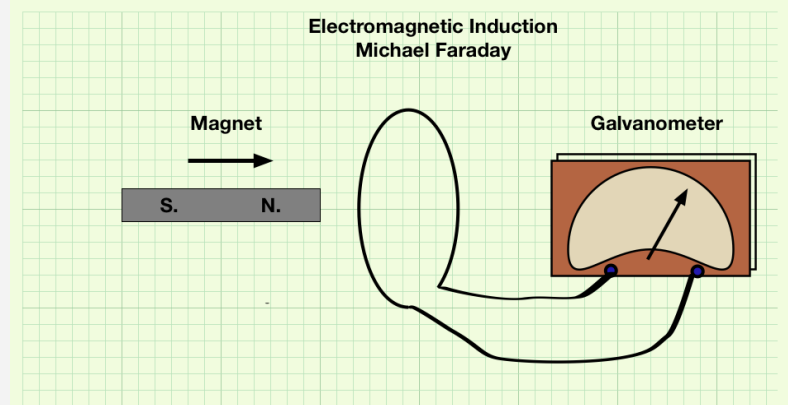


# Electromagnetic Induction

Electromagnetic Induction (E.M.I.) was discovered in 1831, independently, by Michael Faraday (London) and Joseph Henry (Albany NY).

Faraday was a famous scientist and published his results promptly. Henry was a high school science teacher in America, and did not publish his results at the time. Faraday got the credit for the discovery. Henry became famous later, as the first director of the Smithsonian Institution in Washington DC.

The simplest demonstration of electromagnetic induction...

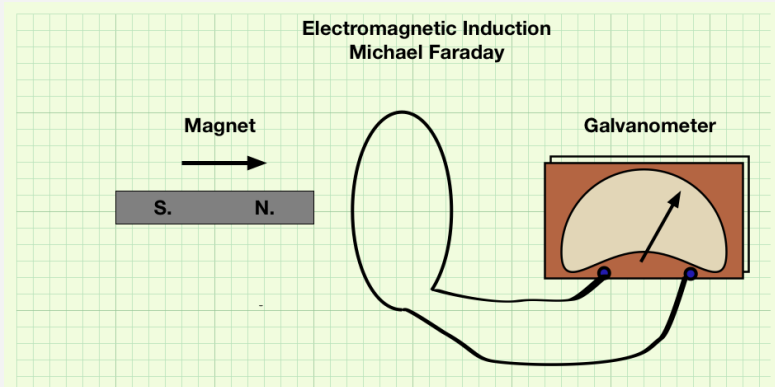


When the magnet moves, either toward or away from the loop of wire, current will flow around the loop indicated by a temporary deflection of the Galvanometer needle.

The galvanometer is just a device to measure current; an early form of ammeter.

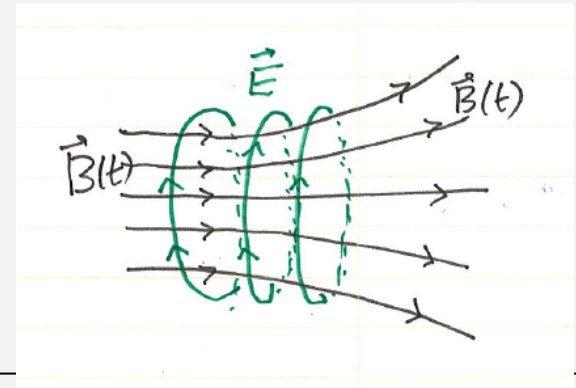
# Electromagnetic Induction

... creating electric fields by changing magnetic fields.



Faraday had many other ways to demonstrate E.M.I.. They all had the same effect: When the magnetic field changes, an electric current occurs in a nearby conducting material.

But the electric current is a secondary effect. The primary effect is that if the magnetic field changes (in time) then an electric field is induced. The electric field circulates around the change of the magnetic field. If there happens to be a conducting material present, the electric field will drive electric current in the material.



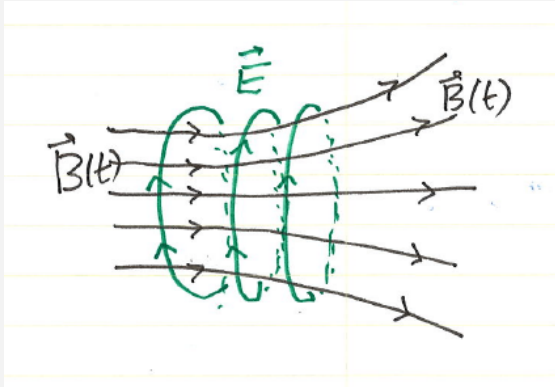
# Faraday's Law

Faraday discovered the physical phenomenon, but Maxwell put it into mathematical terms.

Consider a time-dependent magnetic field  $\mathbf{B}(\mathbf{r},t)$ ; i.e., it changes in time  $t$ .

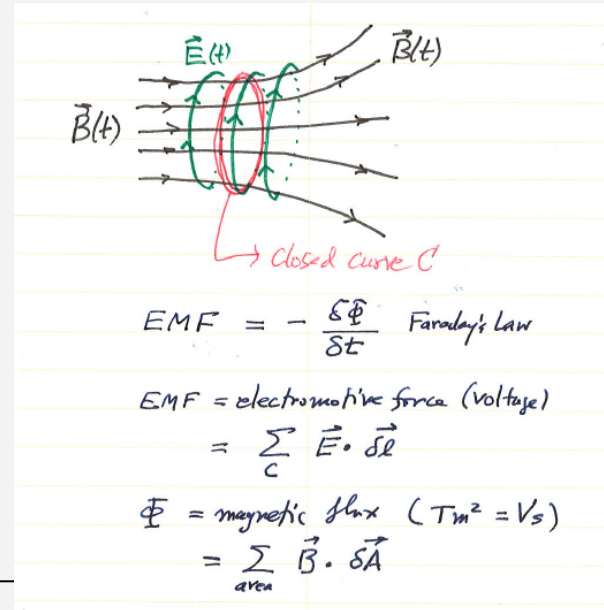
The induced electric field  $\mathbf{E}(\mathbf{r},t)$  circulates around the change of  $\mathbf{B}$ .

Picture:



Faraday's law is a part of the field theory; a *field effect*

Consider a loop, i.e., a closed curve  $C$ . ( $C$  is not a physical loop of material, but just an imaginary curve in space.)



# Electromagnetic generators

Faraday's goal was "to create electricity from magnetism".

His experiments did that.

Later, other scientists and engineers used the phenomenon of E.M.I. to develop practical generators. Today those supply the electricity that we use in daily life.

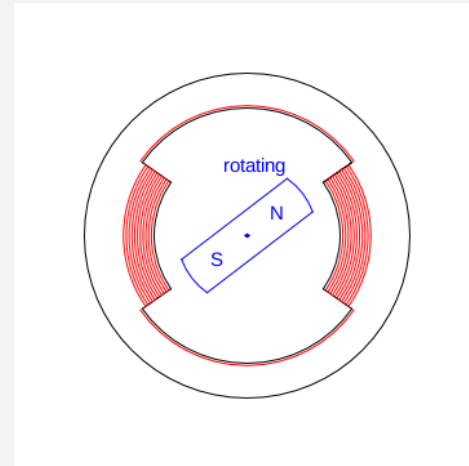
Hippolyte Pixii  
(Paris)



Magneto (circa 1832)

Basic principle of an electromagnetic generator : there is a stationary part (the stator); there is a rotating part (rotor); the rotation creates a changing magnetic field, which induces an electric field --- electromotive force.

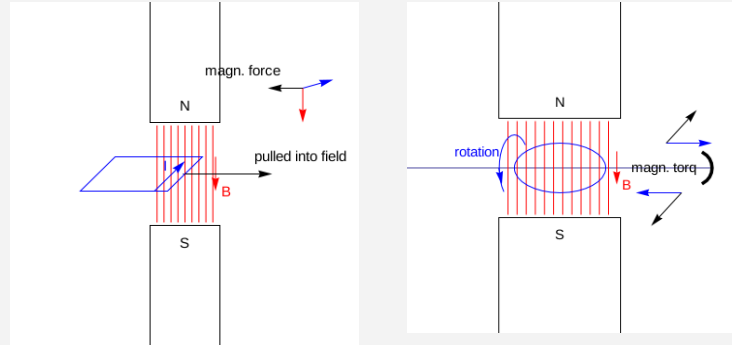
This will be an alternating emf, which will drive *alternating current (AC)* around a circuit.



The self-excited dynamo was invented by Werner von Siemens in 1866, replacing permanent magnets by more powerful electromagnets which get their current from the dynamo itself.

## The generator needs a power source

The rotor experiences a torque, because of the magnetic force;



**Magnetic braking:** the force is opposite in direction to the motion, so the moving (or, rotating) object will slow down and stop unless an opposing force (or, torque) is applied.

The applied force does work, so it requires energy.

## Electric power technology

Many power sources have been used to drive electric generators.

=> mechanical crank

=> belt

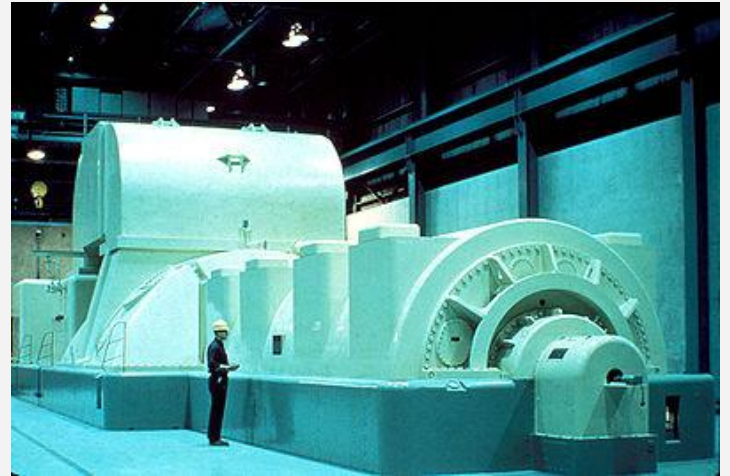
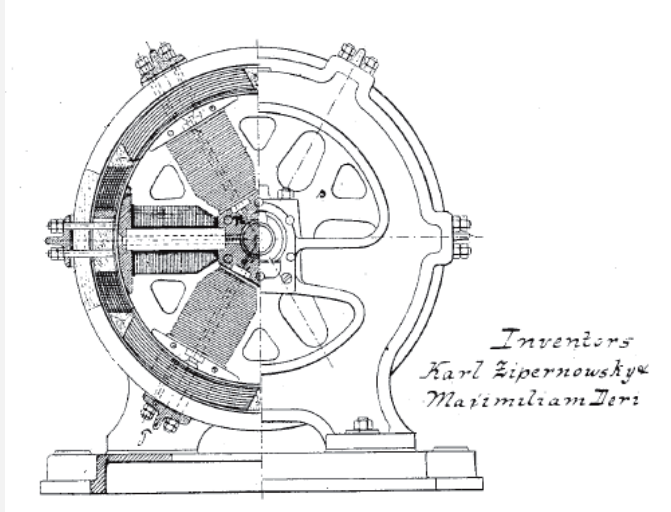
=> water turbine

=> steam turbine (burning coal or gas)

=> wind driven turbine

=> steam turbine driven by nuclear fission

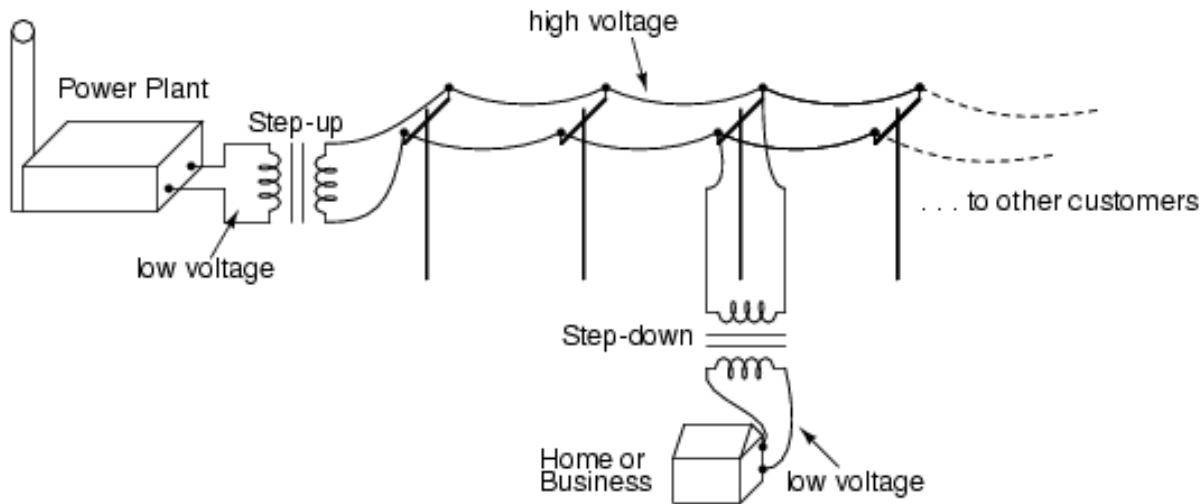
# Electromagnetic generators



# Transformers

The output voltage from the electric generator in a power plant may be 10's of thousands of volts; the transmission voltage may be 100's of thousands of volts. Our appliances use 110 volts.

A transformer is an electromagnetic device that uses E.M.I. to transform voltage, for AC circuits.



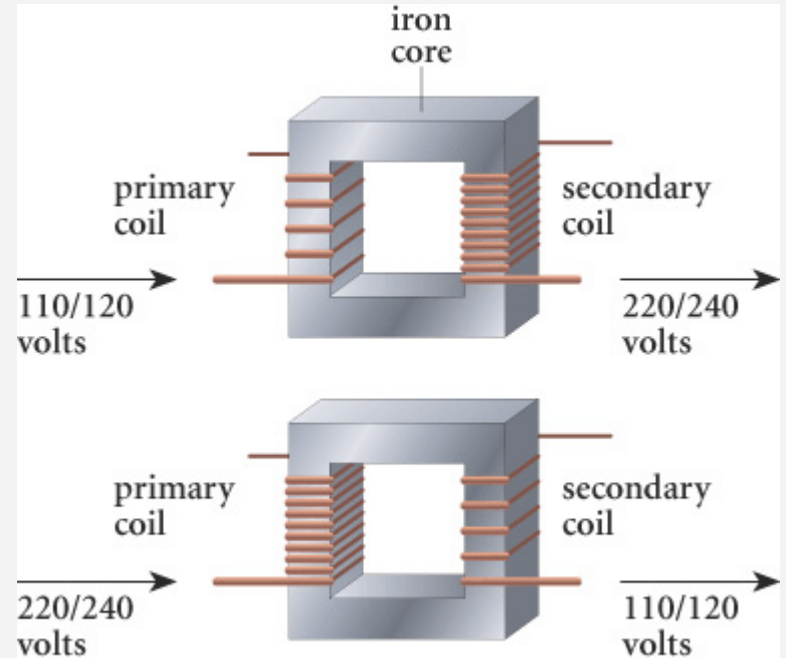
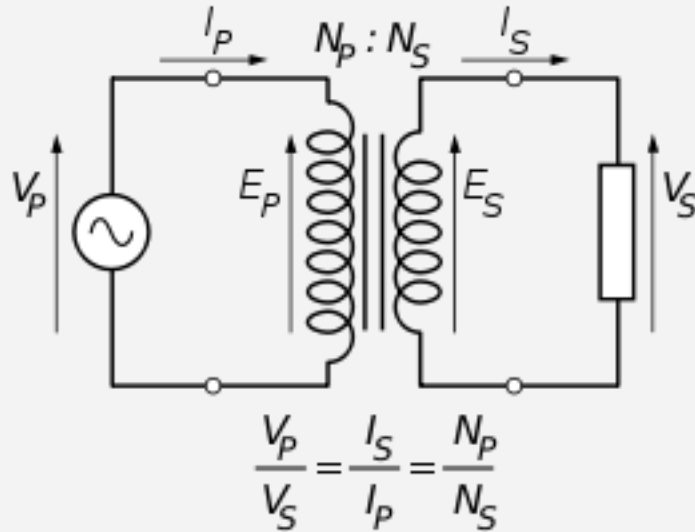
# Principle of the electric transformer

*A transformer has two coils of wire ( 4 leads)*

*P = primary, or input;*

*S = secondary, or output.*

- /1/ Primary AC in  $\Rightarrow$  a magnetic field that alternates in time;
- /2/ E.M.I. creates an electric field around the secondary coil  $\Rightarrow$  AC out.
- /3/  $V_s / V_p = N_s / N_p$





# Transformers in daily life

