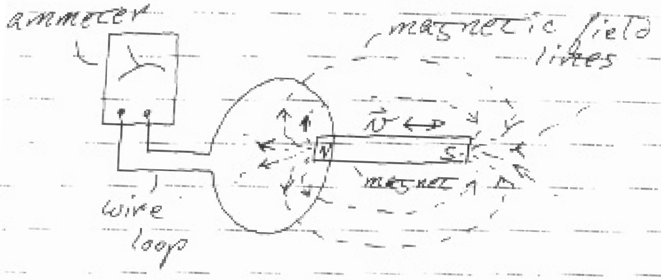
Using Magnet to Induce emf

- see moving charge → B-field
→ what about a moving magnet?



No batteries in circuit.

∴ no EMF + no motion of charges... Right!?

Nope! If we place a magnet near the loop & move it:

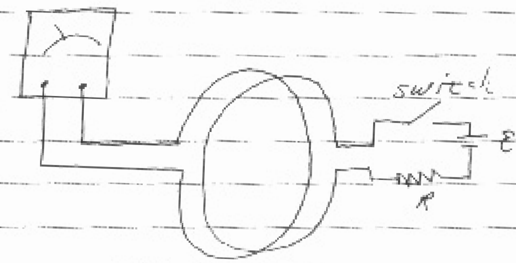
We see a current!

- If stop motion ⟹ $I = 0$
- move in opposite direction: $I = -I_{original}$
- turn magnet around: changes sign of I again

What is this 'induced' current?

Two Conducting Loops

Okay, let's try another way to change B-field: change current in a circuit



Two wire loops very close to each other.

When close switch, see a momentary current in left loop
→ corresponds to time when I is increasing to equilibrium value

(3)

<u>Magnetic Flux</u>

We define, as with $\vec{E}$ + ϕ_E:

$$\boxed{\phi_B = \int \vec{B}\cdot d\vec{A}}$$

{Note: $\oint \vec{B}\cdot d\vec{A}$ = ~~μ_0~~ $q_{mag\text{-}inside}$ $= 0$ since no magnetic monopoles.
closed surface}

- units weber: $1\ Wb = 1\ Tm^2$

In previous examples, it's the magnetic flux thru the surface bounded by the left loop that matters.

→ when more magnet closer: more field lines thru surface

→ when increase I: increase # B-field lines

(4)

<u>Faraday's Law of Induction</u>

"induced emf in a circuit is equal to the negative of the rate at which magnetic flux thru the circuit is changing"

$$\boxed{\mathcal{E} = -\frac{d\phi_B}{dt}}$$

<u>Lenz's Law</u>: induced emf sets up current producing a $\Delta\phi_B$ opposing the "inducing" $\Delta\phi_B$

⇐ - tends to keep original ϕ_B thru circuit from changing

Fundamental form

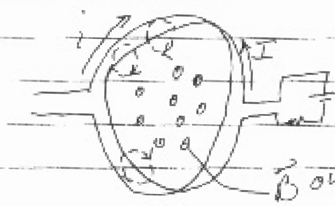
relates $|E|$ + $|B|$ directly

$$\oint \vec{E}\cdot d\vec{l} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A}$$

Wow!

closed loop, C

open surface bounded by C



$\vec{B}$ out of page from circuit

→ if I is increasing, B_{out} rising

→ so induced "i" gives $B_{into\text{-}page}$ to oppose this

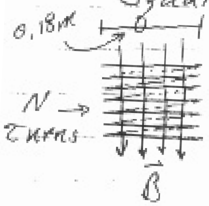
Multiple Loops

If we have a solenoid of N turns, multiply effect

$$\mathcal{E} = -N\frac{d\phi_B}{dt}$$

- because each turn occupies essentially same space
  - therefore has same ϕ_B

Square Coil (Ex 31.1)



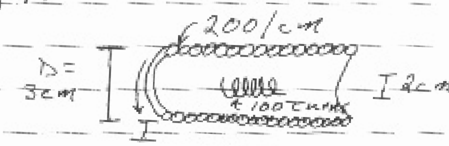
$N = 200$
$B(t=0) = 0T$
$B(t=0.8s) = 0.5T$

$\phi_B^{t=0} = B_0 A = 0$
$\phi_B^{t=0.8s} = B_{0.8} A = (0.5T)(0.18m)^2$
$= \underline{0.0162\ Tm^2}$

$|\mathcal{E}| = N\frac{d\phi_B}{dt} = (200)\frac{(0.0162\ Tm^2 - 0)}{0.8s}$
$= 4.1\ Tm^2/s = \boxed{4.1V}$

Example: Coil inside a Solenoid

Consider a solenoid, A + coil that are co-axial:



I in solenoid lowered from $+1.5A \to 0 \to -1.5A$ in 50 ms.

Since $\phi_B = \int \vec{B}\cdot d\vec{A} = BA$, need to calculate B for $t = 0$ & $t = 50ms$

$B_0 = \mu_0 n I_0 = (4\pi\times10^{-7}\ Tm/A)\left(\frac{200}{0.01m}\right)(1.5A)$
$= \underline{38mT}$

$\phi_{B_0} = B_0 A = (38\times10^{-3}T)(3.1\times10^{-4}m^2)$
$= \underline{12\mu Wb}$

The flux, therefore, goes from $12\mu Wb$ to $-12\mu Wb$ in 50ms. The induced $\mathcal{E}$ in the coil is:

$\mathcal{E} = -N\frac{\Delta\phi_B}{\Delta t} = -(100)\left(\frac{24\times10^{-6}\ Wb}{50\times10^{-3}\ s}\right)$
$= \underline{-48mV}$