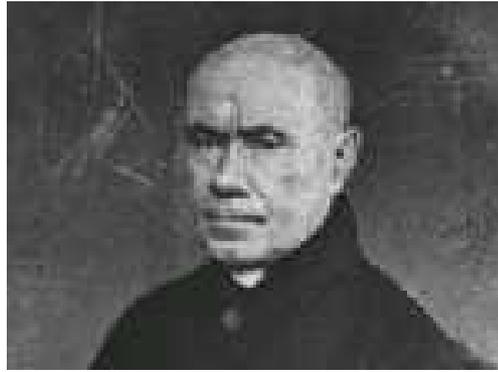


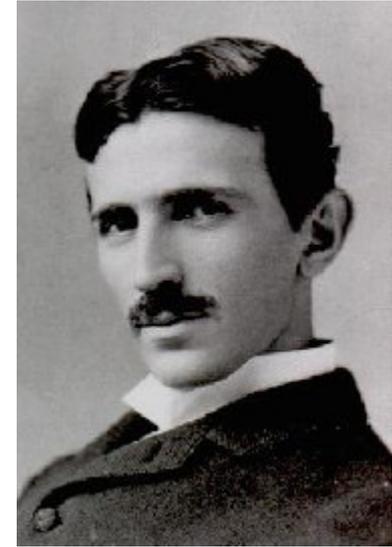
Induced Voltages and Inductance



1



2



3

Significant Discoveries by Significant People

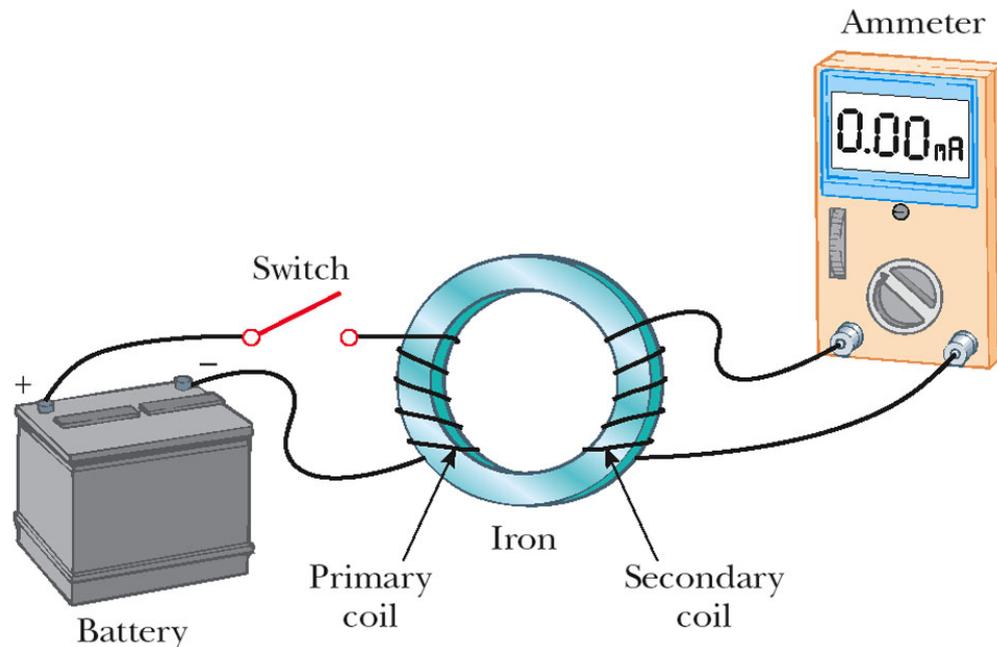
1. Michael Faraday – Electromagnetic Induction
2. Rev. Nicholas Callan – Induction Coil
3. Nikola Tesla – Alternating Current Motor

Faraday's Experiment

A current can be produced by a changing magnetic field.

A **primary coil** is connected to a battery.

A **secondary coil** is connected to an ammeter.



Faraday's Experiment

The purpose of the secondary circuit is to detect current that might be produced by the magnetic field.

When the switch is closed, the ammeter reads a current and then returns to zero.

When the switch is opened, the ammeter reads a current in the opposite direction and then returns to zero.

When there is a steady current in the primary circuit, the ammeter reads zero.

Faraday's Experiment - Conclusions

An electrical current is produced by a *changing* magnetic field.

The secondary circuit acts as if a source of emf were connected to it for a short time.

It is customary to say that *an induced emf is produced in the secondary circuit by the changing magnetic field.*

Faraday's experiment applet



<http://micro.magnet.fsu.edu/electromag/java/faraday/index.html>

Magnetic Flux

An emf is actually *induced* by a change in the quantity called the *magnetic flux* rather than simply by a change in the magnetic field.

Magnetic flux is proportional to both the strength of the magnetic field passing through the plane of a loop of wire and the area of the loop.

Refer to the “nail flux” exercise.

Magnetic Flux

You are given a loop of wire.

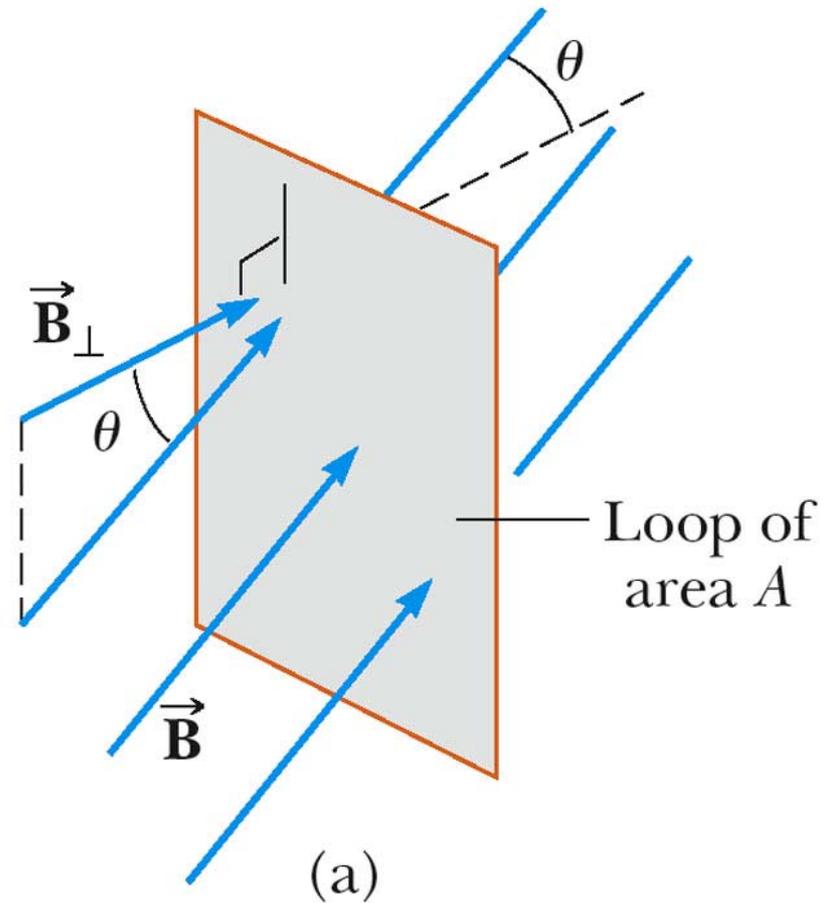
The wire is in a uniform magnetic field \vec{B} .

The loop has an area A .

The flux is defined as

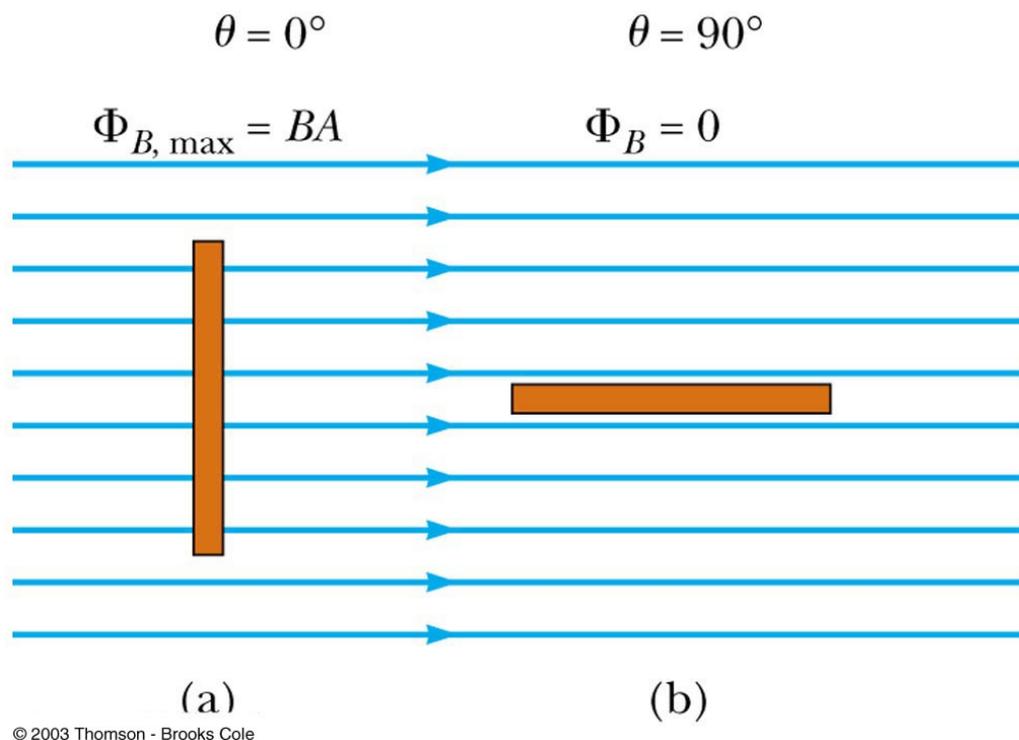
$$\Phi_B = B_{\perp} A = BA \cos \theta$$

θ is the angle between B and the normal to the plane



Magnetic Flux

When the field is perpendicular to the plane of the loop, as in (a), $\theta = 0$ and $\Phi_B = \Phi_{B,\max} = BA$.



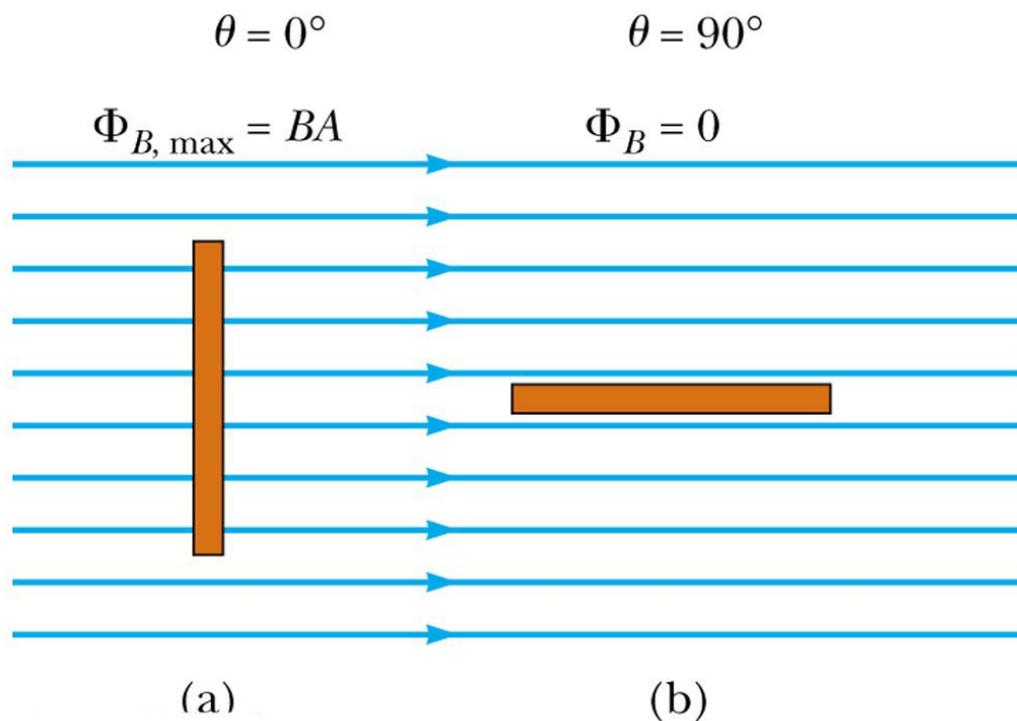
When the field is parallel to the plane of the loop, as in (b), $\theta = 90^\circ$ and $\Phi_B = 0$.

The flux can be negative, for example if $\theta = 180^\circ$.

The SI unit of flux is $\text{T} \cdot \text{m}^2 = \text{Wb}$ (Weber).

Magnetic Flux

The flux can be visualized with respect to magnetic field lines.



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The value of the magnetic flux is proportional to the total number of lines passing through the loop. This applet illustrates the flux concept.

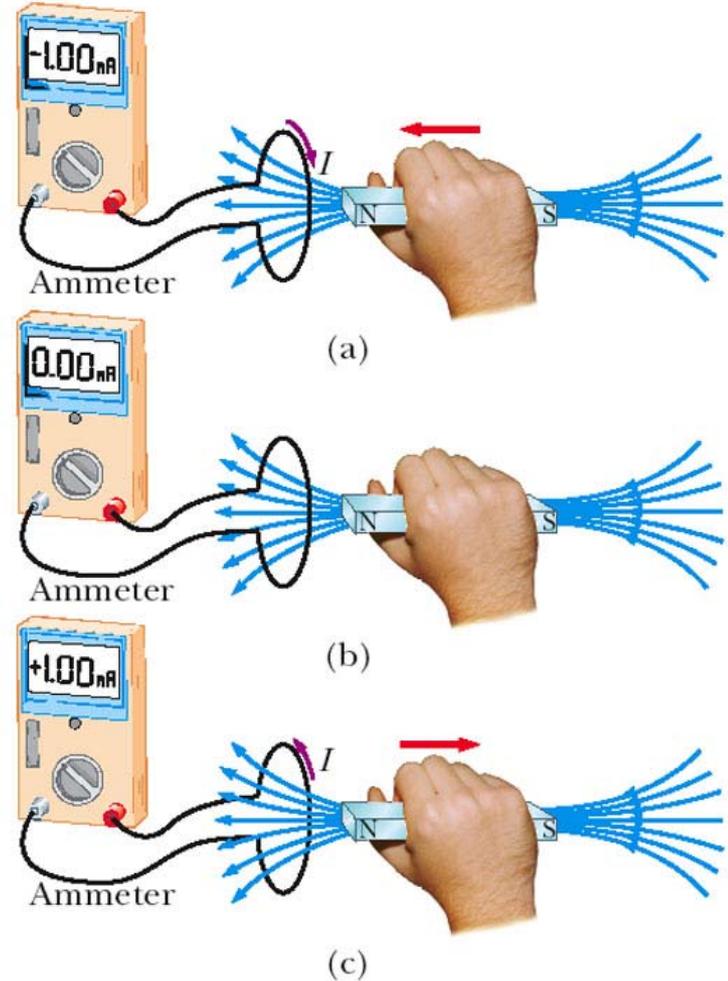


http://www.physics.uoguelph.ca/applets/Intro_physics/kisalev/java/indcur/index.html

Electromagnetic Induction – An Experiment

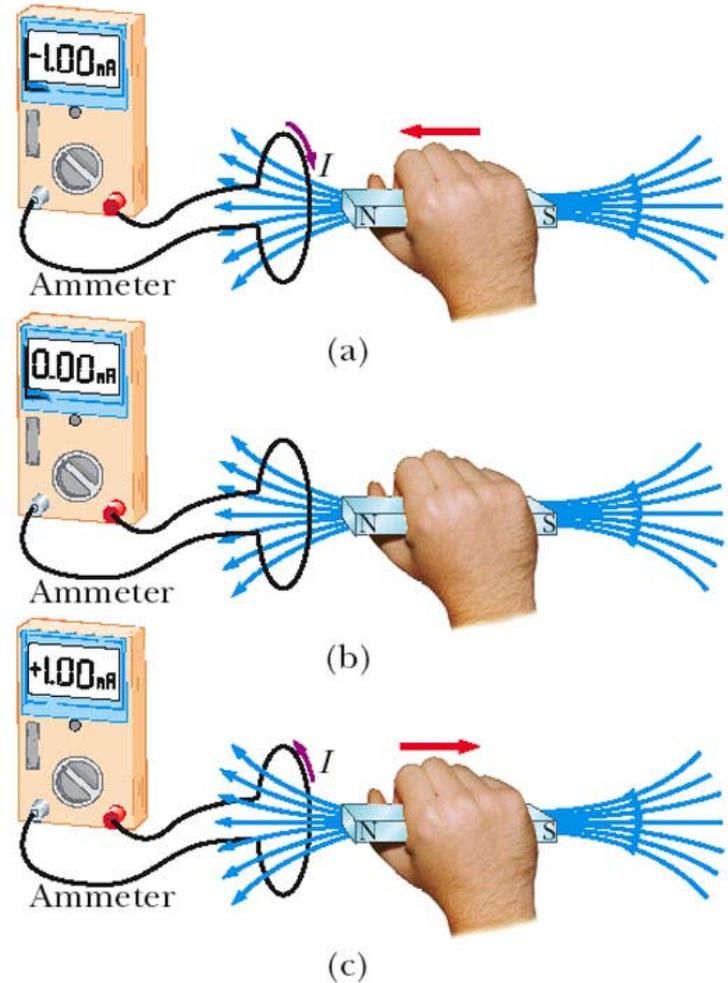
Electromagnetic Induction – An Experiment

(a) When a magnet moves toward a loop of wire, the ammeter shows the presence of a current.



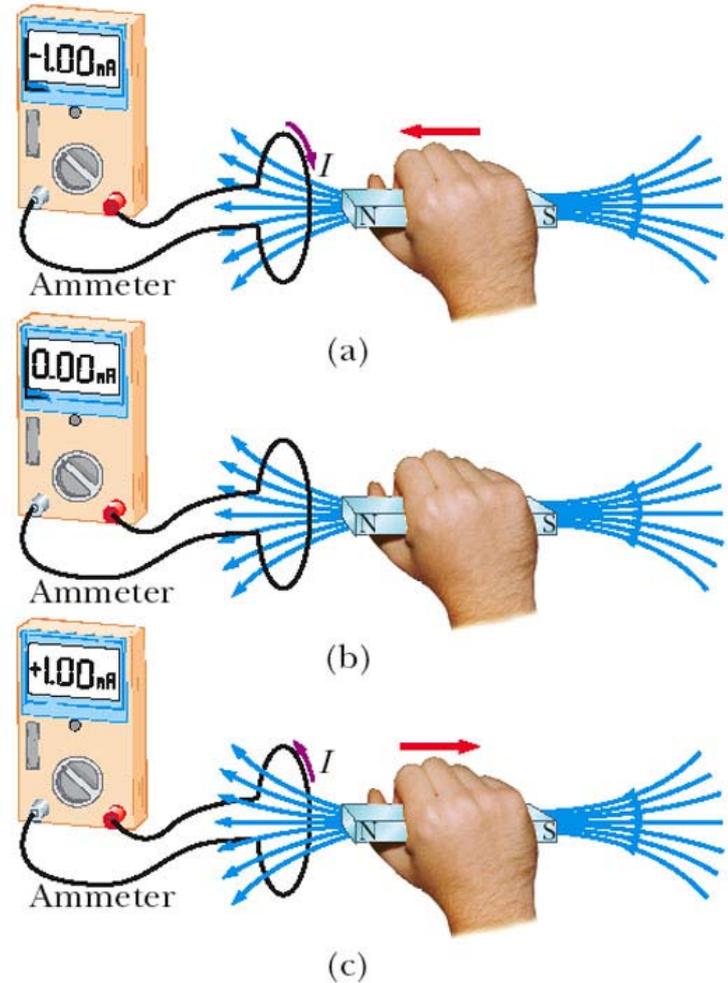
Electromagnetic Induction – An Experiment

(b) When the magnet is held stationary, there is no current.



Electromagnetic Induction – An Experiment

(c) When the magnet moves away from the loop, the ammeter shows a current in the opposite direction.



Electromagnetic Induction – An Experiment

If the loop is moved instead of the magnet, a current is also detected.

A current is set up in the circuit as long as there is *relative motion* between the magnet and the loop.

The same experimental results are found whether the loop moves or the magnet moves.

The current is called an *induced current* because it is produced by an induced emf.

Electromagnetic Induction – An Experiment

**Interactive
applets**



<http://micro.magnet.fsu.edu/electromag/java/faraday2/>



<http://www.lon-capa.org/~mmp/applist/induct/faraday.htm>

Faraday's Law of Electromagnetic Induction

The instantaneous emf induced in a circuit equals the time rate of change of magnetic flux through the circuit.

If a circuit contains N tightly wound loops and the flux changes by $\Delta\Phi_B$ during a time interval Δt , the average emf induced is given by *Faraday's Law*:

$$\mathcal{E} = -N \frac{\Delta\Phi_B}{\Delta t}$$

Faraday's Law of Electromagnetic Induction

$$\mathcal{E} = -N \frac{\Delta\Phi_B}{\Delta t}$$

The change in the flux, $\Delta\Phi_B$, can be produced by a change in B , A or θ , since $\Phi_B = BA\cos\theta$.

The negative sign in Faraday's Law is included to indicate the polarity of the induced emf, which is found by *Lenz's Law*.

Lenz's Law

The current caused by the induced emf travels in the direction that creates a magnetic field with flux **opposing** the change in the original flux through the circuit.

A Lenz's Law applet

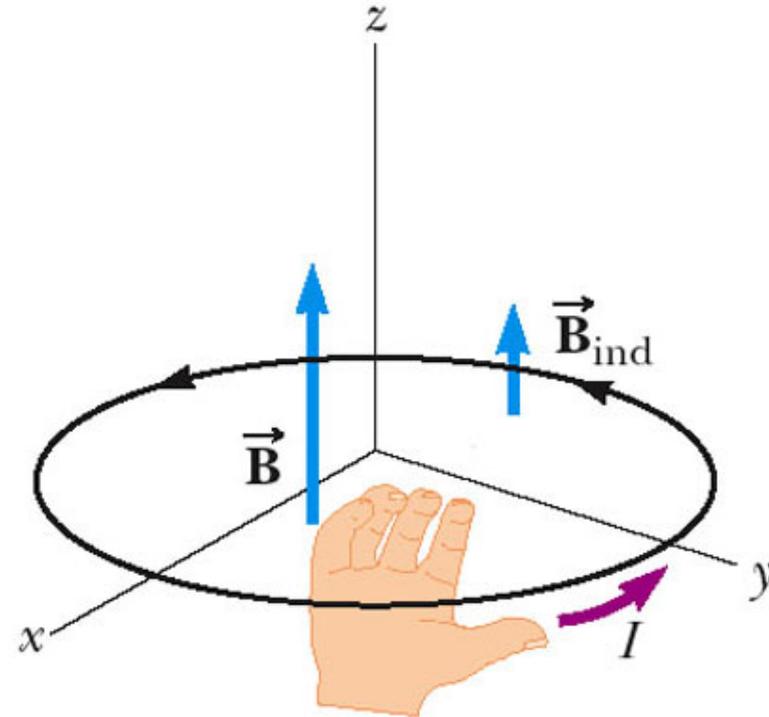


<http://micro.magnet.fsu.edu/electromag/java/lenzlaw/>

Lenz's Law - Example

The magnetic field, \vec{B} , becomes smaller with time.

This reduces the flux
The induced current will produce an induced field, \vec{B}_{ind} , in the same direction as the original field.



Motional emf – An Application of Faraday's Law

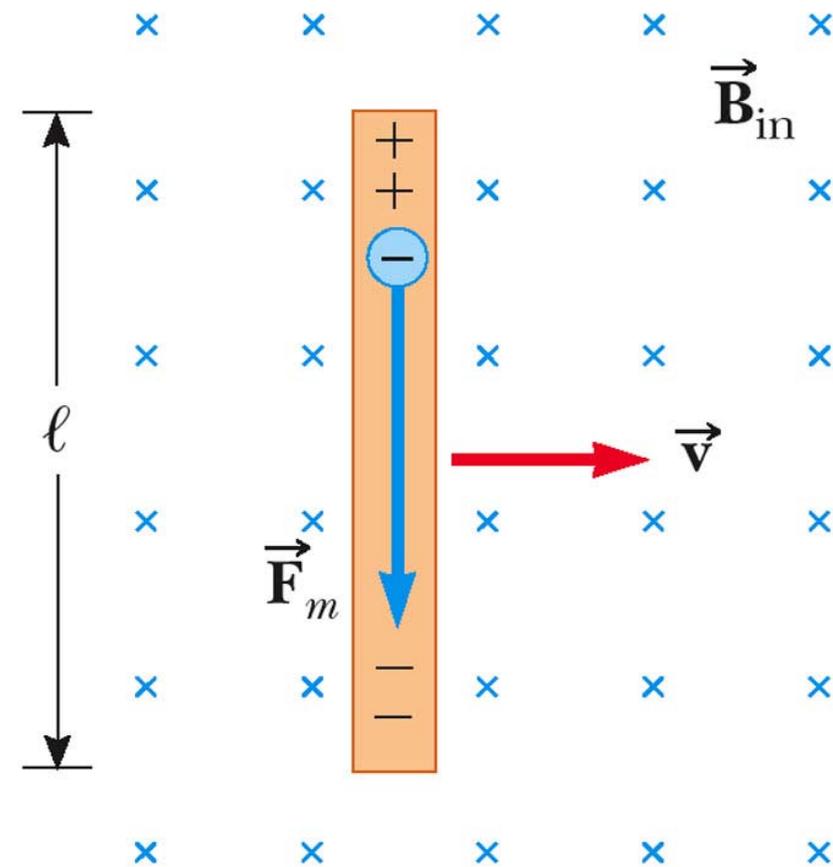
Motional emf – An Application of Faraday's Law

A straight conductor of length ℓ moves perpendicularly with constant velocity through a uniform field.

The electrons in the conductor experience a magnetic force

$$F = qvB.$$

The electrons tend to move to the lower end of the conductor.



Motional emf – An Application of Faraday's Law

As the negative charges accumulate at the base, a net positive charge exists at the upper end of the conductor.

As a result of this charge separation, an electric field is produced in the conductor. Charges build up at the ends of the conductor until the downward magnetic force is balanced by the upward electric force. There is a potential difference between the upper and lower ends of the conductor.

Motional emf – An Application of Faraday's Law

The potential difference between the ends of the conductor can be found by

$$\Delta V = B\ell v$$

The upper end is at a higher potential than the lower end.

A potential difference is maintained across the conductor as long as there is motion through the field.

If the motion is reversed, the polarity of the potential difference is also reversed.