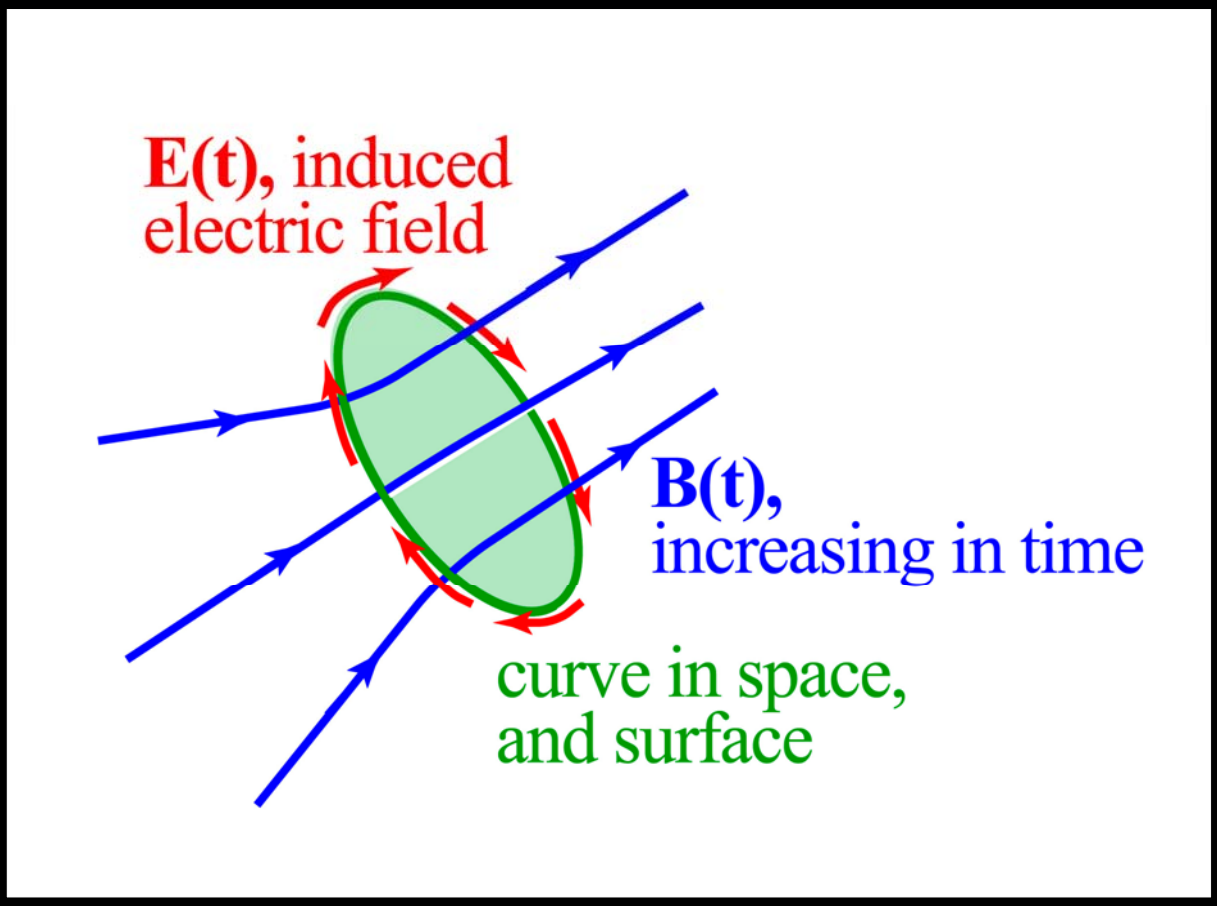
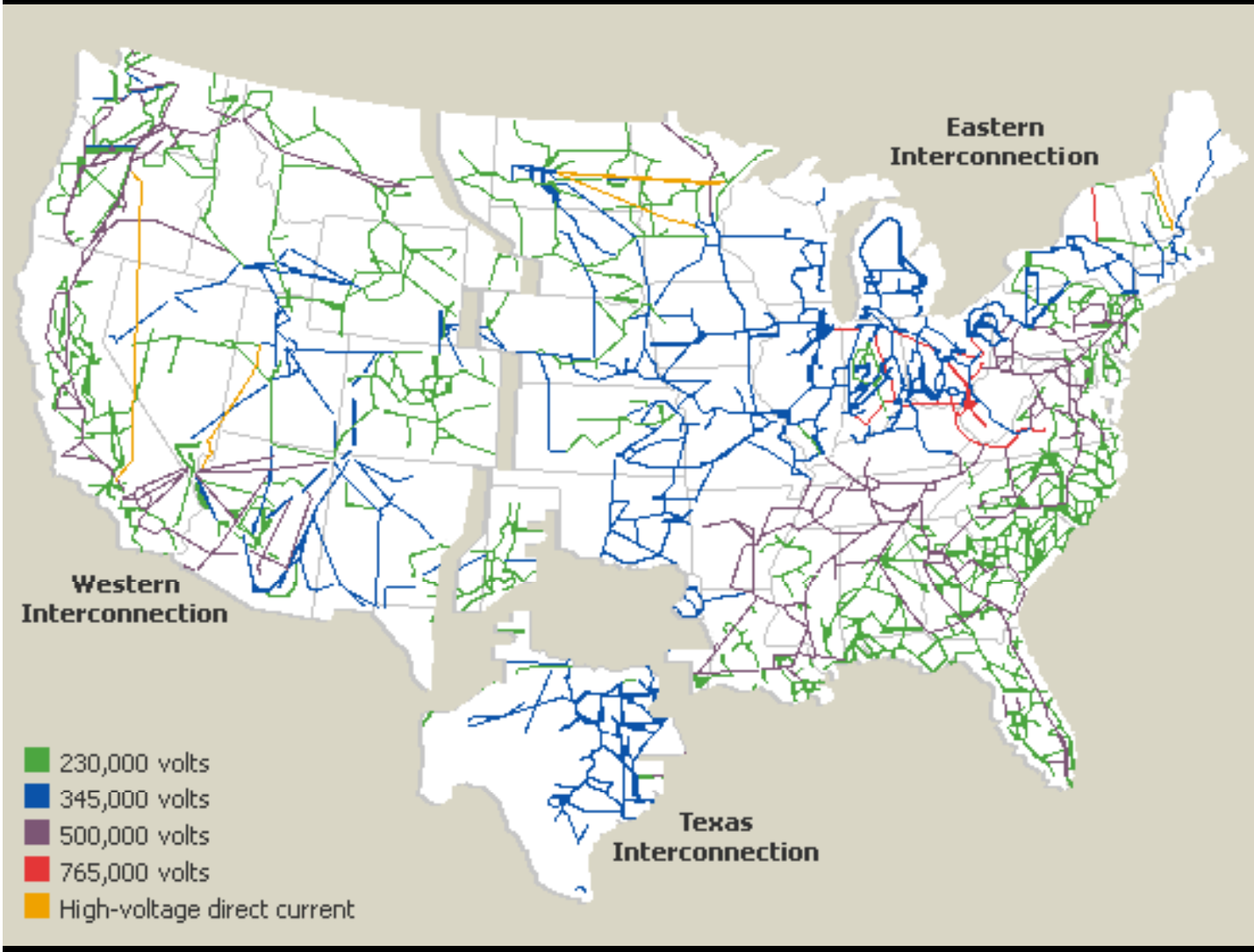
Electromagnetic Induction



$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

US electric power grid



Applications of Electromagnetic Induction

↳ technology used in everyday life

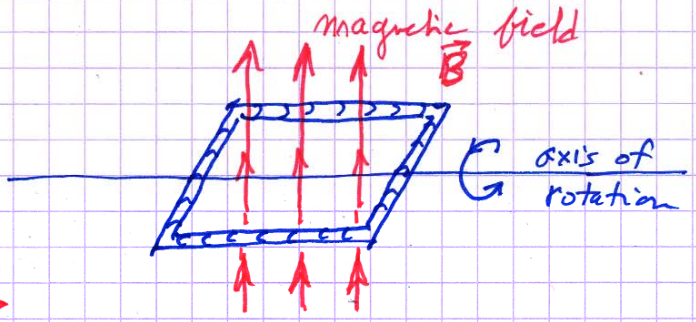
- electric generators
- transformers
- induction motors

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

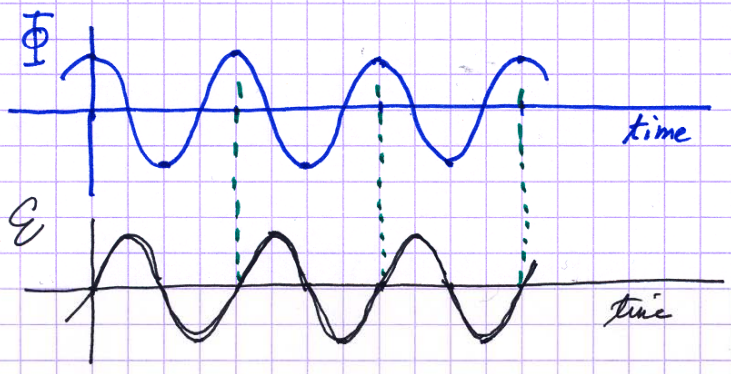
$$\mathcal{E} = -\frac{d\Phi}{dt}$$

Electric Generators

Design principle :



a conducting loop rotates in a magnetic field $\vec{B}$

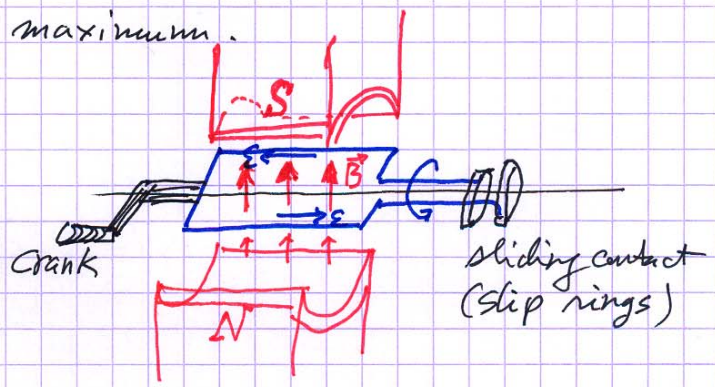


$$\Phi = NBA\cos\omega t$$

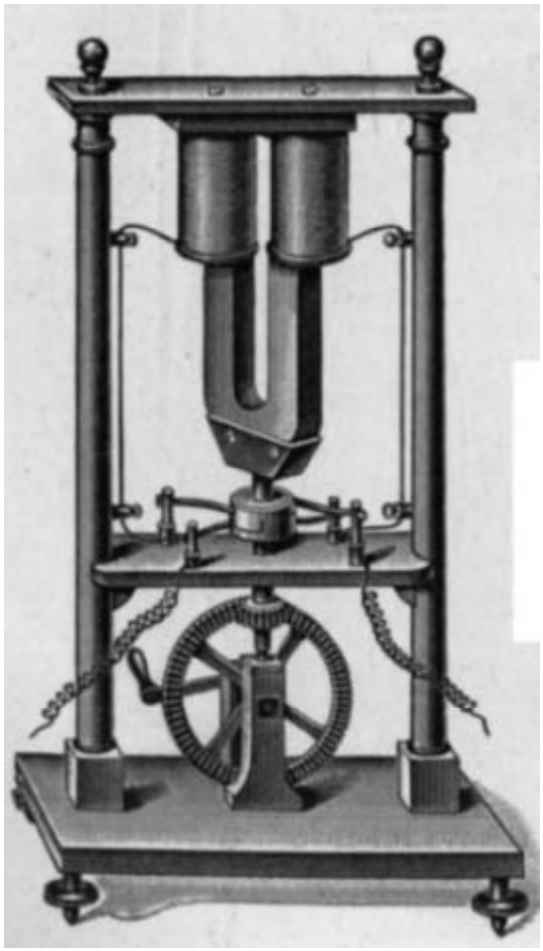
$$\mathcal{E} = NBA\omega \sin\omega t$$

Note that $\mathcal{E}$ is 90 degrees out of phase with Φ. Where $|\Phi|$ is maximum, $\mathcal{E} = 0$; when $\Phi = 0$, $|\mathcal{E}|$ is maximum.

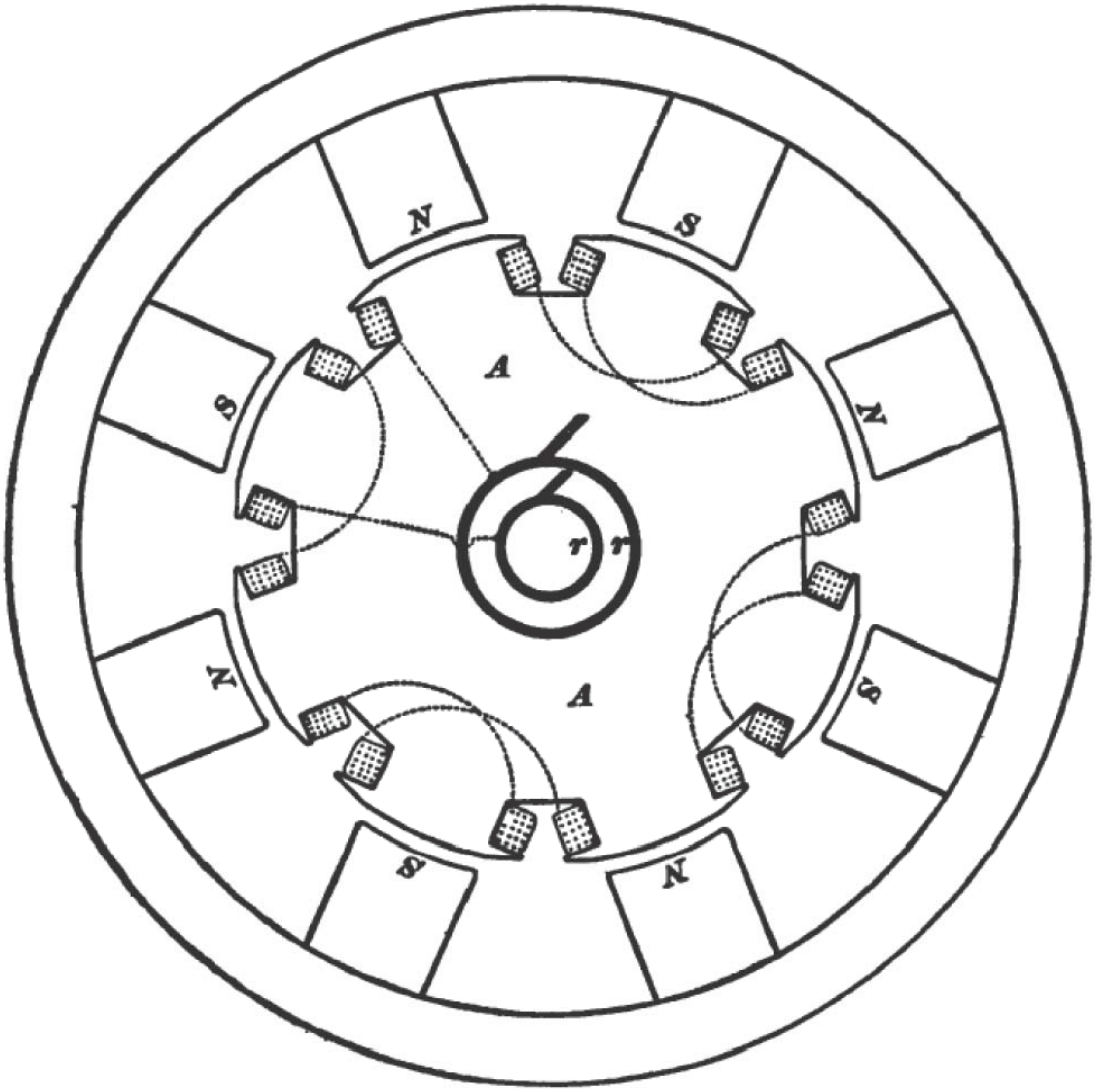
But how would you actually build one?



Hippolyte Pixii – the first attempt to make a practical electric generator, 1832

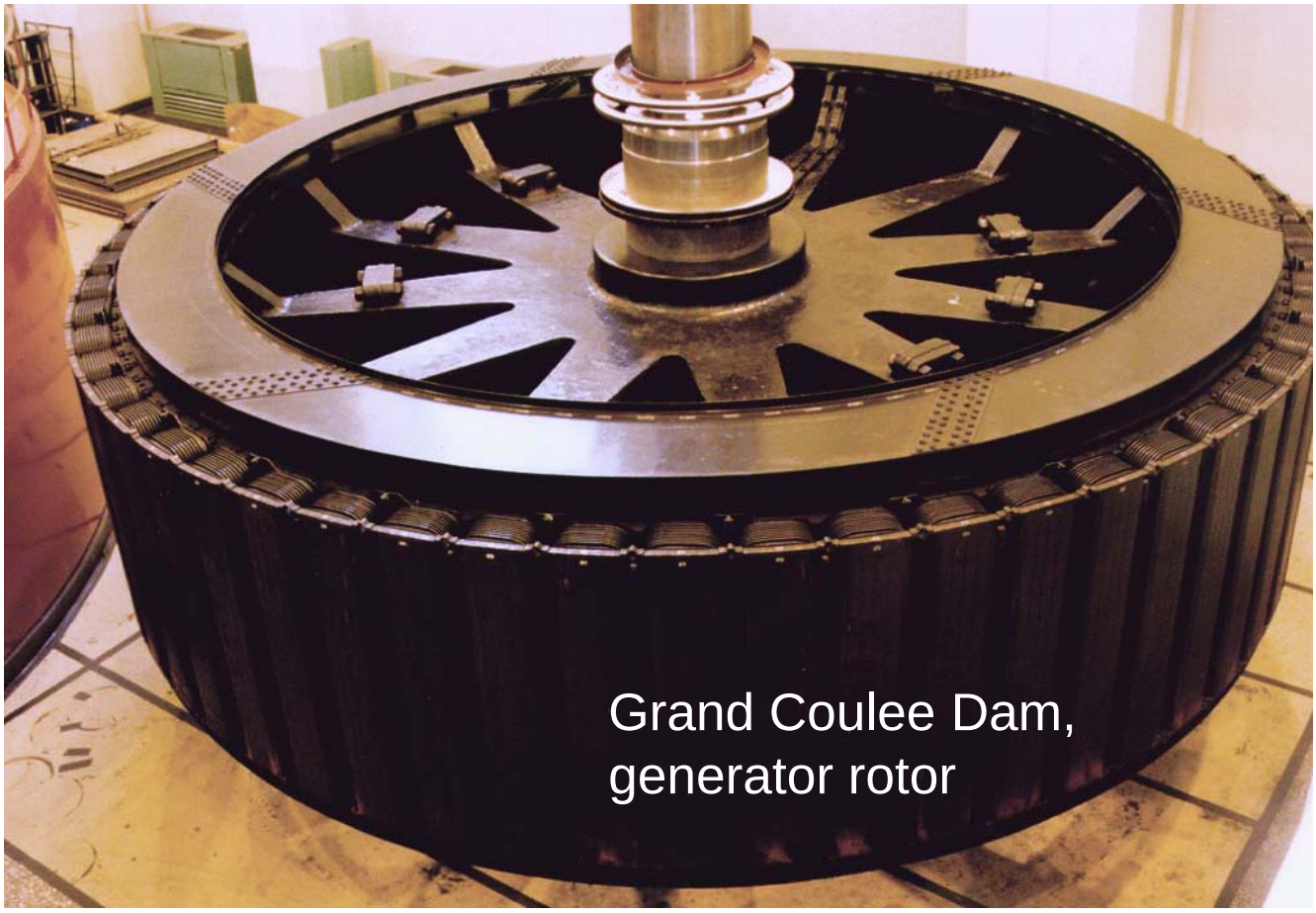


Polyphase Electric Generator end view



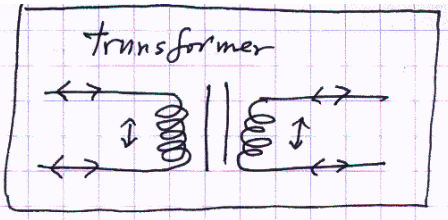
As the rotor turns, the magnetic flux changes and an EMF is generated around the coil of wire.

It is 31 feet in diameter, 18 feet tall and weighs 600 tons. It consists of many vertical bundles of copper conductor wound around iron cores. During operation the copper conductors are energized with DC current turning the rotor into a giant spinning electromagnet. The rotor spins inside the 'stator' -- a ring of vertically oriented coils of copper wire -- at 120 turns per minute. As the magnetic field lines of the spinning rotor sweep through the stator coils they induce an electric current thereby generating electricity.



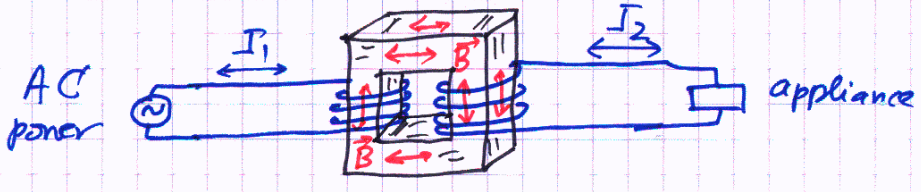
Grand Coulee Dam, generator rotor

The powerhouse contains nine 125,000 kW turbine generators numbered G-10 through G-18 (nearest).



The transformer

Design Principle



primary coil C_1 (N_1 turns)

secondary coil C_2 (N_2 turns)

How does it work? Electromagnetic Induction

AC power is supplied to C_1

$\Rightarrow$ makes an alternating magnetic field

$\Rightarrow$ field $\vec{B}$ is concentrated around the iron core

$\Rightarrow$ an alternating flux through C_2

$\Rightarrow$ emf around C_2

$\Rightarrow$ alternating emf drives an AC in the appliance

Ideal transformer equations

- The magnetic flux is the same through both areas

$$\frac{\mathcal{E}_1}{N_1} = \frac{\mathcal{E}_2}{N_2} \qquad \mathcal{E} = -N\left(\frac{d\Phi}{dt}\right)_{\text{single turn}}$$

- Power supplied into C_1 = power supplied out of C_2

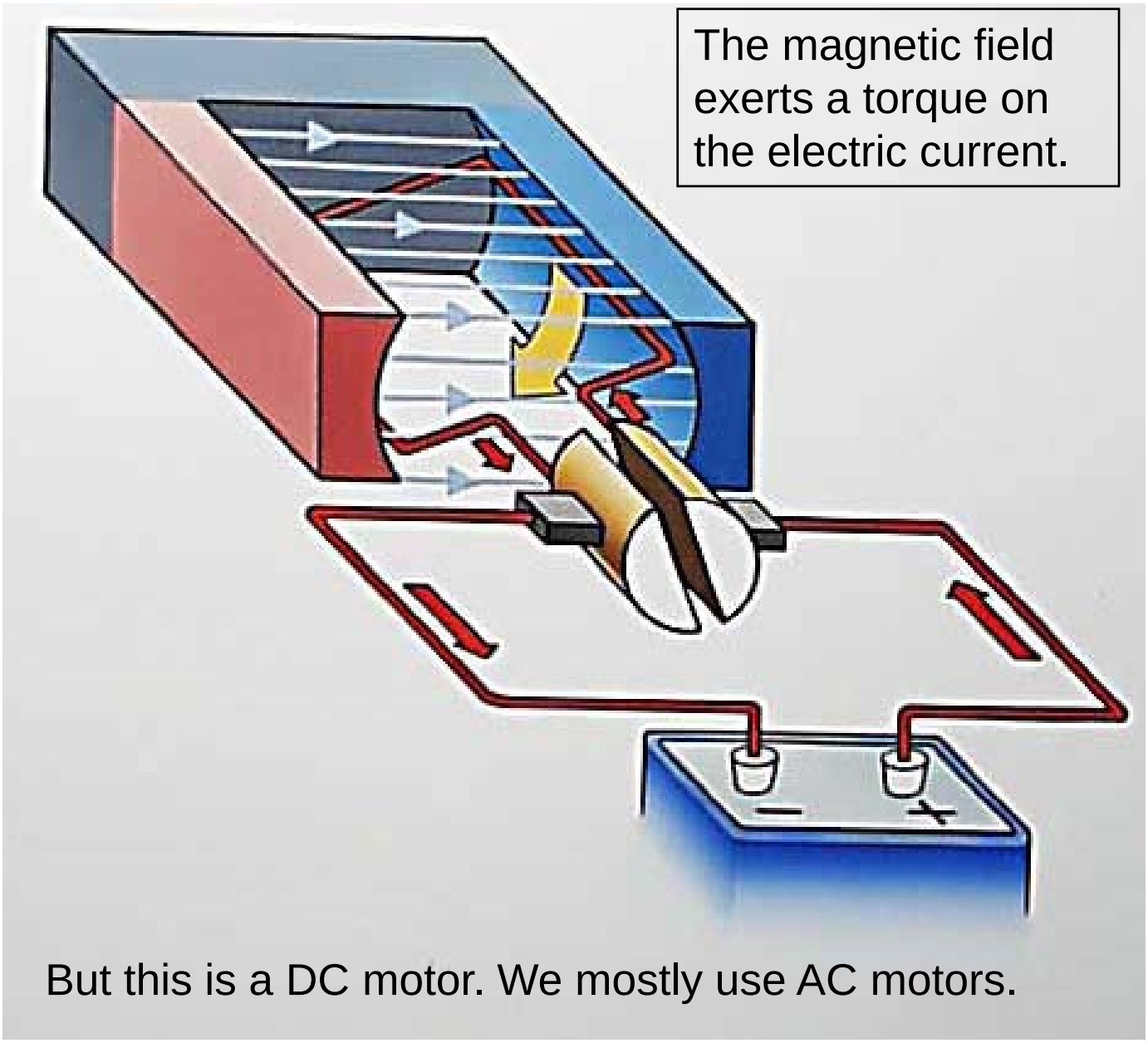
$$I_1 \mathcal{E}_1 = I_2 \mathcal{E}_2 \qquad \text{(RMS values)}$$

$$\boxed{\frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1} \quad \text{(ideal)}}$$

Step-up and Step-down transformers.

22 kilovolts to 66 kilovolts

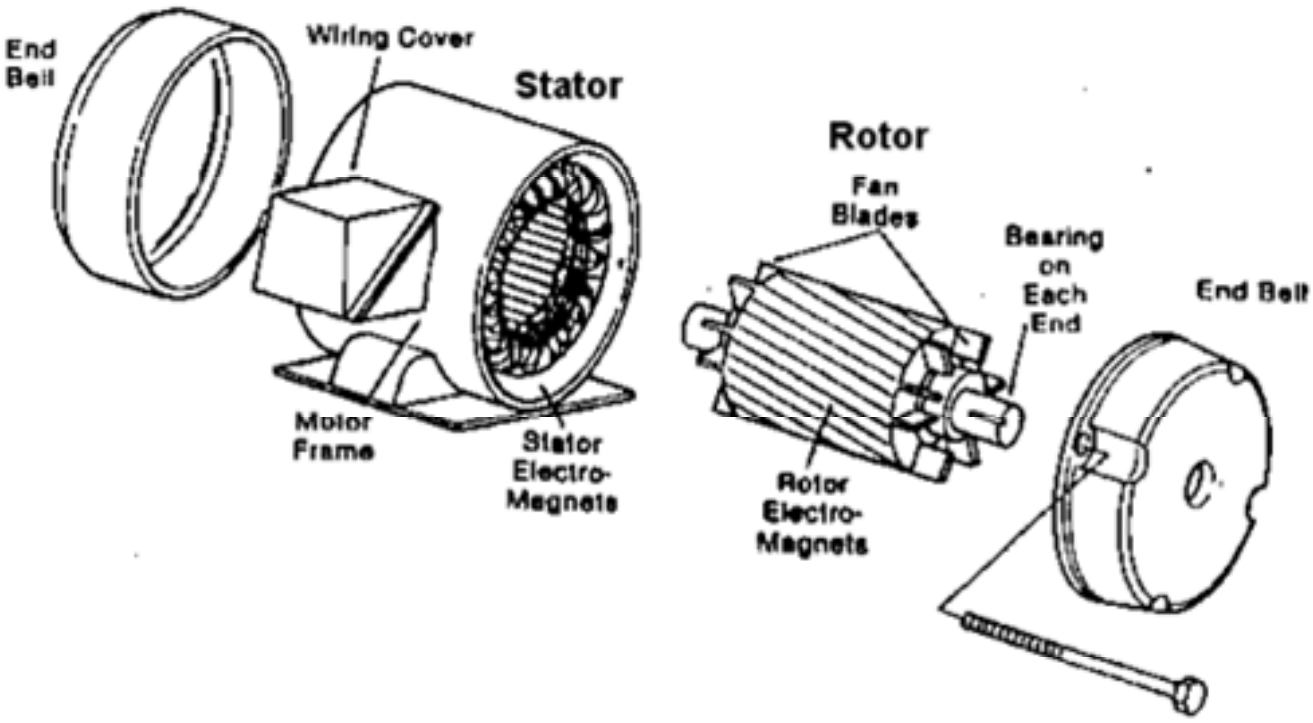
Electric Motors

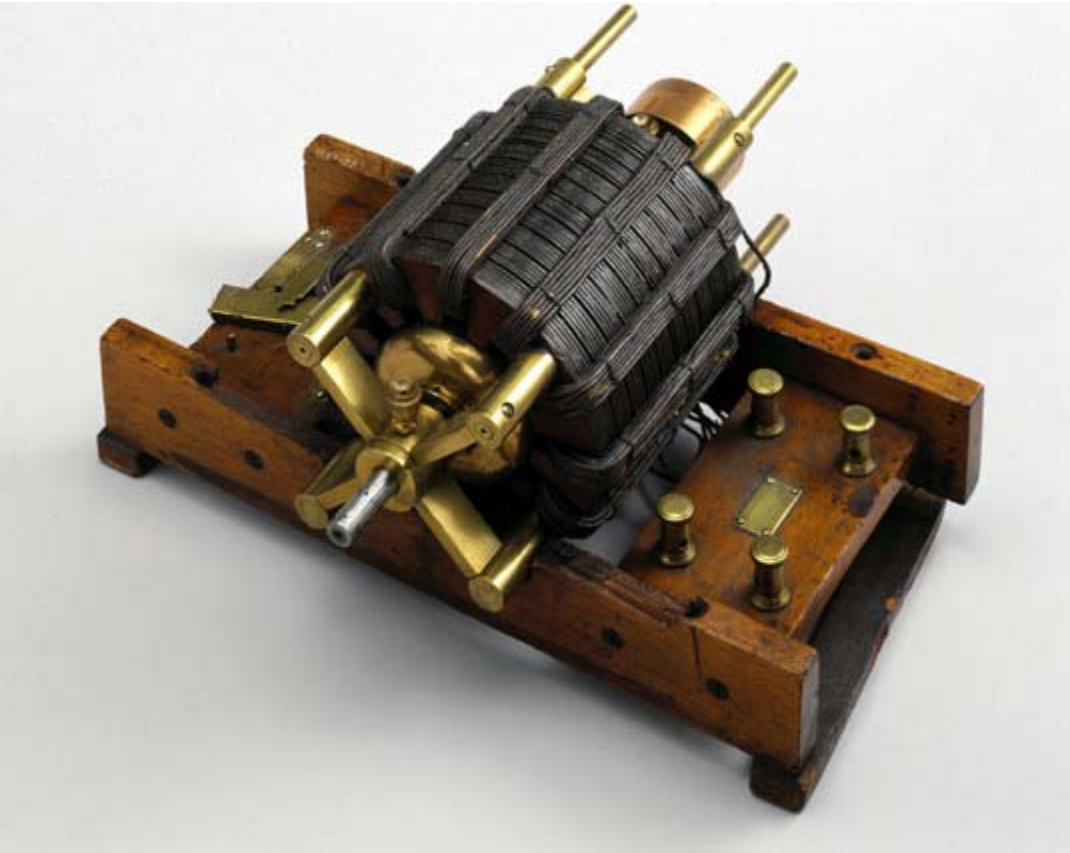


Uh - oh

How would you make an *AC motor*?
-- Electromagnetic Induction

Induction Motors

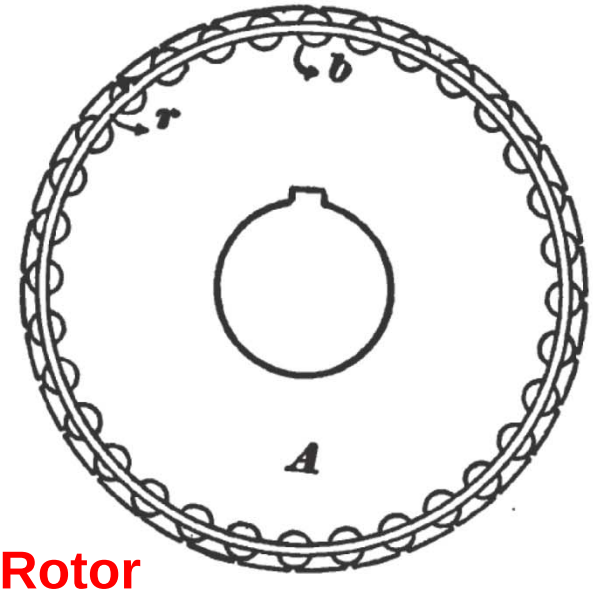




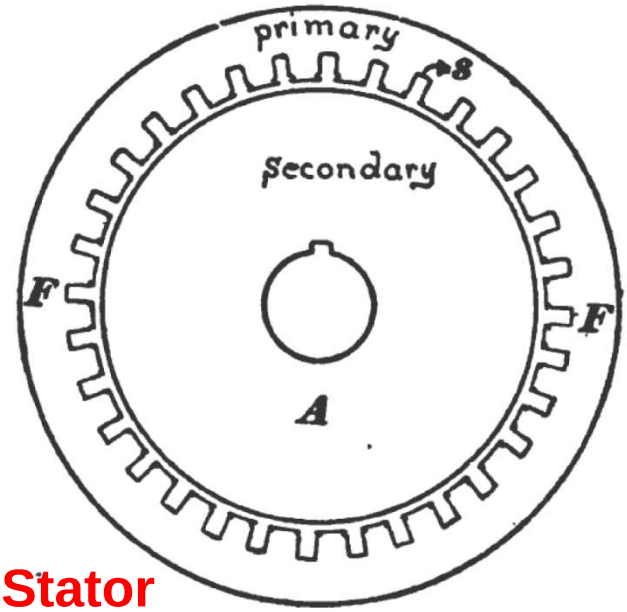
Nikola Tesla (1856-1943), Croatian-born American physicist and electrical engineer, patented in 1887-1888 what has become the most widely used type of electric motor, the induction motor. The induction motor is simple to make because it has no electrical contacts to the rotor. Instead it uses a rotating magnetic field produced by two or more alternating currents in the stationary outer windings (the stator). The induction motor was a major factor in the adoption of alternating current (ac) electricity supplies.

Visit the museum
Exhibition Road, South Kensington, London SW7 2DD.
Switchboard: 0870 870 4868

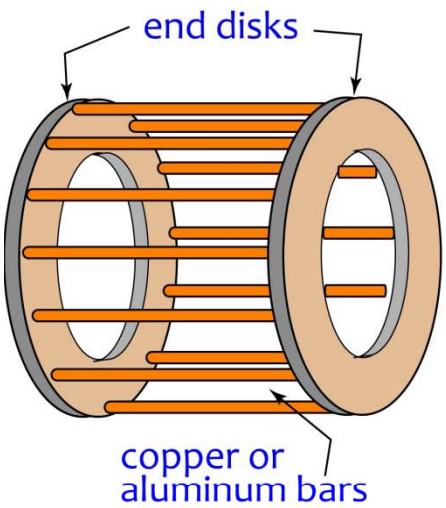
The induction motor was invented by Nikola Tesla, over a period of years from 1882 to 1889.



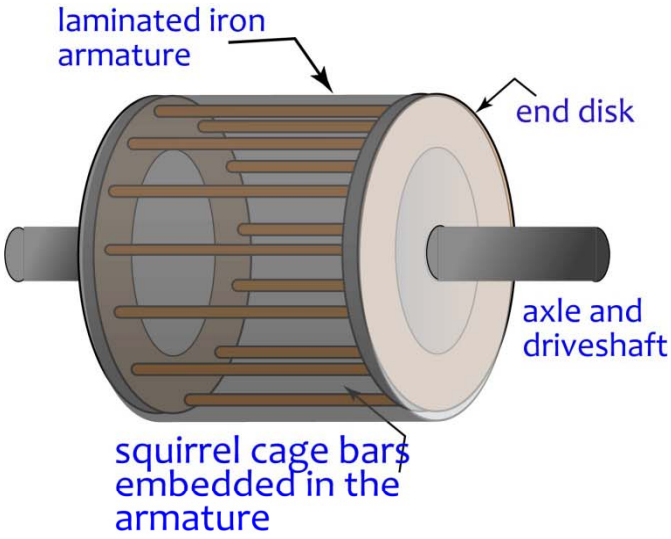
Rotor
- experiences torque



Stator
- for field windings

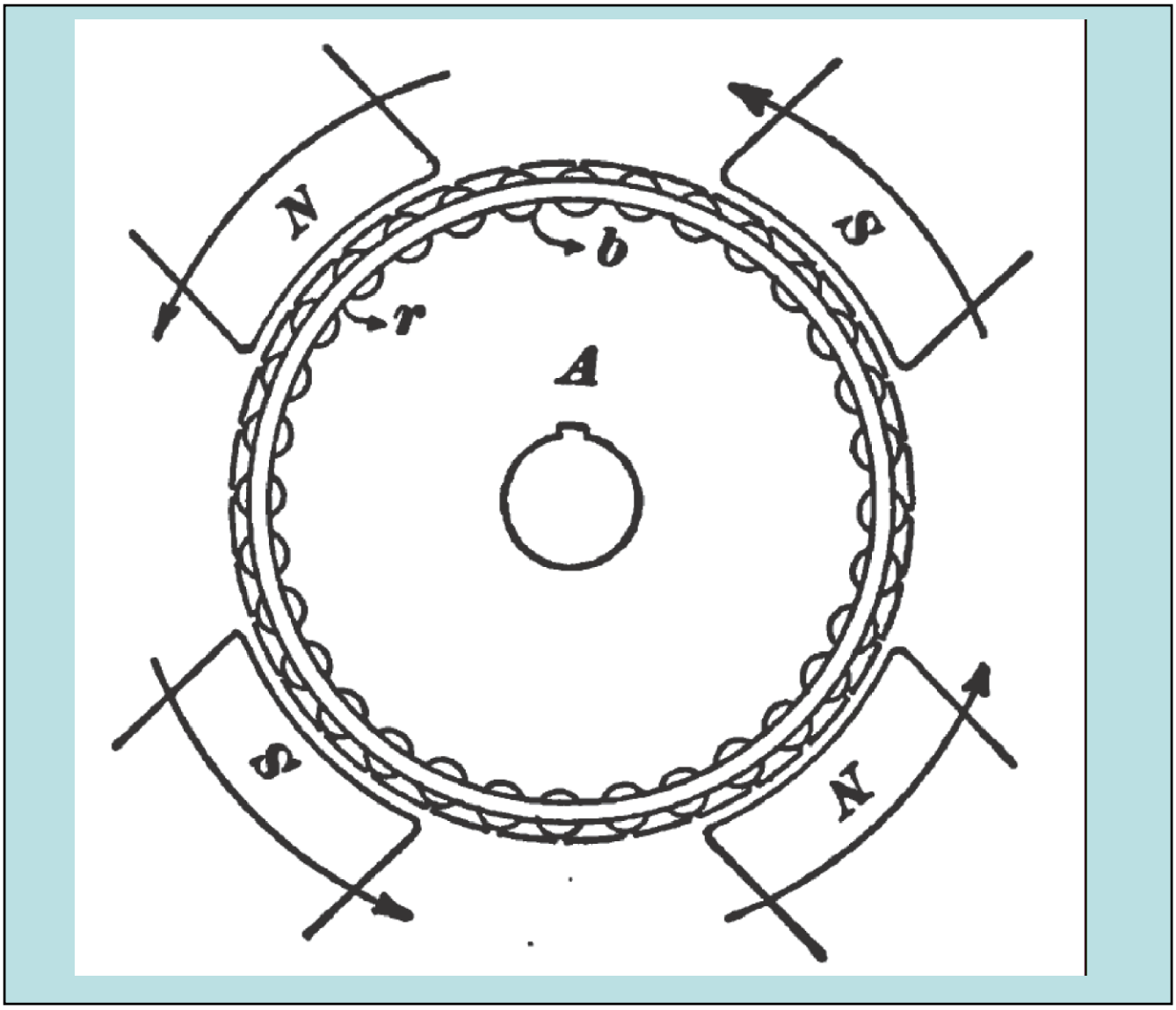


"squirrel cage" rotor



induction motor rotor

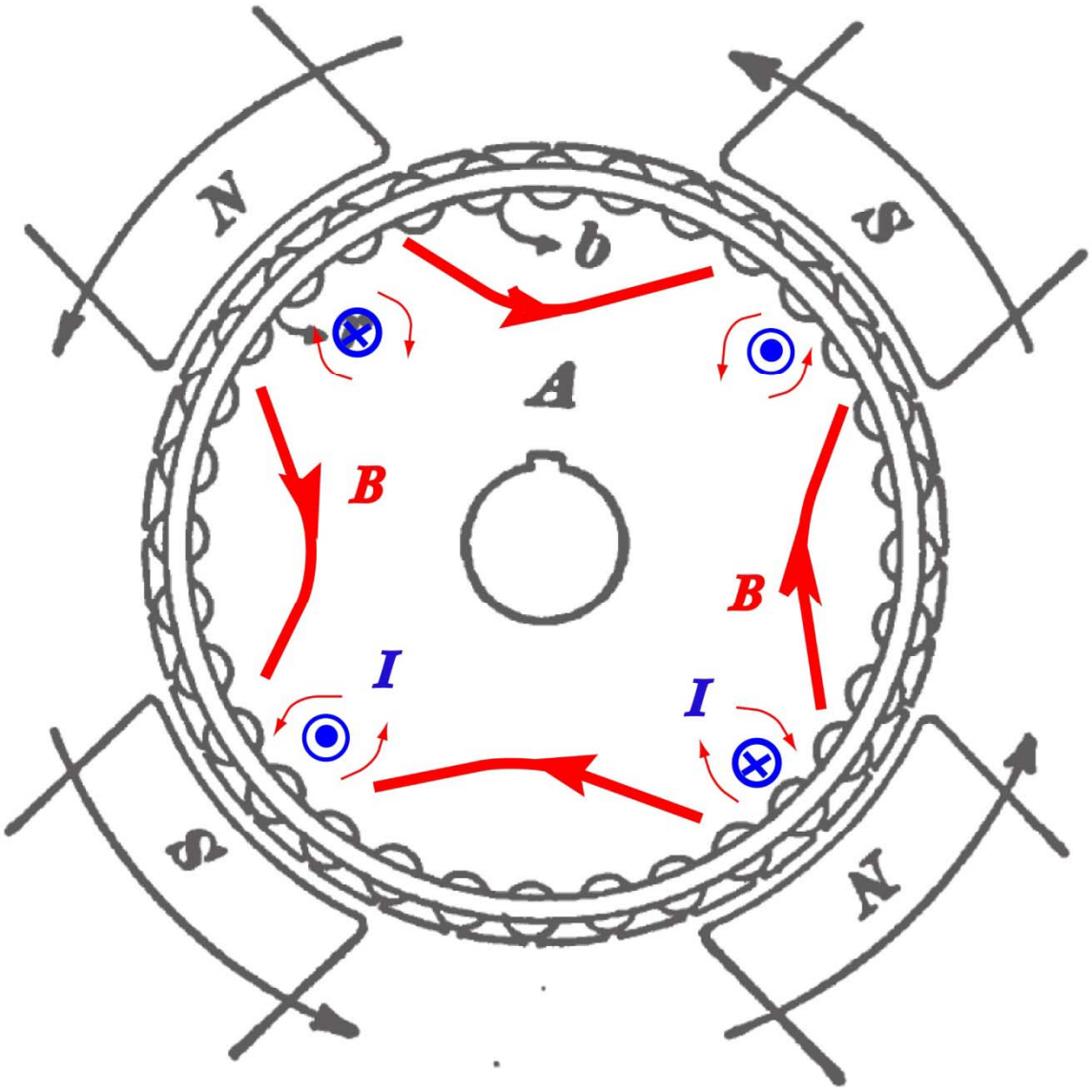
The idea --- a *rotating magnetic field* induces current in the "squirrel cage"; then the magnetic field exerts a torque on that current.



The idea ---

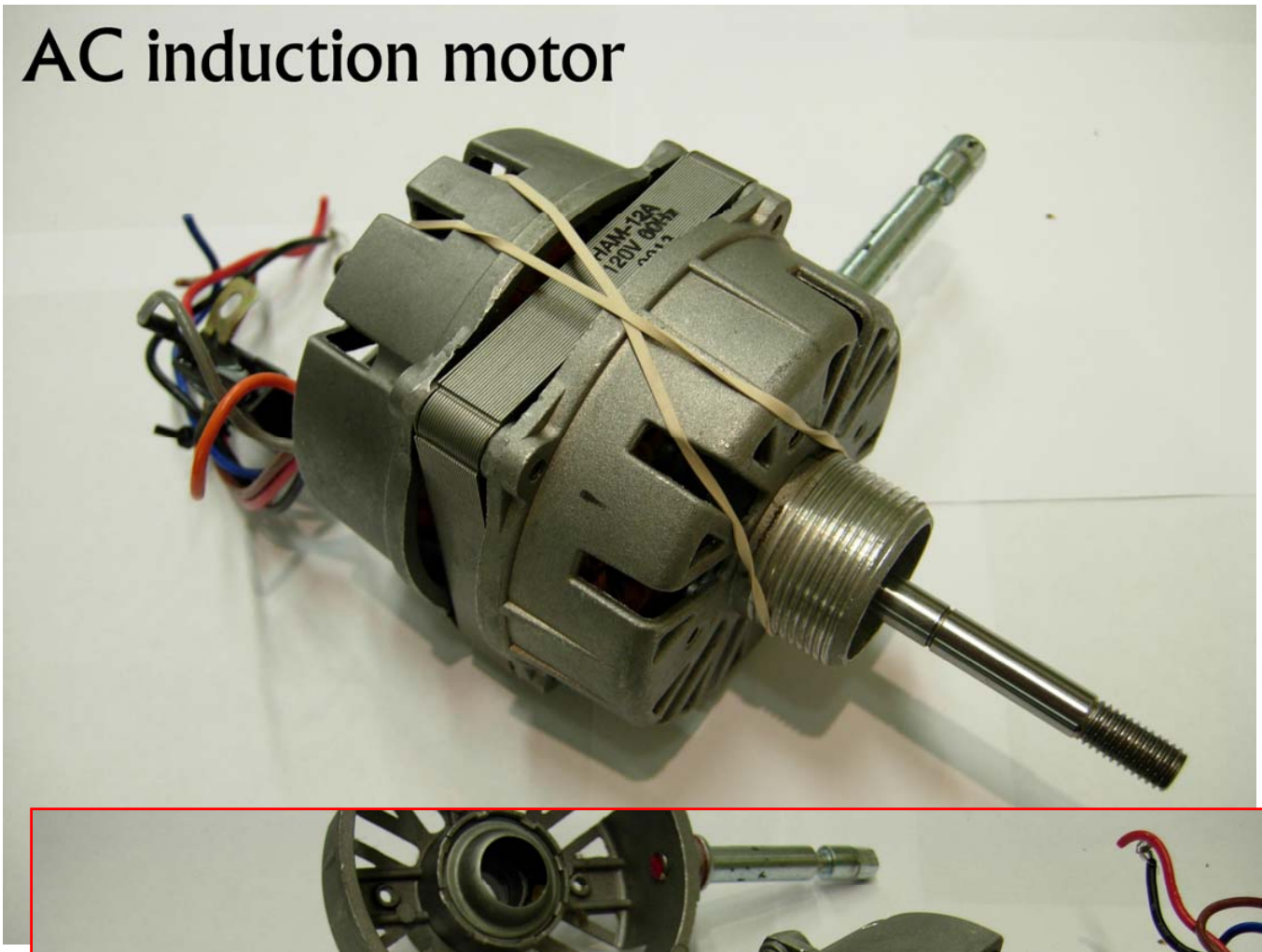
--- a *<u>rotating magnetic field</u>* induces current in the “squirrel cage”; then the magnetic field exerts a torque on that current.

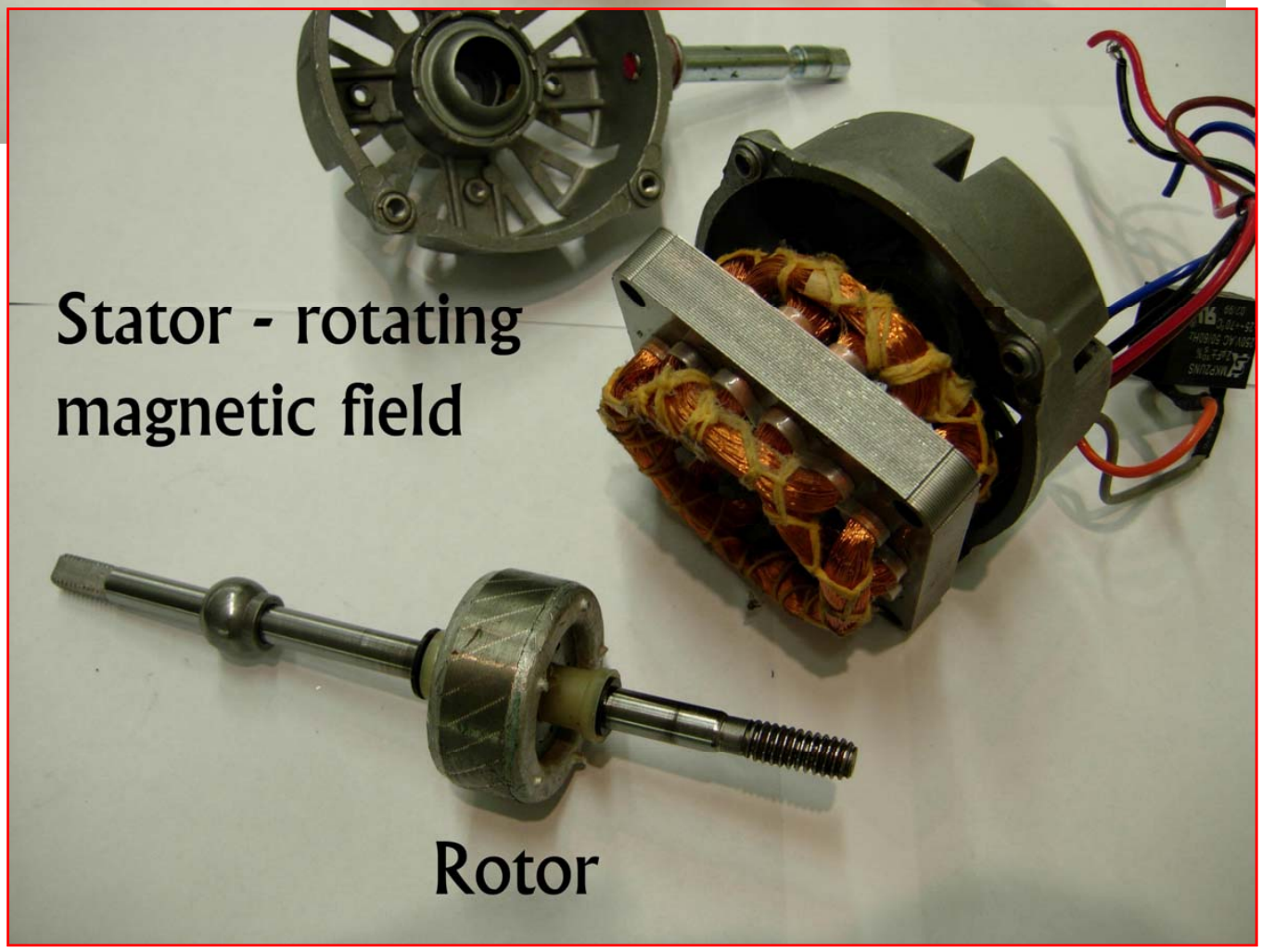
Wind the coils of the stator such that the alternating current makes a rotating magnetic field.



The torque on the induced currents, drags the rotor around with the rotating field.

AC induction motor





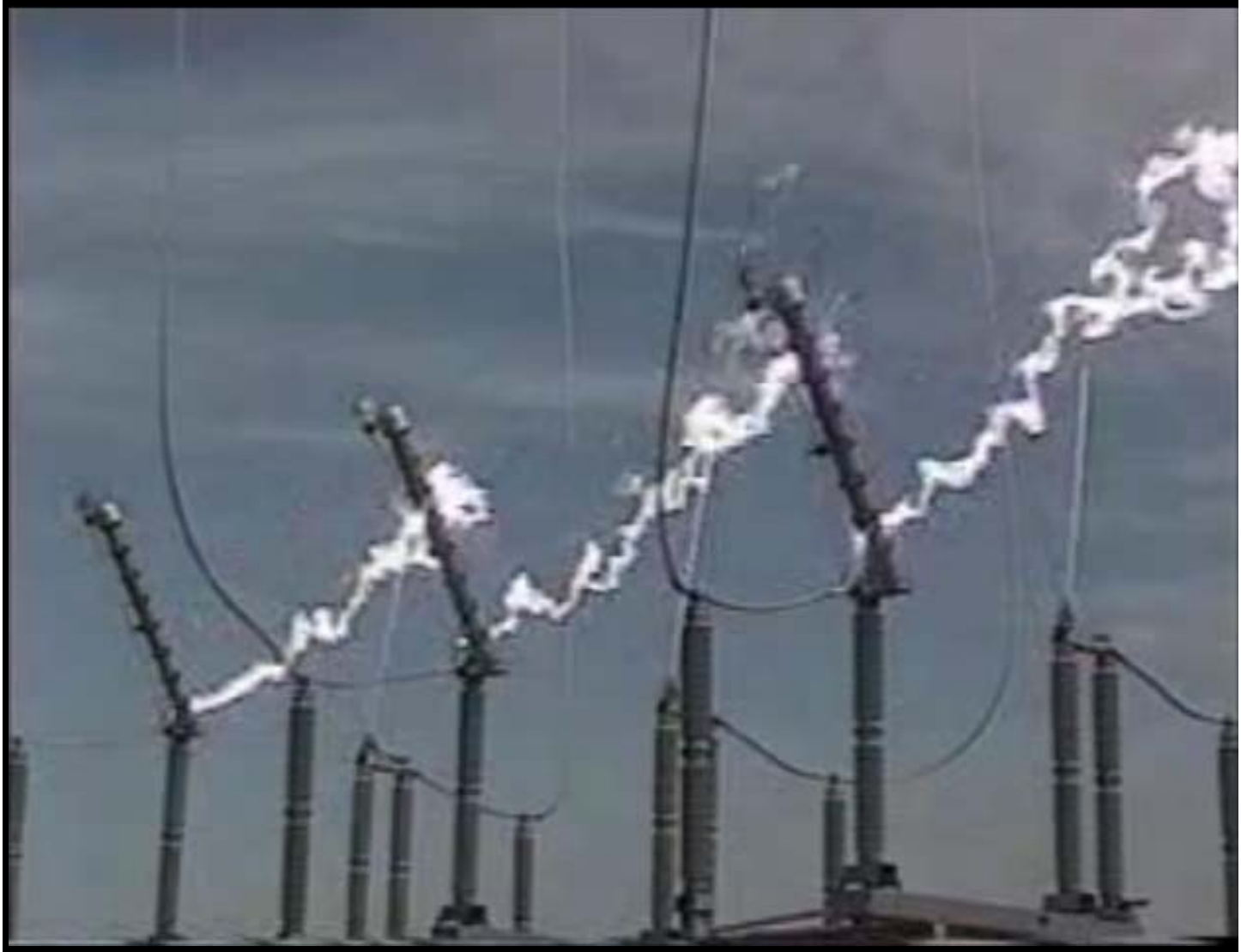
AC induction motor

(salient pole construction)

Coke Can Motor

Ludington Pumped Storage Plant
(2 GB peak power)

Next time:
Inductance



Quiz Question

List 5 electric motors that you use everyday *at home*. (Do ***not*** include electric motors in a car.)