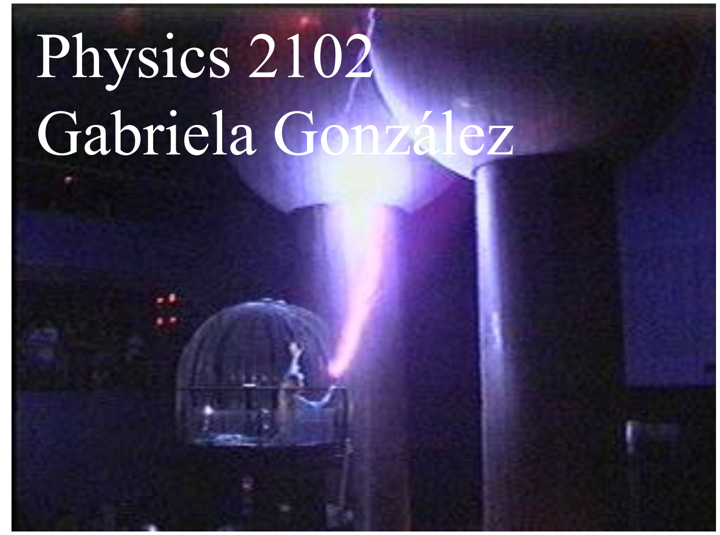
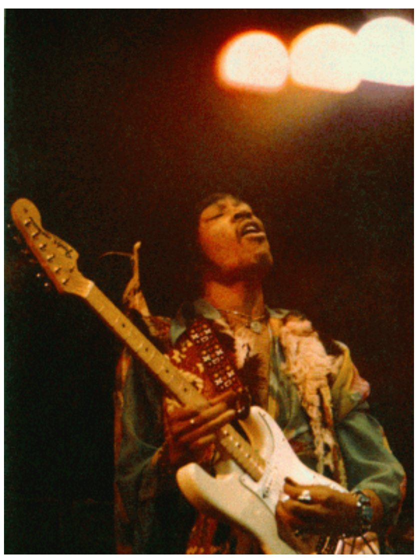


Physics 2102

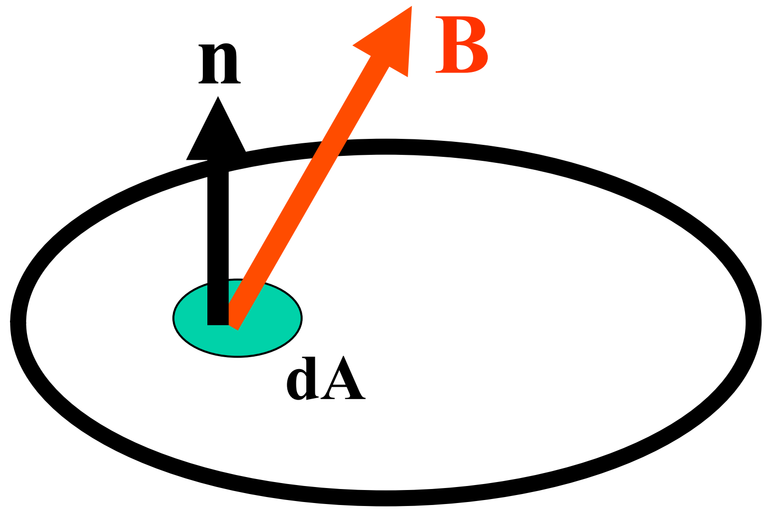
Faraday's law



Faraday's Law

A magnetic field can create a en electrical current too!

If we define magnetic flux, similar to definition of electric flux, but for an open surface with an edge:



$$\Phi_B = \int_S \vec{B} \cdot \hat{n} dA$$

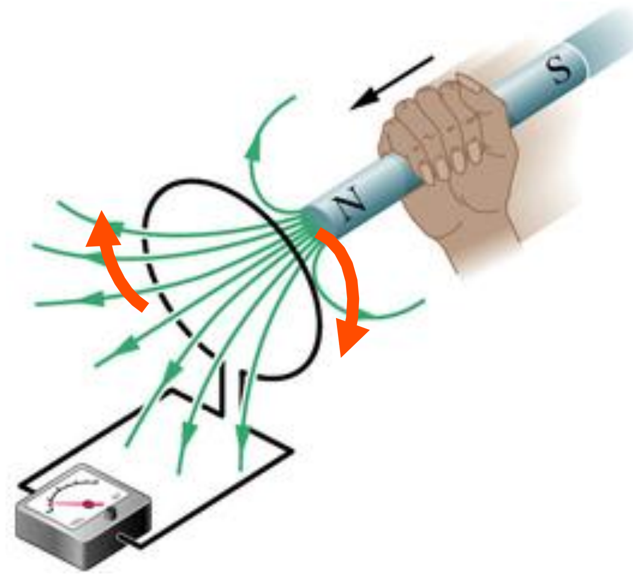
Then a <u>time varying</u> magnetic FLUX creates an induced EMF, and thus an electrical current if the edge is a wire!:

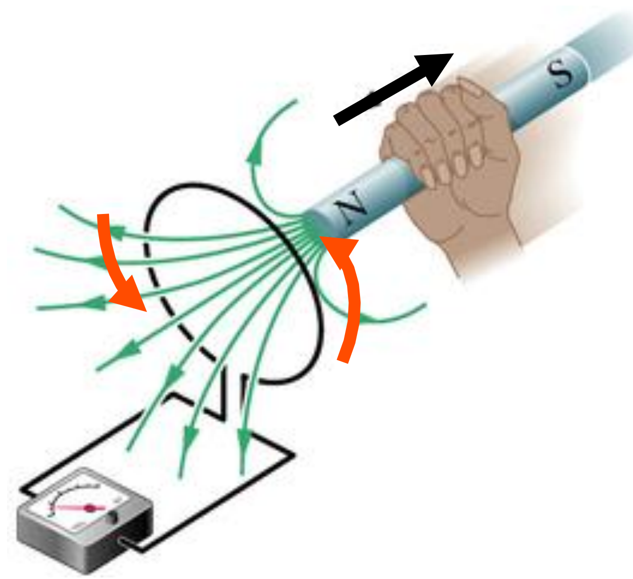
$$EMF = -\frac{d\Phi_B}{dt}$$

- Take note of the MINUS sign!!
- The induced EMF acts in such a way that it OPPOSES the change in magnetic flux ("Lenz's Law").

Example

- When the N pole approaches the loop, the flux "into" the loop ("downwards") increases
- The loop can "oppose" this change if a current were to flow clockwise, hence creating a magnetic flux "upwards."
- So, the induced EMF is in a direction that makes a current flow clockwise.
- If the N pole moves AWAY, the flux "downwards" DECREASES, so the loop has a counter clockwise current!

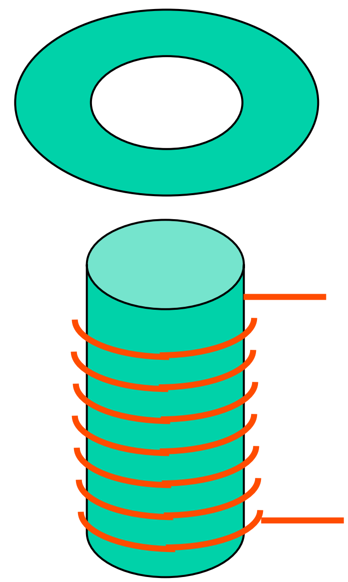




Faraday's law: Eddy Currents

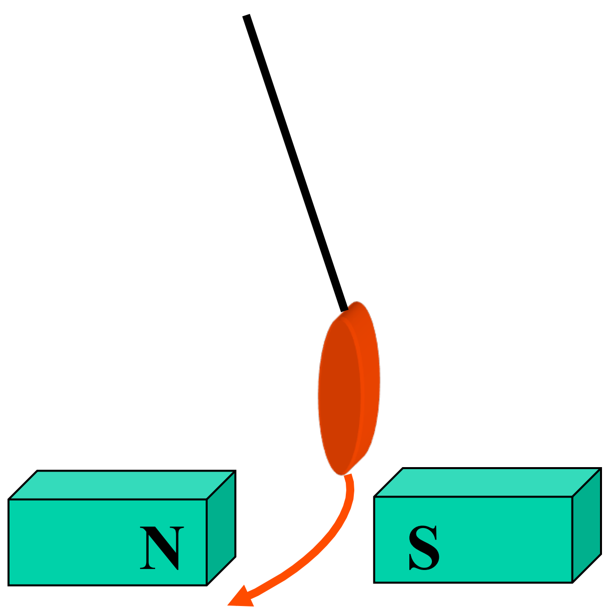
$$\Phi_B = \int_S \vec{B} \cdot \hat{n} dA \qquad EMF = -\frac{d\Phi_B}{dt}$$

- A non-magnetic (e.g. copper, aluminum) ring is placed near a solenoid.
- What happens if:
  - There is a steady current in the solenoid?
  - The current in the solenoid is suddenly changed?
  - The ring has a "cut" in it?
  - The ring is extremely cold?



Another Experimental Observation

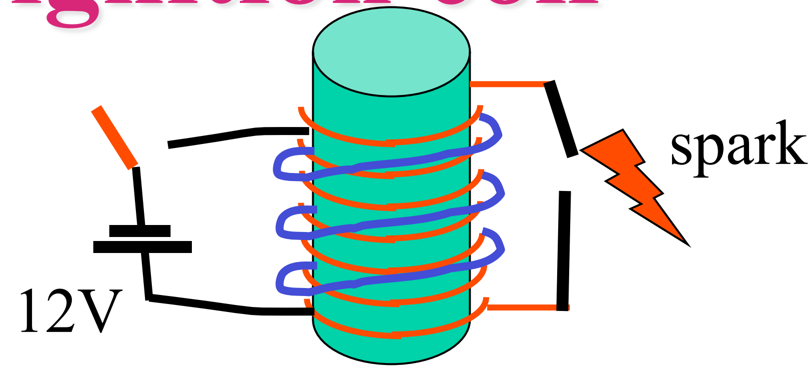
- Drop a non-magnetic pendulum (copper or aluminum) through an inhomogeneous magnetic field
- What do you observe? Why? (Think about energy conservation!)



Pendulum had kinetic energy
What happened to it?
Isn't energy conserved??

Example : the ignition coil

- The gap between the spark plug in a combustion engine needs an electric field of ~10^7 V/m in order to ignite the air-fuel mixture. For a typical spark plug gap, one needs to generate a potential difference > 10^4 V!
- But, the typical EMF of a car battery is 12 V. So, how does a spark plug work??



•Breaking the circuit changes the current through "primary coil"

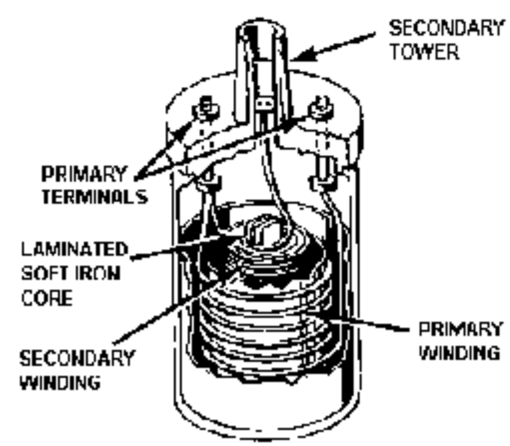
• Result: LARGE change in flux thru secondary -- large induced EMF!

The "ignition coil" is a double layer solenoid:

• Primary: small number of turns -- 12 V

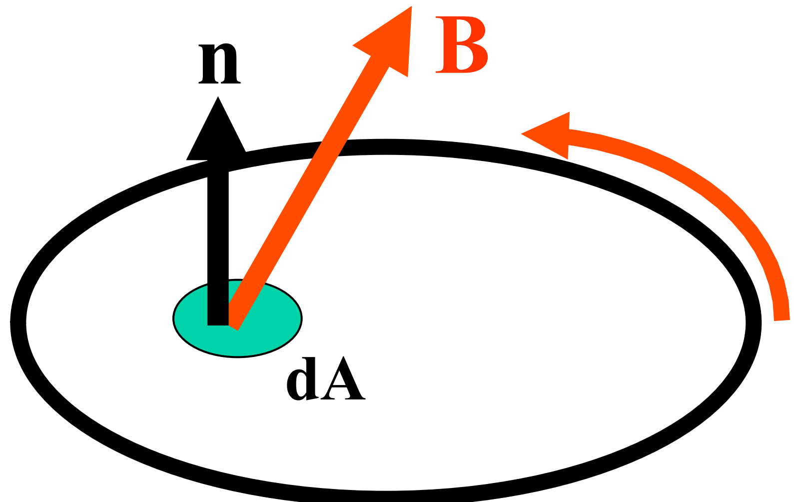
• Secondary: MANY turns -- spark plug

http://www.familycar.com/Classroom/ignition.htm



Another formulation of Faraday's Law

- We saw that a time varying magnetic FLUX creates an induced EMF in a wire, exhibited as a current.
- Recall that a current flows in a conductor because of electric field.
- Hence, a time varying magnetic flux must induce an ELECTRIC FIELD!
- Closed electric field lines!!?? No potential!!

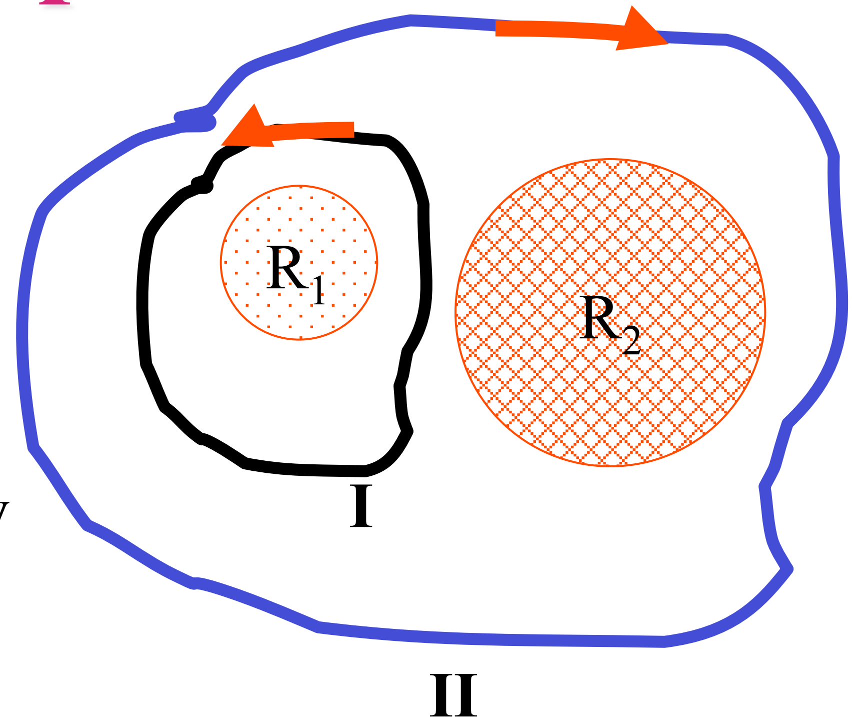


$$\oint_C \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

Another of Maxwell's equations!
To decide SIGN of flux, use right hand rule: curl fingers around loop, +flux -- thumb.

Example

- The figure shows two circular regions R_1 & R_2 with radii $r_1 = 1m$ & $r_2 = 2m$. In R_1, the magnetic field B_1 points out of the page. In R_2, the magnetic field B_2 points into the page.
- Both fields are uniform and are DECREASING at the SAME steady rate = 1 T/s.
- Calculate the "Faraday" integral $\oint_C \vec{E} \cdot d\vec{s}$ for the two paths shown.



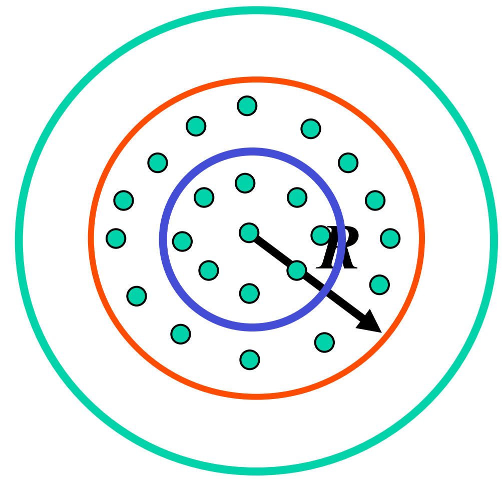
Path I: $\oint_C \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} = -(\pi r_1^{\,2})(-1T/s) = +3.14V$

Path II:

$$\oint_C \vec{E} \cdot d\vec{s} = -\left[-(\pi r_1^{\,2})(-1T/s) + (\pi r_2^{\,2})(-1T/s)\right] = +9.42V$$

Example

- A long solenoid has a circular cross-section of radius ***R***.
- The current through the solenoid is <u>increasing</u> at a steady rate ***di/dt***.
- Compute the variation of the electric field as a function of the distance ***r*** from the axis of the solenoid.



First, let's look at ***r < R:***

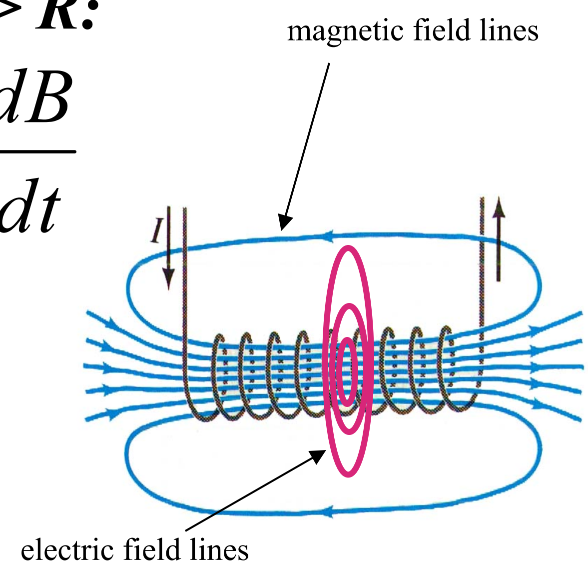
$$|E|(2\pi r) = (\pi r^2)\frac{dB}{dt}$$

$$E = \frac{r}{2}\frac{dB}{dt}$$

Next, let's look at ***r > R:***

$$|E|(2\pi r) = (\pi R^2)\frac{dB}{dt}$$

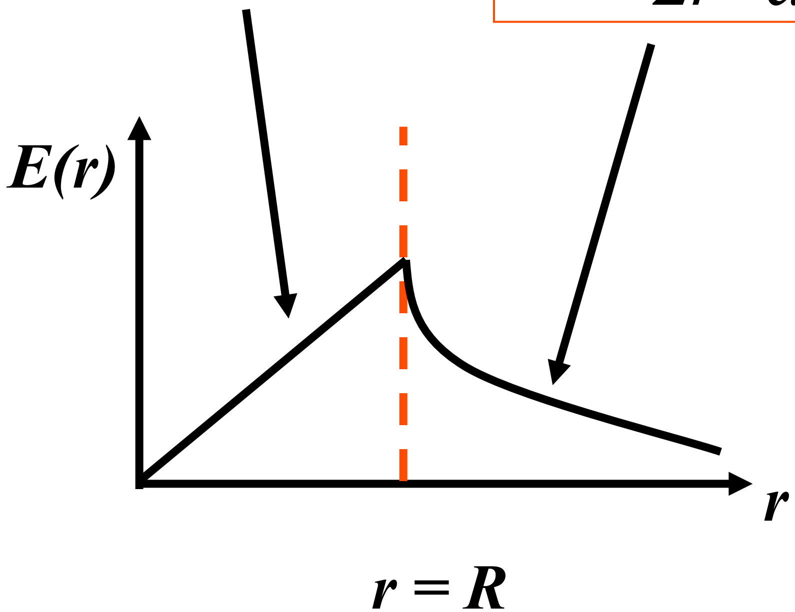
$$E = \frac{R^2}{2r}\frac{dB}{dt}$$



Example (continued)

$$E = \frac{r}{2}\frac{dB}{dt}$$

$$E = \frac{R^2}{2r}\frac{dB}{dt}$$



Summary

Two versions of Faradays' law:

– A varying magnetic flux produces an EMF:

$$EMF = -\frac{d\Phi_B}{dt}$$

– A varying magnetic flux produces an electric field:

$$\oint_C \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$