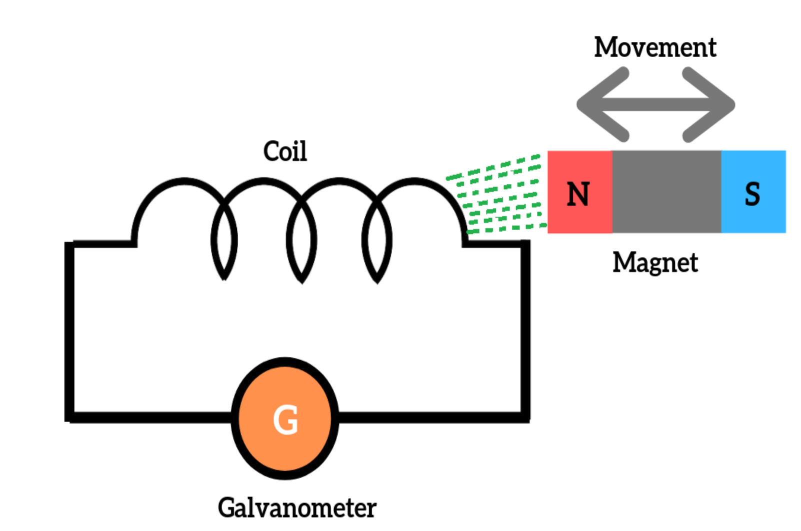
20-Magnetism

Faraday’s Law

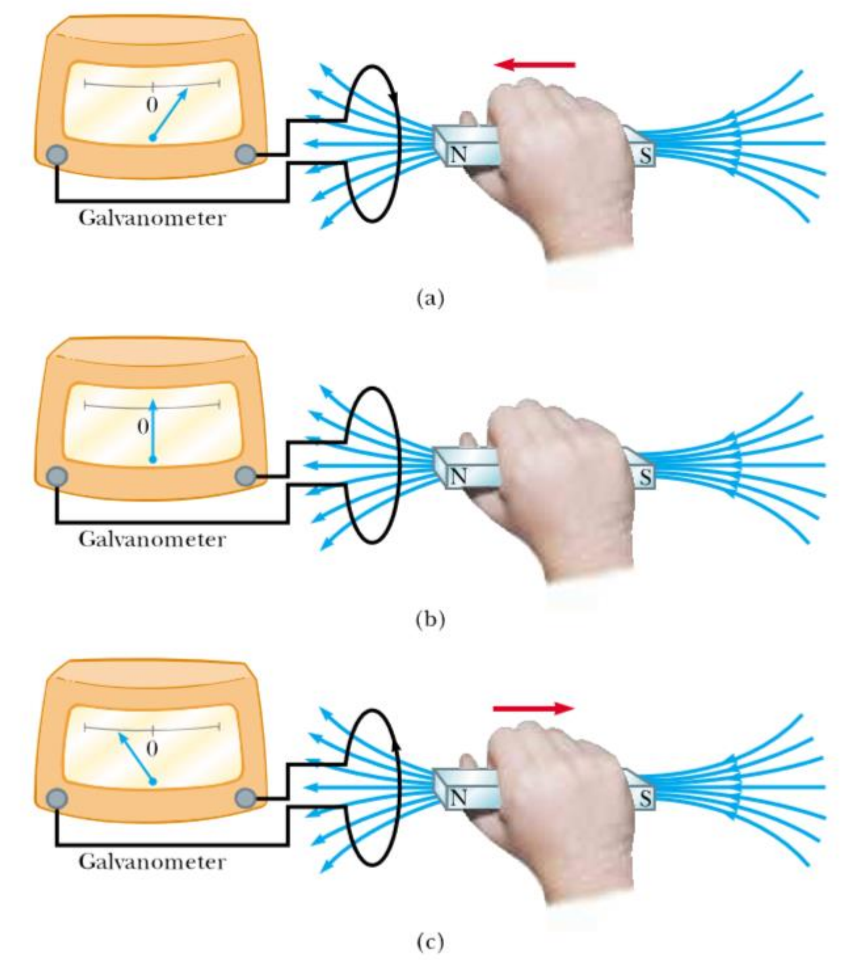
Faraday’s Law:

- **Faraday's law of induction** (briefly, **Faraday's law**) is a basic law of electromagnetism predicting how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF)—a phenomenon known as electromagnetic induction. It is the fundamental operating principle of transformers, inductors, and many types of electrical motors, generators and solenoids.



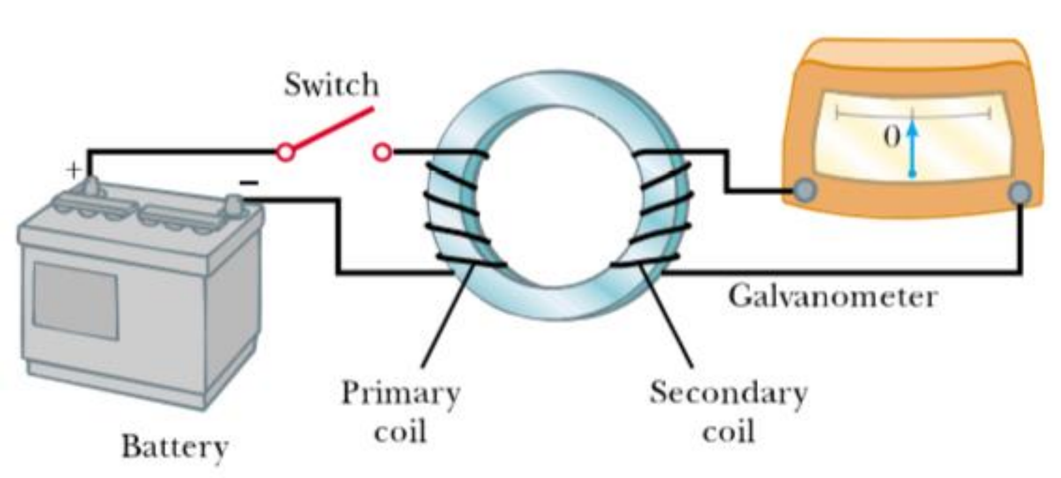
Faraday’s Law:

- (a) – When a magnet is moved toward a loop of wire connected to a galvanometer, the galvanometer deflects, indicating that current is induced in loop.
- (b) – When the magnet is held stationary, there is no induced current in the loop, even when the magnet is inside the loop.
- (c) – When the magnet is moved away from the loop, the galvanometer deflects in opposite direction, indicating that the induced current is opposite that shown in part (a).



Faraday’s Experiment

- When the switch in the primary circuit is closed, the galvanometer in the secondary circuit deflects momentarily. The emf induced in the secondary circuit is caused by the changing magnetic field through the secondary coil.



Faraday's Law

- The emf induced in a circuit is directly proportional to the time rate of change of the magnetic flux through the circuit.

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

where $\Phi_B = \int \mathbf{B} \cdot d\mathbf{A}$

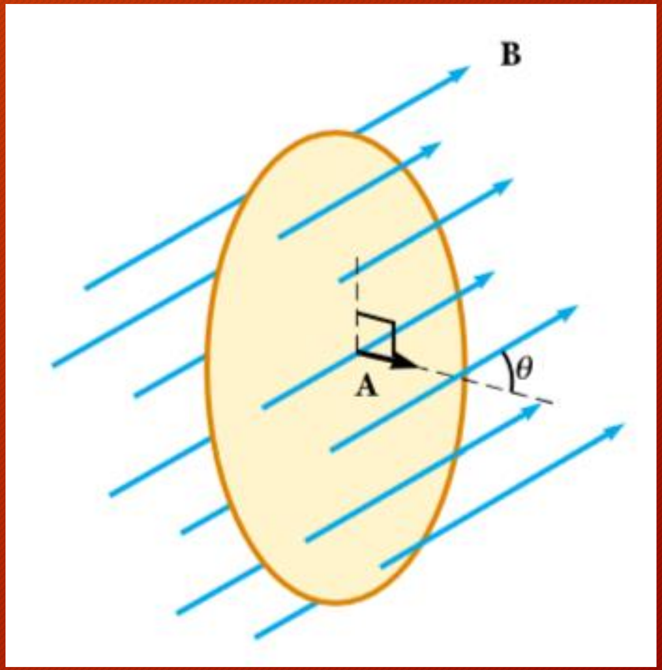
- If the circuit is a coil consisting of N loops all of the same area and if Φ_B is the flux through on loop, the total induced emf in the coil is given by:

$$\mathcal{E} = -N\frac{d\Phi_B}{dt}$$

Faraday’s Law

- Suppose that a loop enclosing an area *A* lies in a uniform magnetic field **B**. The magnetic flux through the loop is equal to $BA \cos \theta$.

$$\mathcal{E} = -\frac{d}{dt}(BA \cos \theta)$$



Faraday's Law

$$\mathcal{E} = -\frac{d}{dt}(BA\cos\theta)$$

- From this expression, we see that an emf can be induced in a circuit in several ways:
- The magnitude of **B** can change with time.
- The area enclosed by the loop can change with time.
- The angle θ between **B** and the normal to the loop can change with time.
- Any combination of the above can occur.

EXAMPLE 31.1 **One Way to Induce an emf in a Coil**

A coil consists of 200 turns of wire having a total resistance of 2.0 Ω. Each turn is a square of side 18 cm, and a uniform magnetic field directed perpendicular to the plane of the coil is turned on. If the field changes linearly from 0 to 0.50 T in 0.80 s, what is the magnitude of the induced emf in the coil while the field is changing?

Solution The area of one turn of the coil is $(0.18\ \text{m})^2 = 0.032\,4\ \text{m}^2$. The magnetic flux through the coil at $t = 0$ is zero because $B = 0$ at that time. At $t = 0.80$ s, the magnetic flux through one turn is $\Phi_B = BA = (0.50\ \text{T})(0.032\,4\ \text{m}^2) = 0.016\,2\ \text{T}\cdot\text{m}^2$. Therefore, the magnitude of the induced emf is, from Equation 31.2,

$$|\mathcal{E}| = \frac{N\,\Delta\Phi_B}{\Delta t} = \frac{200(0.016\,2\ \text{T}\cdot\text{m}^2 - 0\ \text{T}\cdot\text{m}^2)}{0.80\ \text{s}}$$

$$= 4.1\ \text{T}\cdot\text{m}^2/\text{s} = \boxed{4.1\ \text{V}}$$

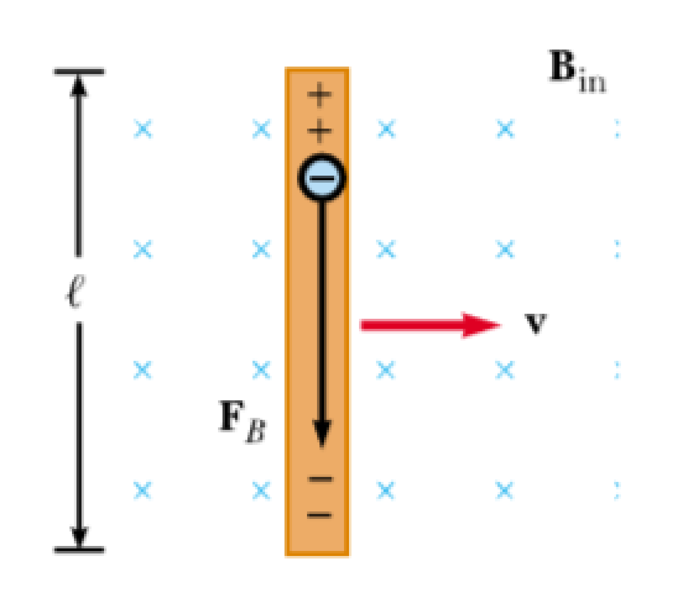
You should be able to show that $1\ \text{T}\cdot\text{m}^2/\text{s} = 1\ \text{V}$.

Exercise What is the magnitude of the induced current in the coil while the field is changing?

Answer 2.0 A.

Motional EMF

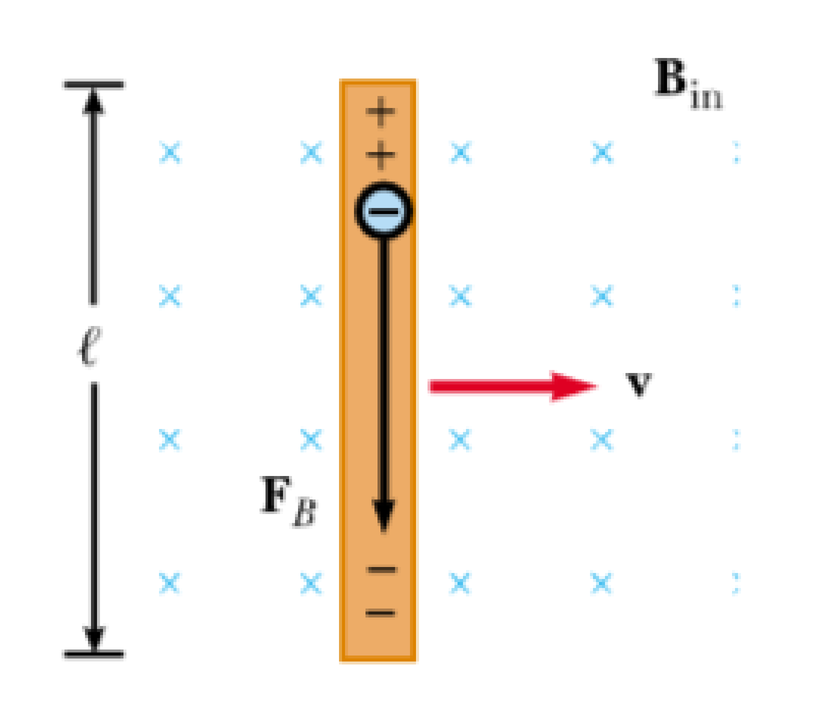
- Motional EMF is the EMF induced in a conductor moving through a constant magnetic field.
- A straight electrical conductor of length *l* moving with velocity **v** through a uniform magnetic field **B** directed perpendicular to **v**, is shown in the figure.



Motional EMF

- The electron in conductor experience a force $F_B = q\mathbf{v} \times \mathbf{B}$.
- The electron move to the lower end, leaving the net positive charge at the upper end.
- The charges accumulate at both ends until

$$qE = qvB \quad \text{or} \quad E = vB$$

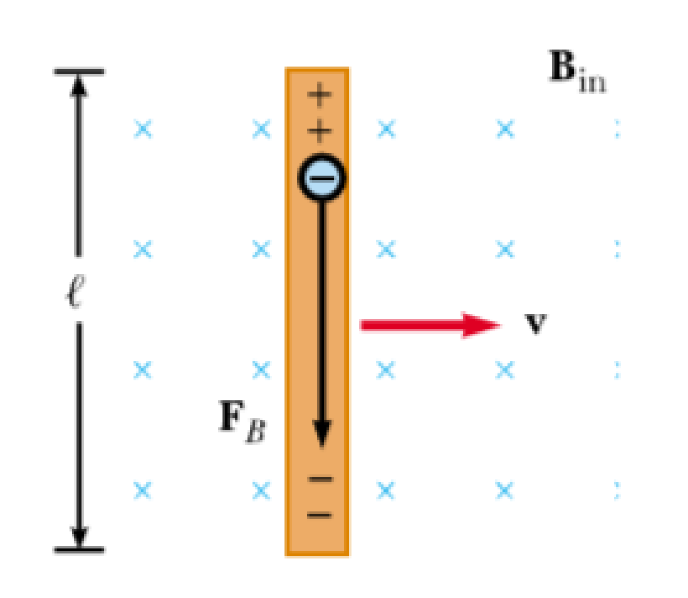


Motional EMF

- The electric field produced in the conductor (once the electrons stop moving and E is constant) is related to the potential difference across the end of conductors according to:

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

- A potential difference is maintained between the ends of the conductor as long as the conductor continues to move through the uniform magnetic field.



Induced EMF

It can be defined as the generation of a potential difference in a coil due to the changes in the magnetic flux through it.

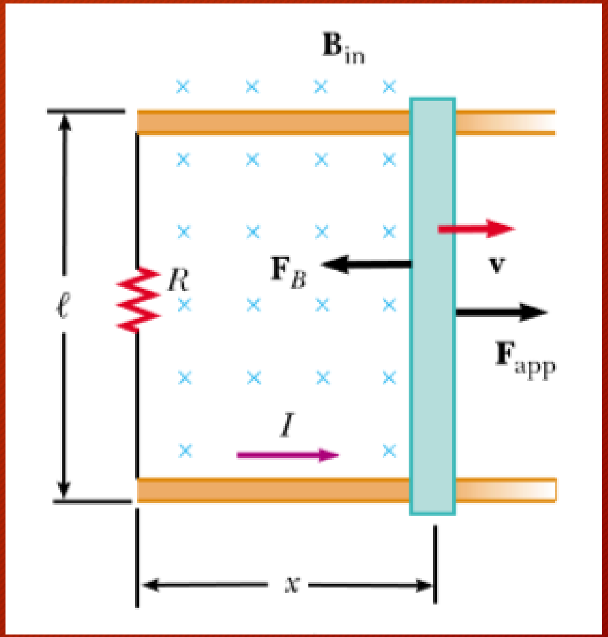
- A conducting bar sliding with a velocity **v** along two conducting rails under the action of an applied force $\mathbf{F}_{app}$. The magnetic force $\mathbf{F}_B$ opposes the motion, and a counter clock wise current *I* is induced in a loop.
- The area enclosed by circuit is lx, and magnetic flux is

$$\Phi_B = B\ell x$$

- Using Faraday's law, and dx/dt = v, we find the EMF

$$\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}(B\ell x) = -B\ell\frac{dx}{dt}$$

$$\mathcal{E} = -B\ell v$$



Induced Current

- Because the resistance of the circuit is R, the magnitude of induced current is

$$I = \frac{|\mathcal{E}|}{R} = \frac{B\ell v}{R}$$

Induced current describes the movement of charge carriers in a conductor due to the presence of a changing magnetic field.