AP Physics 2: Magnetism Reference Sheet

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December 31, 2018

Magnets and Magnetic Fields

Any magnet, whether it is in the shape of a bar or ahorse-shoe, has two ends or faces, called **poles**, which is where the magnetic effectis strongest. The pole of a freely-suspended magnet that points toward geographic north is called the **north pole** of the magnet. The other pole points toward the south and is called the **south pole**.

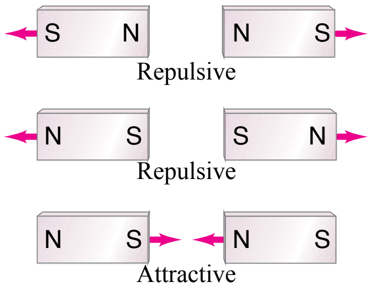


Figure 1: Like poles of twomagnets repel; unlike poles attract.

Physicists have searched for isolated single magnetic poles (monopoles), but no **magnetic monopole** has ever been observed. Besides iron, a few other materials, such as cobalt, nickel, gadolinium, andsome of their oxides and alloys, show strong magnetic effects. They are said to be **ferromagnetic** (from the Latin word ferrumfor iron). We can picture a **magnetic field** surrounding a magnet. Just as we drew electric field lines, we can also draw **magnetic field lines**, so that

1. the direction of the magnetic field is tangent to a field line at any point, and
2. the number of lines per unit area is proportional to the strength of the magnetic field.

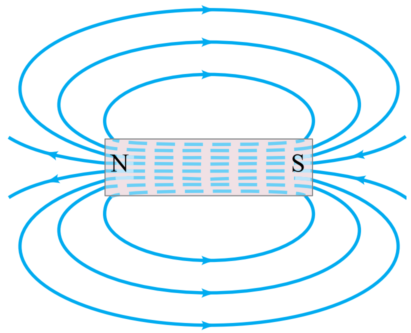


Figure 2: Diagram ofmagnetic field lines for a bar magnet.

Earth's Magnetic Field

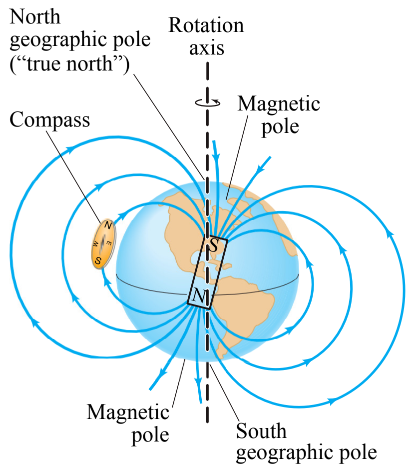


Figure 3: The Earth acts like a huge magnet. But its magnetic poles are not at the geographic poles (on the Earth's rotation axis).

Uniform Magnetic Field

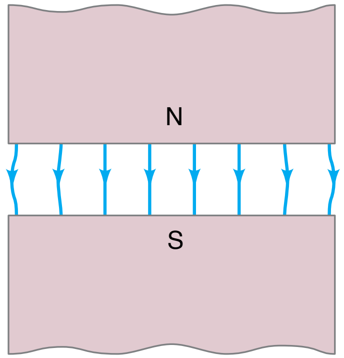


Figure 4: Magnetic field between two wide poles of a magnet is nearly uniform, except near the edges.

Electric Currents Produce Magnetic Fields

In 1820, Hans Christian Oersted (1777–1851) found that when a compass is placed near a wire, the compass needle deflects if (and only if) the wire carries an electric current, which showed that **an electric current produces a magnetic field**. There is a simple way to remember the direction of the magnetic field lines in this case. It is called a **right-hand rule** (See: Summary of RHRs - 1).

Force on an Electric Currentin a Magnetic Field; Definition of $\vec{\mathbf{B}}$

A magnetic field exerts a force on an electric current. The SI unit for magnetic field is the **tesla** (T). For a straight wire of length l carrying a current I, the force has magnitude

$$F = I\ell B \sin\theta, \tag{1}$$

where θ is the angle between the magnetic field $\vec{\mathbf{B}}$ and the current direction. The direction of the force is perpendicular to the current-carrying wire and to the magnetic field, and is given by another right-hand rule (See: Summary of RHRs - 2). Equation (1) serves as the definition of B magnetic field $\vec{\mathbf{B}}$.

Force on an Electric Charge Moving in a Magnetic Field

Similarly, a magnetic field exerts a force on a charge q moving with velocity v of magnitude

$$F = qvB\sin\theta, \tag{2}$$

where θ is the angle between $\vec{\mathbf{v}}$ and $\vec{\mathbf{B}}$. The direction of $\vec{\mathbf{F}}$ is perpendicular to $\vec{\mathbf{v}}$ and to $\vec{\mathbf{B}}$ (again a right-hand rule; see: Summary of RHRs - 3). The path of a charged particle moving perpendicular to a uniform magnetic field is a circle.

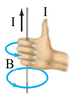
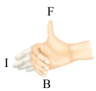
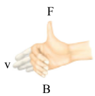
Summary of Right-hand Rules (= RHR)			
Physical Situation	Example	How to Orient Right Hand	Result
1. Magnetic field produced by current (RHR-1)		Wrap fingers around wire with thumb pointing in direction of current I	Fingers curl in direction of B
2. Force on electric current I due to magnetic field (RHR-2)		Fingers first point straight along current I, then bend along magnetic field B	Thumb points in direction of the force F
3. Force on electric charge +q due to magnetic field (RHR-3)		Fingers point along particle's velocity v, then along B	Thumb points in direction of the force F

Figure 5: Summary of RHRs.

Magnetic Field Due to a Long Straight Wire

The magnitude of the magnetic field produced by a current I in a long straight wire, at a distance r from the wire, is

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}. \tag{3}$$

The value of the constant μ_0, which is called the **permeability of free space**, is $\mu_0 = 4\pi \times 10^{-7}\mathrm{T}\cdot\mathrm{m/A}$.

Force between Two Parallel Wires

The force F_2 exerted by B_1 on a length l_2 of wire 2, carrying current I_2 is

$$F_2 = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d}\ell_2 \tag{4}$$

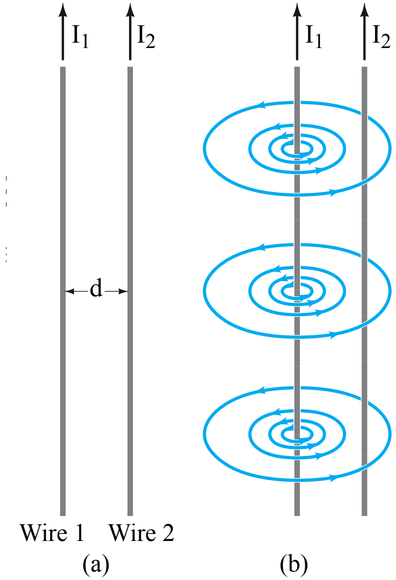


Figure 6: (a) Two parallel conductors carrying currents I_1 and I_2. (b) Magnetic field $\vec{\mathrm{B}}_1$ produced by I_1. (Field produced by I2 is not shown.) $\vec{\mathrm{B}}_1$ points into page at position of I_2.

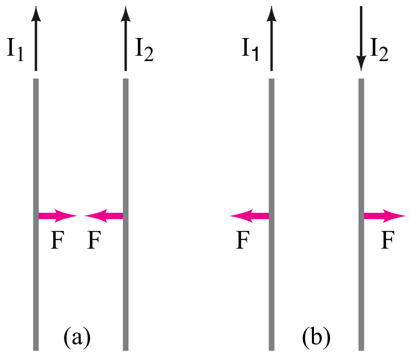


Figure 7: (a) Parallel currents in the same direction exert an attractive force on each other. (b) Antiparallel currents (in opposite directions) exert a repulsive force on each other.

Definition of the Ampere and the Coulomb

We use the force between two parallel current-carrying wires, Eq. (4), to define the ampere precisely. If $I_1 = I_2 = 1\mathrm{A}$ exactly, and the two wires are exactly 1m apart, then

$$\frac{F}{\ell} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{d} = \frac{(4\pi \times 10^{-7}\mathrm{T}\cdot\mathrm{m/A})}{(2\pi)}\frac{(1\mathrm{A})(1\mathrm{A})}{(1\mathrm{m})} = 2{\times}10^{-7}\mathrm{N/m}.$$

Thus, *one* **ampere** *is defined as that current flowing in each of two long parallel wires, 1m apart, which results in a force of exactly* $2 \times 10^{-7}N$ *per meter of length of each wire.* This is the precise definition of the ampere, and because it is readily reproducible, is called an **operational definition**. The **coulomb** is defined in terms of the ampere as being exactly one ampere-second: $1\mathrm{C} = 1\mathrm{A}\cdot\mathrm{s}$.

Solenoids and Electromagnets

Ampère's Law

Torque on a Current Loop; Magnetic Moment

Applications: Motors, Loudspeakers, Galvanometers