Faraday’s Law of Induction II

Physics 2415 Lecture 20

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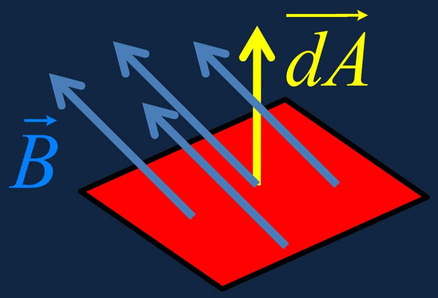
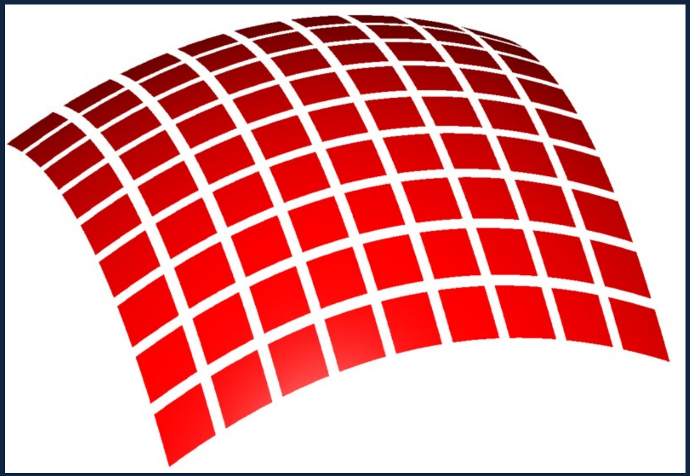
Today's Topics

- Faraday's Law of Induction
- Electric Generators
- Eddy Currents
- Electric Motors
- Transformers

Magnetic Flux through a Loop

- Recall Gauss' theorem related flux of electric field through an area enclosing a volume to the charge inside.
- Faraday introduced the concept of magnetic flux through a loop: the loop is "roofed" with a surface having the loop as boundary, the magnetic flux through the loop is





$$\Phi_B = \int \vec{B} \cdot \overrightarrow{dA}$$

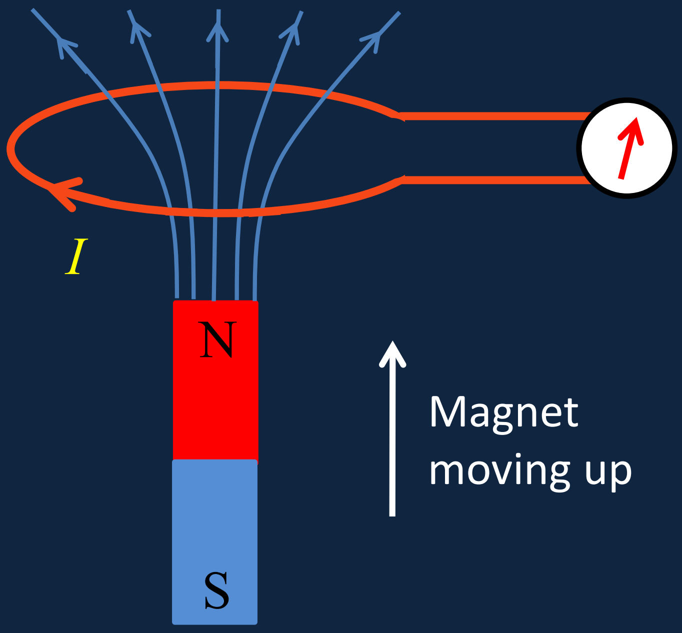
The integral is over the surface, adding contributions from tiny squares.

Faraday's Law of Induction

- Faraday's law of induction states that when the magnetic flux through a loop is changing, there is an induced emf in the loop given by:

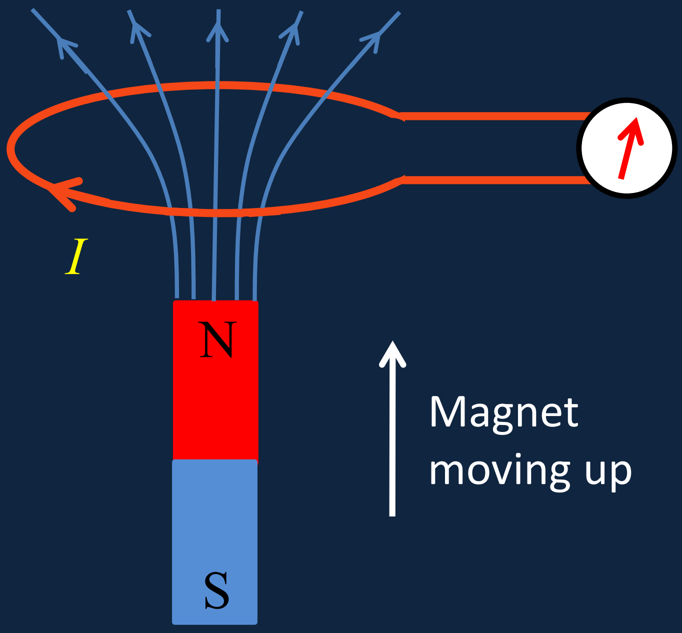
$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

- You get the sign of the emf from Lenz's law…



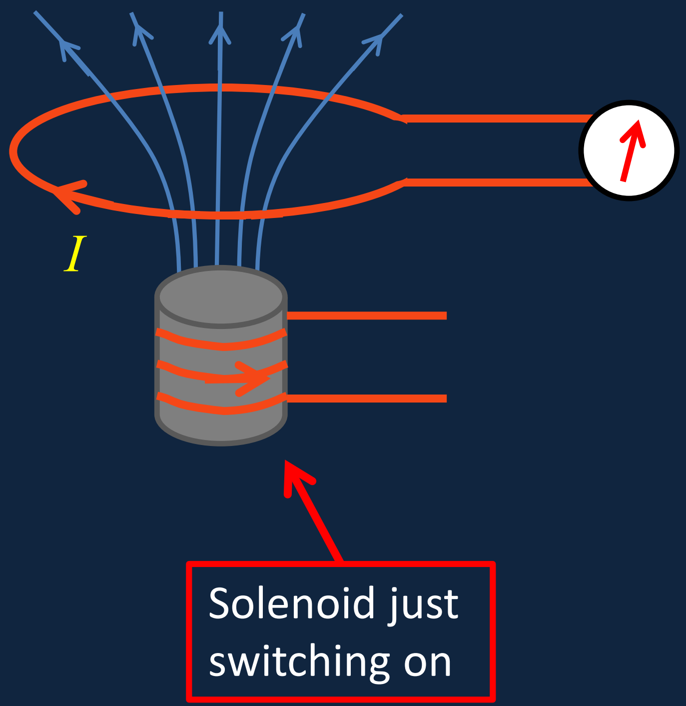
Lenz's Law

- The direction of the induced emf generated by a changing magnetic flux is always such as to oppose the motion.
- Example: as the N pole moves up towards the loop, the current induced generates an N pole underneath to repel and slow down the approaching magnet.



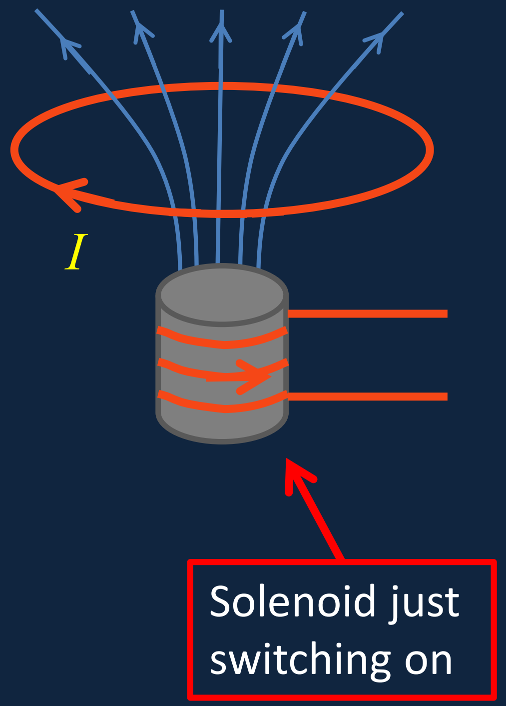
Lenz's Law Continued…

- The direction of the induced emf generated by a changing magnetic flux is always such as to oppose the change in flux through the loop.
- <u>Example</u>: as the solenoid switches on, creating upward magnetic flux through the loop, the current generated in the loop will add <u>downward</u> flux.



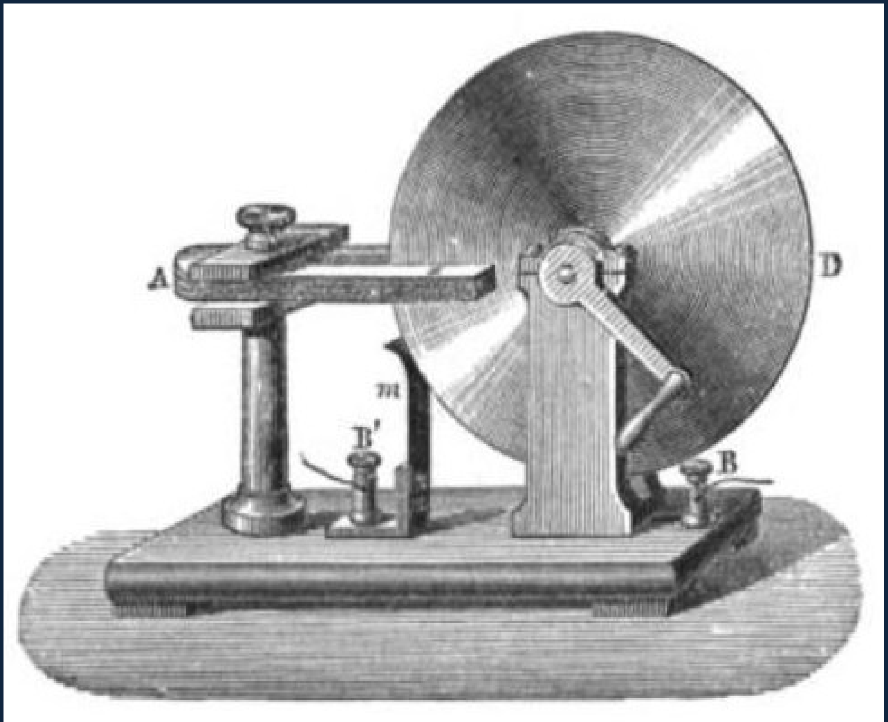
More on Lenz's Law

- Example: as the solenoid switches on, creating upward magnetic flux through the loop, the current generated in the loop will add downward flux.
- This means there is considerable transient force on the loop!



Electric Generators

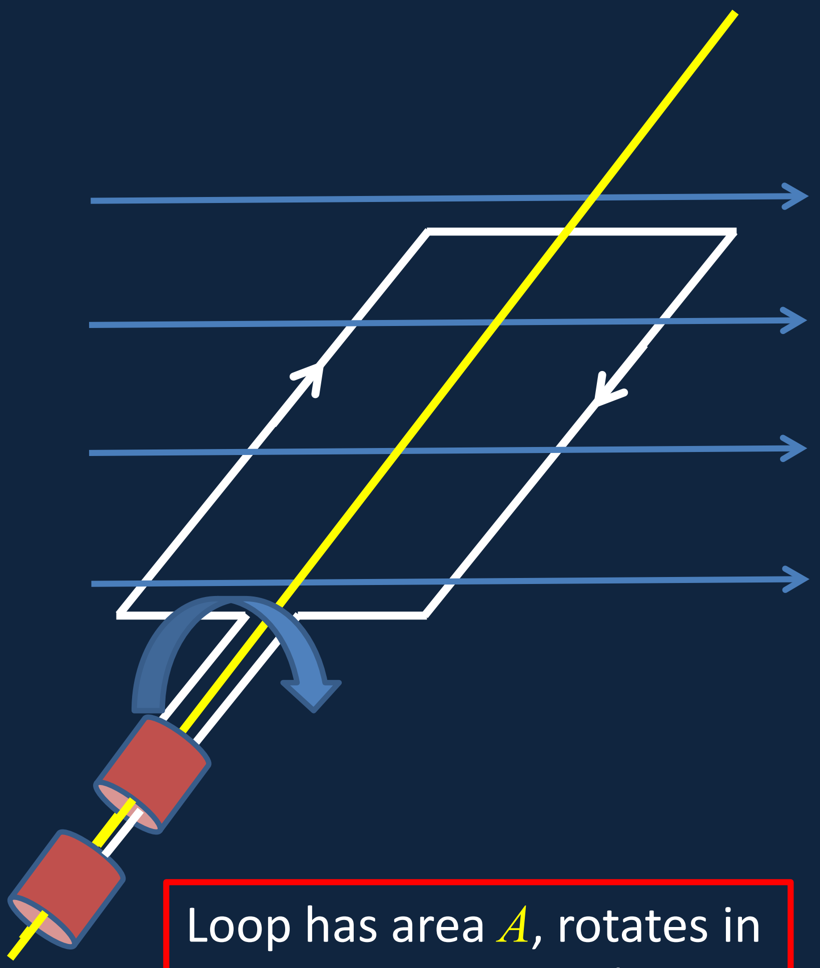
- The basic idea is to do work moving a conductor through a magnetic field, producing an emf, then provide a circuit so the emf can generate a current and therefore electrical energy.



Copy of the first electric generator, constructed by Michael Faraday in 1831. A is the magnet; B, B' the terminals.

Electric Generators

- The essential mechanism is a loop, or in practice a coil of many loops, rotating in a magnetic field, such as between the poles of a horseshoe magnet.
- If the current is collected via slip rings (no commutator) it will be ac, for one loop:



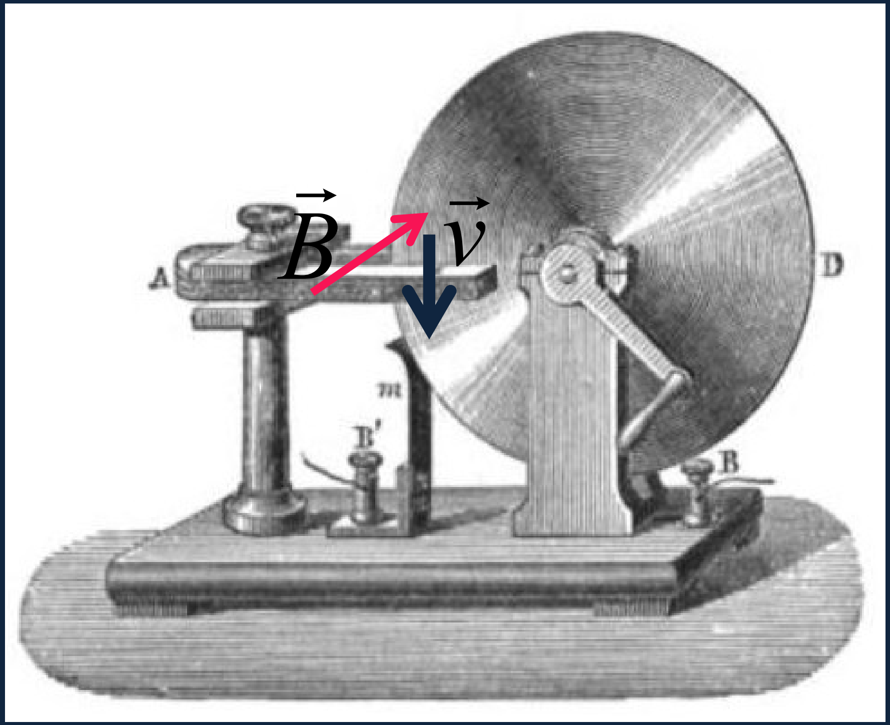
$$\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d}{dt} BA\cos\omega t = BA\omega \sin\omega t$$

Loop has area A, rotates in field B at ω radians/sec.

ωt is the angle between $\vec{B}$ and coil area vector $\vec{A}$

Back to Faraday's Generator

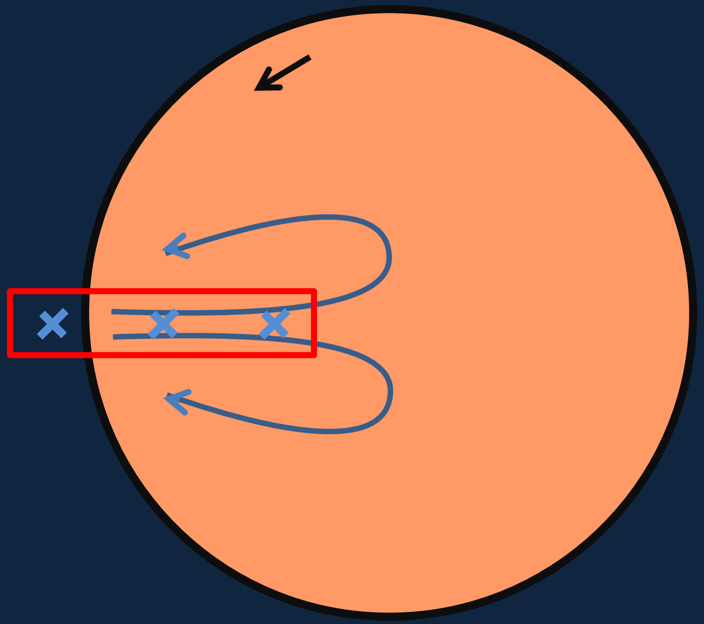
- If the disc is spinning anticlockwise, $\vec{v} \times \vec{B}$ points inwards, so while the disc is rotating, an electric current is generated under and near the magnet flowing inwards to the axle, and round the external circuit.



What happens if there is no external circuit?

Eddy Currents

- If we have an isolated rotating conducting disc, part between the poles of a magnet, the current generated in the magnetic field must find its way back: the circling currents are called eddy currents.
- They look like the eddies for a boat going through water.



Eddy Currents and Lenz' Law

- The magnet's field is pointing downwards.
- The eddy current before the magnet tries to minimize the field increase, that after the magnet tries to minimize the field decrease: in both cases, they oppose the motion.
- Since the conductor has resistance to current flow, heat is generated: this can be eliminated by breaking the circuit—or used for cooking!