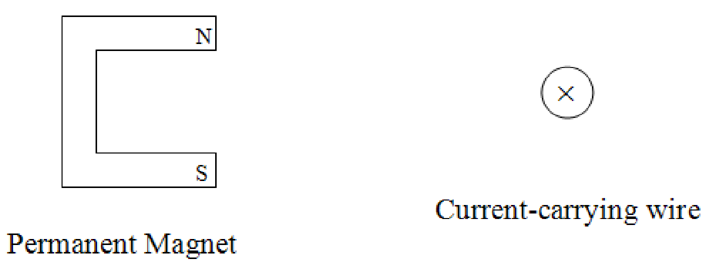
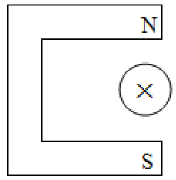
Lesson 3
Forces on Moving Charges

Michael Faraday found that an external magnetic field exerts a force on a current carrying wire. His discovery was known as the motor principle.

Motor Principle:
The force exerted on a current-carrying wire in the presence of an external magnetic field is perpendicular to both the direction of the current and the direction of the magnetic field lines.

Consider:





When we place the wire into the magnetic field of the horseshoe magnet, note that on the left side the magnetic fields reinforce one another while on the right side they cancel. Therefore the wire experiences a greater force on the left and is pushed to the right out of the magnet. The force is perpendicular to both the permanent magnetic field lines and to the current.

Left Hand Rule for Motor Principle:

Thumb = current direction

Fingers point in the direction of the permanent magnetic field lines.

Palm of hand faces in the direction of the force on the wire.

The electric motor is based on this principle.

Like electrostatic and gravitational fields, a magnetic field has a field strength B. The magnetic force F is at a maximum when the conductor is perpendicular to the external magnetic field and zero when it is parallel to the external magnetic field.

$$F = BIL\sin\theta$$

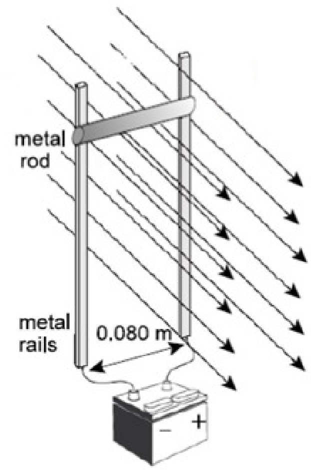
Where:

θ = the angle between the wire and the magnetic field
F = magnetic force (N)
B = magnetic field strength (Tesla, T). Note that $1T = 1\frac{N}{A \cdot m}$.
I = current (A)
L = length of the wire (m)

Example:
A wire carrying a 30.0 A current has a length of 12 cm between the pole faces of a magnet at an angle of 60.0°. The magnetic field is approximately uniform at 0.90 T. What is the force on the wire?

Example:

A 0.16 kg metal rod is placed in a horizontal magnetic field of 0.75 T and maintains contact with two vertical metal rails that are separated by a distance of 0.080 m. Calculate the current that must flow through the rod in order for it to remain at rest.



Biot's Law:

We have already studied that magnetic fields are created around current-carrying wires. What affects the strength of the magnetic field around a conductor? As with the electric and gravitational fields, the strength of the magnetic field around a conductor varies inversely as the distance r from the source. Field strength is also affected by magnetic permeability (μ), current and length of the segment. This relationship is expressed in a simplified form of Biot's Law.

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

Where,

B = magnetic field strength (T)

μ_o = magnetic permeability ($\frac{T \cdot m}{A}$)

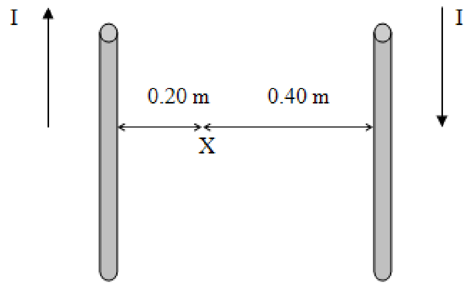
I = current (A)

r = perpendicular distance away from the conductor (m)

Note that for a conductor in air, the value of μ_o (the permeability of free space) is $4\pi \times 10^{-7} \frac{T \cdot m}{A}$.

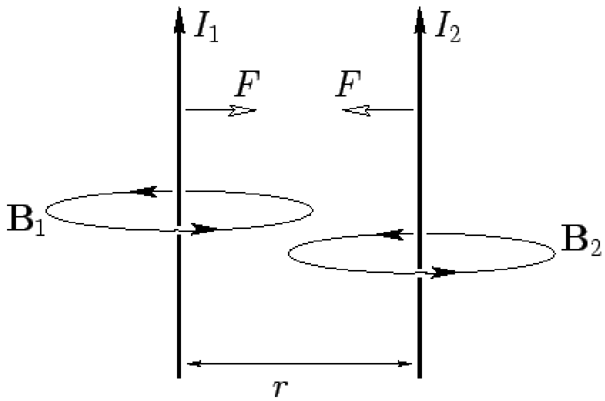
Example:
A vertical electric wire in the wall of a building carries a current of 25 A upward. What is the magnetic field at a point 10.0 cm away from the wire?

Example:
What is the net magnetic field at X in the diagram shown?



Operational Definition of an Ampere:

Recall that 1 A = 1 C/s. This definition is impractical because it is difficult to obtain a given amount of charge precisely. The accepted definition of an ampere is actually based on the magnetic field created by current flowing in two straight parallel conductors. The force experienced by one conductor depends on the magnetic field B created by the other conductor.



For these parallel conductors:

$$F = \frac{\mu_o I^2 L}{2\pi r}$$

Where,

L = length of the conductor (m)
μ_o = magnetic permeability ($\frac{T \cdot m}{A}$) = $4\pi \times 10^{-7} \frac{T \cdot m}{A}$
I = current (A)
r = distance between two conductors (m)

If we work this out for I = 1 A, L = 1 m, and r = 1 then we see that,

$$F = \frac{\mu_o I^2 L}{2\pi r}$$

$$F = \frac{(4\pi \times 10^{-7} \frac{T \cdot m}{A})(1A)^2(1m)}{2\pi(1m)}$$

$$F = 2 \times 10^{-7} \frac{N}{m}$$

One ampere is the magnitude of the current which, when flowing in each of two long parallel wires one meter apart, results in a force between the wires of exactly 2×10^{-7} N per meter of length.

Example:
Two wires of a 2.0 m long appliance cord are 3.0 mm apart and carry a current of 8.0 A. Calculate the force between these wires.