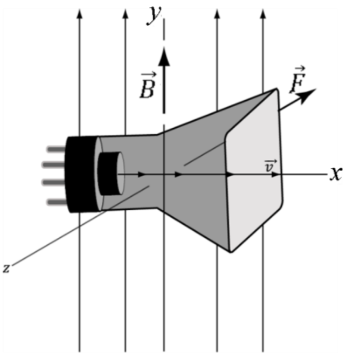
Another unit of B, the gauss ($1G = 10^{-4}T$) is also in common use. Instruments for measuring magnetic field are sometimes called gauss meters



Two charges of the same magnitude but opposite sign moving with the same velocity in the same magnetic field. The magnetic forces on the charges are equal in magnitude but opposite in direction.

The magnetic field of the earth is of the order of 10^{-4}T or 1G. Magnetic fields of the order of 10T occur in the interior of atoms and are important in the analysis of atomic spectra. The largest steady magnetic field that can be produced at present in the laboratory is about 45 T. Some pulsed –current electromagnets can produce fields of the order of 120 T for short time intervals of the order of a millisecond. The magnetic field at the surface of a neutron star is believed to be of the order of $10^8 T$.





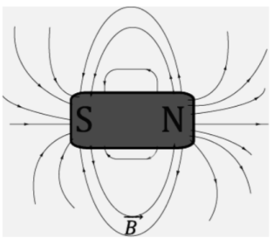
(a) if tube axis is parallel to the y–axis, beam is un deflected; hence $\vec{B}$ is in either + y or –y direction

(b) if tube axis is parallel to the x-axis, beam is deflected in –z direction; hence $\vec{B}$ is in +

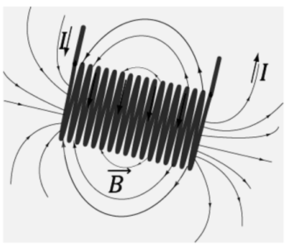
Determining the direction of a magnetic field using a cathode – *ray* tube. Because electrons have a negative charge, the magnetic force $\vec{F} = q\vec{v} \times \vec{B}$ in part (b) points in the direction opposite to the rule

Magnetic Field Lines and Magnetic Flux Caution

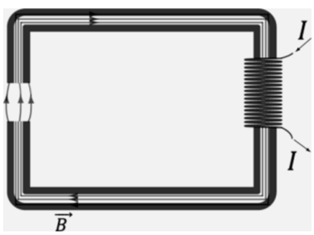
Magnetic field lines are sometimes called "magnetic lines of force," but that's not a good name for them; unlike electric field lines, they do not point in the direction of the force on a charge. Equation shows that the force on a moving charged particle is always perpendicular to the magnetic field, and hence to the magnetic field line that passes through the particle's position. The direction of the force depends on the particle's velocity and the sign of its charge, so just looking at magnetic field lines cannot in itself tell you the direction of the force on an arbitrary moving charged particle. Magnetic field lines do have the direction that a compass needle would point at each location; this may help you to visualize them,



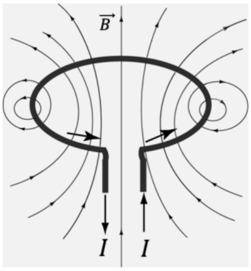
(a) Magnetic field lines through the center of a permanent magnet



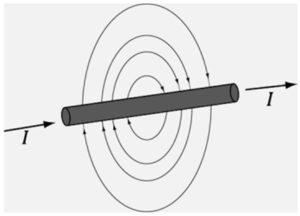
(b) Magnetic field lines through the center of cylindrical current-carrying coil



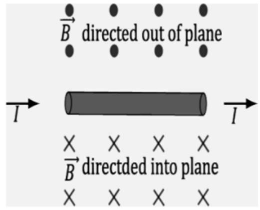
(c) Magnetic field lines through the center of an iron-core electromagnet



(d) Magnetic field lines in a plan containing the axis of a circular current-carrying loop



(e) Magnetic field lines in a plane perpendicular to a long, straight, current-carrying wire



(f) Magnetic field lines in a plane containing a long, straight, current-carrying wire

Illustration

A charged particle is projected in a magnetic field $\vec{B} = 3\hat{\imath} + 4\hat{\jmath} \times 10^{-2}T$. The acceleration of the particle is found to be $\vec{a} = (x\hat{\imath} + 2\hat{\jmath})m/s^2$. Find the value of *x*

Solution

$$\overrightarrow{F_m} \perp \vec{B}$$
$$\vec{a} \perp \vec{B}$$
$$\vec{a}.\vec{B} = 0$$
$$x = -\frac{8}{3}$$

Illustration

An electron travels a circular path of radius 20 cm in a magnetic field of $2 \times 10^{-3}T$. Find its speed, and the p. d. through which the electron should be accelerated to acquire this speed.
$(e = 1.6 \times 10^{-19}C,\ m = 9.1 \times 10^{-31}Kg)$

Solution

The magnetic force evB on the electron acts as the centripetal force mv^2/r. That is,

$$evB = mv^2/r$$
$$\therefore v = \frac{eBr}{m}$$
$$\Rightarrow \frac{(1.6\times10^{-19}C) \times (2\times10^{-3}T) \times (0.20m)}{9.1\times10^{-31}Kg}$$
$$\Rightarrow 7.0 \times 10^7\ ms^{-1}$$

If V be the p.d. to give a speed *v* to an electron, then

$$eV = \frac{1}{2}\ mv^2$$
$$V = \frac{mv^2}{2e}$$
$$\Rightarrow \frac{(9.1\times10^{-31}Kg)\times(7.0\times10^7 ms^{-1})^2}{2\times(1.6\times10^{-19}C)} \Rightarrow 13.9 \times 10^3 V = 14kV$$

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