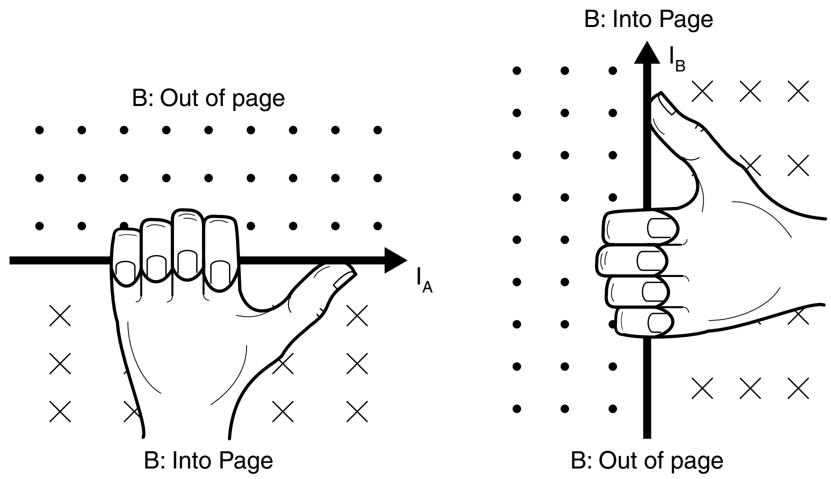


Adding fields produces the resultant field:

$$\mathbf{B_{TOT}} = 9.3 \times 10^{-6}\ \text{T} - 3.6 \times 10^{-6}\ \text{T} = \mathbf{5.7 \times 10^{-6}\ T\ into\ the\ page.}$$

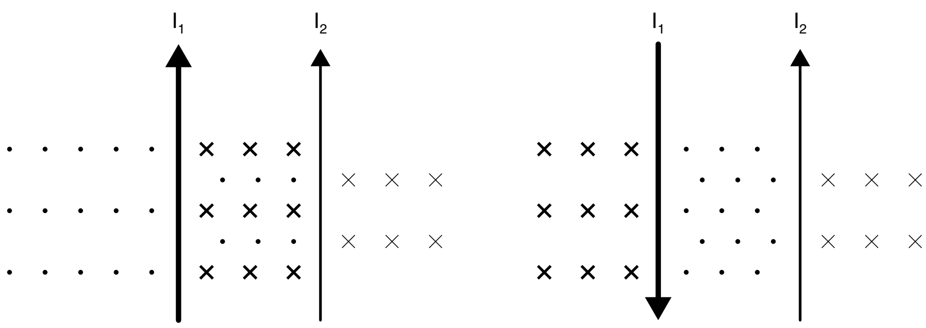
(into page) (out of page)

Current-Carrying Wires in Magnetic Fields

In the event that two current-carrying wires are parallel and are in close proximity, the effects of the magnetic fields of each on one another are either attractive or repulsive. The current in the wire generates a magnetic field around it as indicated by the right hand model.

For two parallel wires whose currents are in the **same direction**: where the fingers curl around the first wire and intersect the fingers of a hand around the second, **parallel** current, the magnetic fields interlock and **attract** each other.

For two parallel wires whose currents are in **opposite directions:** where the fingers curl around each wire and intersect the fingers of a hand around the second, **antiparallel** current, the magnetic fields push against and **repel** one other.



B_1 opposite B_2
PARALLEL CURRENTS'
WIRES ATTRACT.

B_1 aligned with B_2
ANTIPARALLEL CURRENTS'
WIRES REPEL.

The force between two parallel, current-carrying wires is given as

$$\mathbf{F} = \frac{\mu_0 I_1 I_2 l}{2\pi r}$$

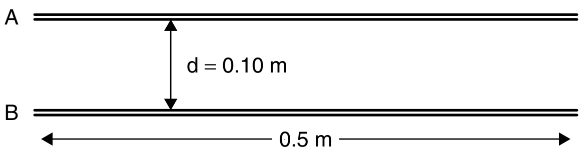
where μ_o is the permeability of free space, I_1 and I_2 are the currents in the two parallel wires, l is the length of the wires, and r is the distance between the wires.

Example

Two long, parallel current-carrying wires are separated by 10.0 cm as shown in the following illustration. Wire A carries a current of 1.0 A, wire B carries a current of 2.0 A, and each is 0.5 m long. Determine the resultant force on each wire if the currents are

(a) parallel

(b) antiparallel (opposite)



Solution

(a) Using $\mathbf{F_B} = \dfrac{\mu_0 I_1 I_2 l}{2\pi r}$,

$$\mathbf{F}_{PAR} = \frac{(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A})(1.0\ \mathrm{A})(2.0\ \mathrm{A})(0.5\ \mathrm{m})}{(2\pi)(0.10\ \mathrm{m})}$$

$$= \mathbf{2.0 \times 10^{-6}\ N\ ATTRACTING}$$

(b) By Newton's Third Law, the force would be the same but in the opposite direction:

$$\mathbf{F}_{ANTIPAR} = \mathbf{2.0 \times 10^{-6}\ N\ REPELLING}$$

Ampere's Law (C Exam)

To explain the reason for the attraction or repulsion of parallel current-carrying wires, it is necessary to examine the magnetic fields outside of wires and the resultant forces that arise on and from charges moving inside those wires.

One explanation arises from the fact that **F = qv X B.** The current flowing through either wire is immersed in the magnetic field of the opposite wire. The right hand, with fingers pointed in the direction of current flow, crossed into the external magnetic field, yields a force perpendicular to both. In the case of the parallel currents, the force is inward, toward the other current. In the case of antiparallel currents, the force is outward, away from the other current.

Ampere's Law for such wires also helps explain this phenomenon:

$$\oint \mathbf{B} \cdot \mathbf{dl} = \mu_0 I$$

where **B** is the magnetic field in T, **dl** is a small length of wire in a closed loop (hence the closed integral sign), μ_O is the permeability of free space or vacuum, and I is the net current enclosed in the loop. It essentially says that adding up all the parts of the magnetic field (in the direction of the magnetic field. . .the dot product) and multiplying those parts times each small length of wire (**dl**) equals the permeability of free space times the *net current* (the sum of all currents) in the loop. If the wire is made into a loop, the entire length becomes the circumference, or $\oint \mathbf{B}(2\pi r) = \mu_0 I$.

When a wire with the proper orientation is moved through a magnetic field, the electrons in the wire are pushed by the external magnetic field. If the wire is part of a closed path or loop, current will flow through the circuit. The direction of current flow depends on the direction of the field and the direction of motion of the wire.

Electric and magnetic fields vibrate at right angles to each other. To induce an electric current in a wire that moves through a magnetic field, a force must be applied to the wire (via mechanical energy). The wire must then cut the magnetic field lines at a right angle to give the maximum current (resulting in electrical energy).

For any coil, supplying current causes the magnetic field to develop over a small period of time as the current grows. The larger the coil or the greater its resistance, the longer it takes to reach maximum magnetic flux. If the current in the coil changes (usually by turning the current on and off), so does the magnetic field and therefore so does the emf induced in the coil. This is expressed by:

$$\varepsilon = -\frac{L\Delta I}{\Delta t} \text{ or } \varepsilon = -\frac{LdI}{dt}$$

where ε is the induced emf in the coil, **L** is the **inductance** (magnetizing ability) of the coil in **henrys** H, **I** is the current in the coil in Amperes A, and t is magnetizing time in seconds s. Again, the negative sign indicates that the emf induced in the coil opposes the directional change of current flow that induced it.

Finally, there is energy gradually built up in the coil as it magnetizes. That energy is expressed by

$$U_L = \frac{1}{2} LI^2$$

where $\mathbf{U_L}$ is the energy stored in the inductor (or work done by the circuit in storing that energy) in Joules J, **L** is the inductance of the coil in **henrys** H, and **I** is the current in Amperes A.

Inductance acts as "electrical inertia," that is, it produces an opposing voltage to react against the increasing current. For this reason, it is the current that is slow to grow to its final value.

Example

A current of 3.0 A is supplied to a coil of wire having 500 turns. If a flux of 10^{-3} Wb (Weber) through the center of the coil develops in 0.10 sec, determine:

(a) The average emf induced in the coil.

(b) The coil's inductance.

(c) The energy stored in the coil's magnetic field.

Solution

(a) Using $\varepsilon = -\mathbf{N}\frac{\Delta\Phi_B}{\Delta t} = -\mathbf{N}\frac{d\Phi_B}{dt}$,

$$\varepsilon = -\frac{(500\text{ turns})(10^{-3}\text{ Wb})}{(0.10\text{ sec})} = \mathbf{-5.0\ V}$$

(b) Using $\varepsilon = -\frac{L\Delta I}{\Delta t}$ or $\varepsilon = -\frac{LdI}{dt}$,

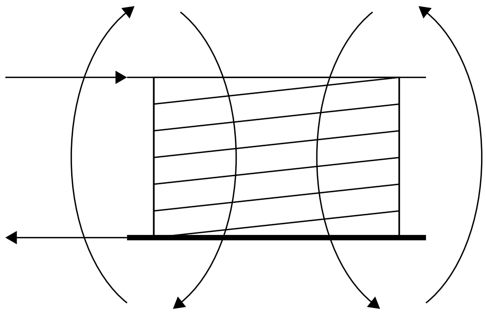
$$L = \frac{-\varepsilon}{\Delta I/\Delta t} = \frac{-\varepsilon}{dI/dt}$$

$$= \frac{-(-5.0\text{ V})}{(3.0\text{ A})/(0.1\text{ sec})} = \mathbf{0.17\ H}\ \ \textbf{ANS}$$

(c) Using $\mathbf{U_L = \frac{1}{2}LI^2}$,

$$U_L = \left(\frac{1}{2}\right)(0.17\text{ H})(3.0\text{ A})^2 = \mathbf{0.77\ J}\ \ \textbf{ANS}$$

3. **(a)**



Pointing the thumb of the right hand in the direction of the current flow, the fingers curl downward, through the coil.

(b) Using $\varepsilon = -\frac{N\Delta\Phi_B}{\Delta t}$ or $\varepsilon = -\frac{Nd\Phi_B}{dt}$

$$\Delta\Phi = -\frac{\varepsilon\Delta t}{N} = -\frac{(-9.0\text{ V})(2.0\text{ sec})}{(50\text{ turns})} = \mathbf{0.36\ Wb}$$

(c) Using $\mathbf{L} = -\frac{\varepsilon}{\Delta I/\Delta t}$,

$$L = \frac{-(-9.0\text{ V})}{(0.5\text{ A})/(2.0\text{ sec})} = \mathbf{36.0\ H\ \ ANS}$$

(d) Using $\mathbf{U_L} = \frac{1}{2}\mathbf{LI^2}$,

$$U_L = \frac{1}{2}(36.0\text{ H})(0.5\text{ A})^2 = \mathbf{4.5\ J\ \ ANS}$$