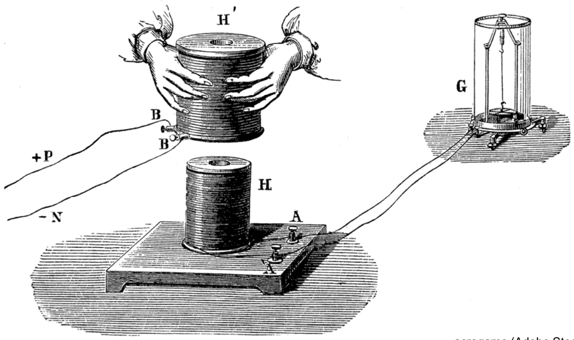
Electromagnetic Induction



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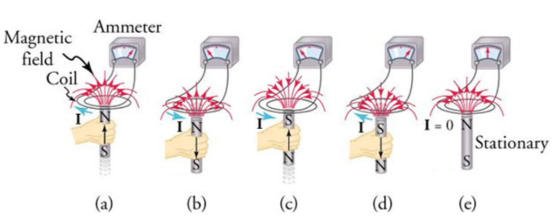
- English scientist Michael Faraday (1791–1862) demonstrated that magnetic fields can produce currents.
  - The basic process of generating currents with magnetic fields is called induction.

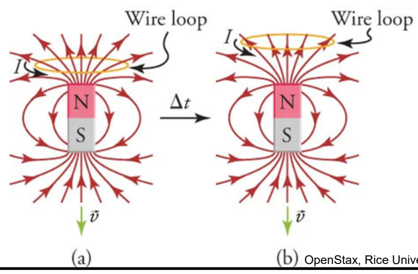
Henry Williams Picker (after) Wellcome Collection (public domain)

- Current is only induced when the magnetic field moves with respect to a coil.
- The current goes to zero immediately when the movement stops.

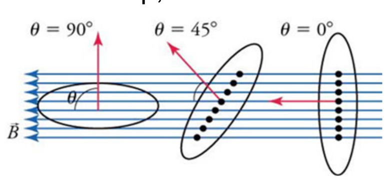


- If a current is induced in the coil, Faraday reasoned that there must be what he called an *electromotive force* pushing the charges through the coil.
- This interpretation turned out to be incorrect; instead, the external source doing the work of moving the magnet adds energy to the charges in the coil.
- The energy added per unit charge has units of volts, so the electromotive force is actually a potential.

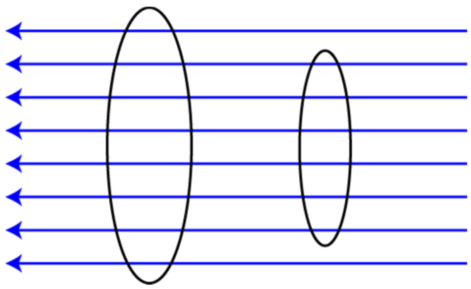
- The emf (ε) is the energy per unit charge **added** by a source.
- An emf is induced in a wire loop when the number of magnetic field lines passing through the loop changes.



- Magnetic field lines that lie in the plane of the wire loop do not actually pass through the loop.
- What is important in generating an emf in the wire loop is the component of the magnetic field that is perpendicular to the plane of the loop, which is $B\cos\theta$.



- We can also change the number of field lines going through the conducting loop by changing the area of the loop.



- The emf produced in a conducting loop is proportional to the rate of change of the product of the perpendicular magnetic field and the loop area.

$$\varepsilon \propto \frac{\Delta(BA\cos\theta)}{\Delta t}$$

- $BA\cos\theta$ is the number of magnetic field lines that pass perpendicularly through a surface of area A.
- It is called the **magnetic flux** and is represented by Φ.

$$\boxed{\Phi = BA\cos\theta}$$ Units: Webers (Wb)

Faraday's Law

- The magnitude of the induced emf is proportional to the rate of change of the magnetic flux through a conducting loop.

$$\varepsilon \propto N\frac{\Delta\Phi}{\Delta t}$$

(N is the number of loops in a coil)

Lenz's Law

- In 1834, Russian physicist Heinrich Lenz explained that the current flows in the direction that creates a magnetic field that tries to keep the flux constant in the loop.

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- Combining Faraday's law and Lenz's law then gives us equation for induced emf.

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

Example

- The magnetic flux through a coil of wire containing 5 loops, changes from -25 Wb to 15 Wb in 0.12 s. What is the induced emf in the coil?

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

$$= -(5)\frac{(15 - -25)}{0.12\ s} = -1667\ \text{V}$$