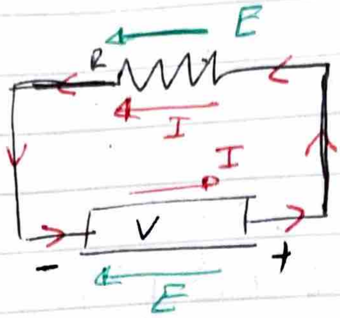
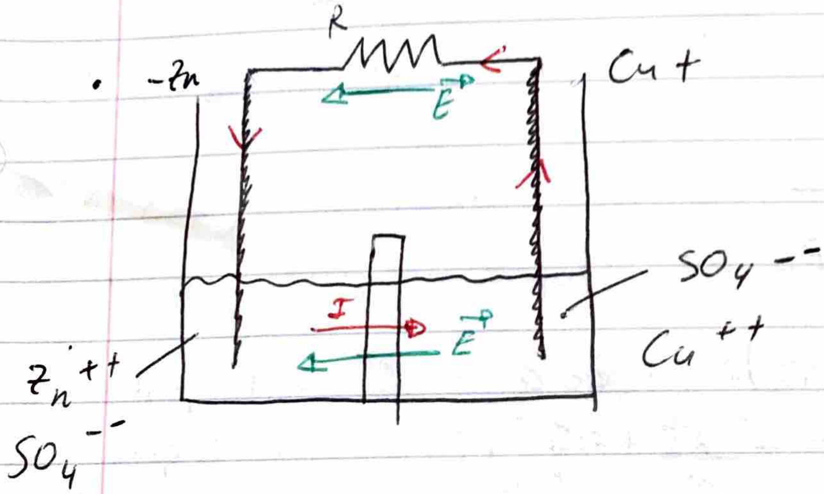
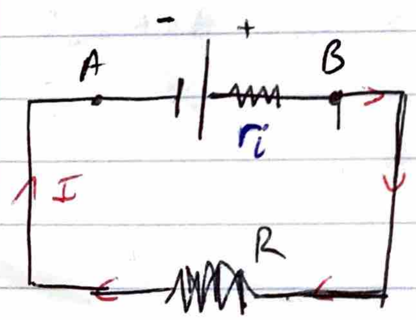
Lect 10

- Batteries, Power, Kirchoff's Rules, Circuits, Kelvin Water Dropper

• 

• 

• 

• $R = \infty$ $\quad I = 0 \quad V_B - V_A = \varepsilon$ internal resistance

• $\varepsilon = I(R + r_i) \quad V_b = IR = \varepsilon - I r_i$

• $R = 0 \quad I_{max} = \dfrac{\varepsilon}{r_i} \quad V_b = 0$

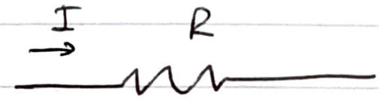
>  3ε

$V_A > V_B$

$$V_A \xrightarrow{dq} V_B$$

$$\frac{dW}{dt} = \frac{dq}{dt}(V_A - V_B)$$

$\boxed{P = IV}$ $\qquad V = IR \qquad P = I^2R = \frac{V^2}{R}$

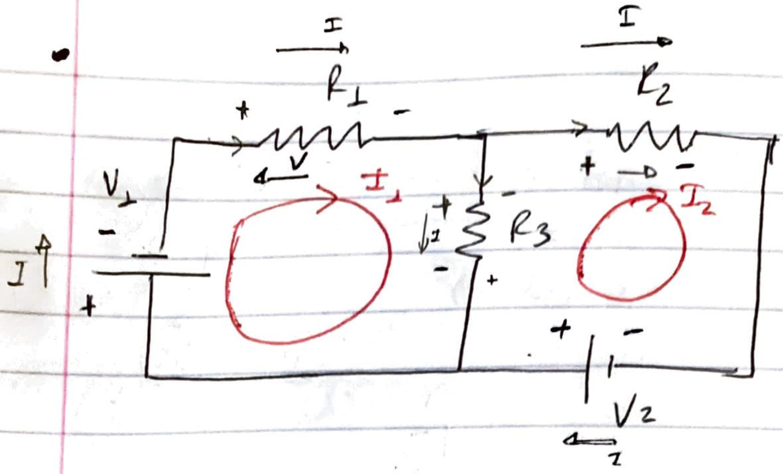


I R P

> $P = I\mathcal{E} = I^2(R + r_i) \qquad R = 0$

$I_{max} = \frac{\mathcal{E}}{r_i}$; $P_{max} = \frac{\mathcal{E}^2}{r_i} = I_{max}^2 r_i$.

- $kWh = 10^3 \cdot 3600\ J$.



Kirchoff's Rules

1) $\oint \vec{E} \cdot d\vec{l} = 0$

2) charge conservation.

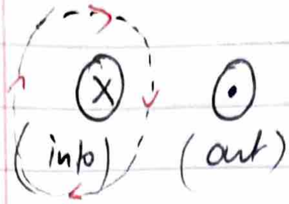
- Loop ① → $-V_1 - I_1 R_1 - I_1 R_3 + I_2 R_3 = 0$
- Loop ② → $-I_2 R_3 + I_1 R_3 - I_2 R_2 + V_2 = 0.$

$I_1 = +3A$ $\quad I_2 = +1A$ $\quad I_3 = 3 - 1 = 2A$

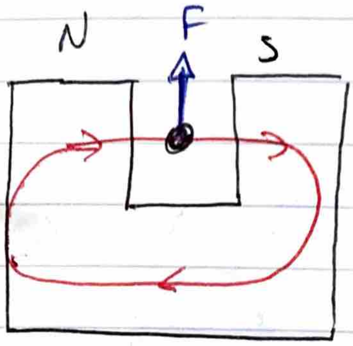
Lect 11

- Magnetic Fields, Lorentz Force, Torques, Electric Motors (DC)

• (vectors → coming from History)



(RH Rule.) → magnetic field going around wires.

> 

$\hat{F} = \hat{I} \times \hat{B}$

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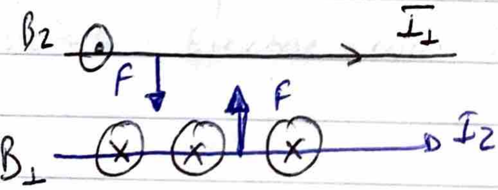
(N3L) 

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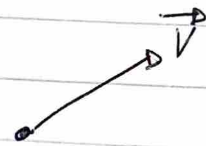
* $\vec{F_{el}} = q\vec{E}$ $\left[\vec{F_B} = q_B \vec{B} \times\right]$ → do not have a magnetic mono-pole

∴ 

(Found experimentally)

$\vec{F_B} \perp \vec{V}$

$\vec{F_B} \propto v$ $\vec{F_B} \propto q$

$\boxed{\vec{F_B} = q(\vec{v} \times \vec{B})}$

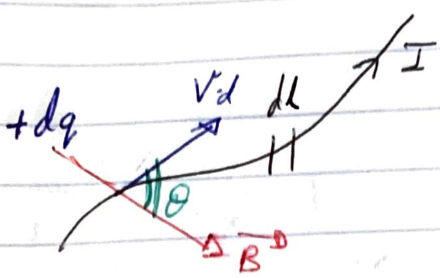
Lorentz Force.

(sign sensitive)

$\vec{B} = \left[\frac{Nsec}{Cm}\right] = [T]$

Tesla.

- $\vec{F}_{TOT} = q(\vec{E} + \vec{v} \times \vec{B})$ } Total force.

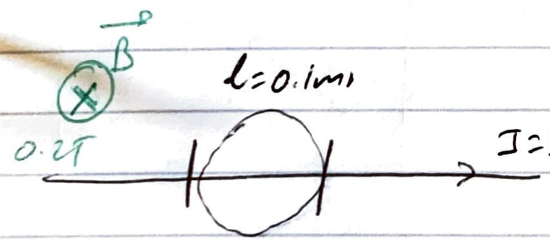


$$d\vec{F}_B = dq(\vec{v}_d \times \vec{B})$$

$$I = \frac{dq}{dt}$$

$$\therefore d\vec{F}_B = I\,\underbrace{dt(\vec{v}_d}_{dl} \times \vec{B})$$

$$\int_{wire} d\vec{F}_B = I(d\vec{l} \times \vec{B})$$



$$F_B = I l \vec{B} \quad (90^\circ)$$
$$= 300 \times 0.1 \times 0.2 = 6\,N$$

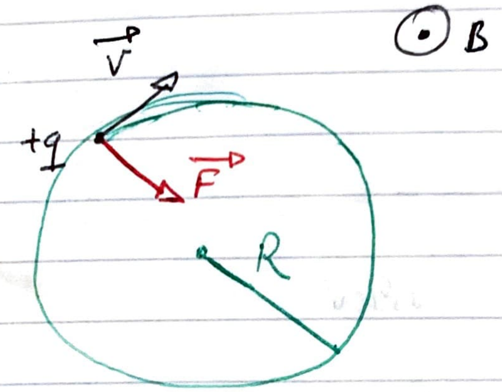
* Note: Fuel gauge & Temperature gauge on a car → are current meters (Electric Motor Effect).

Lect 13

- Moving charges in B-fields, Cyclotrons, Mass Spectrometers, LHC

- Lorentz Force

$$\vec{F} = q(\vec{v} \times \vec{B})$$



centrifugal force

$$qvB = \frac{mv^2}{R}$$

$$R = \frac{mv}{qB} \rightarrow \text{momentum} = \frac{p}{qB}$$

* $KE = q\Delta V = \frac{1}{2}mv^2 =$

$$R = \sqrt{\frac{2mV}{qB^2}}$$

* Now taking into account relativistic speed.

$$KE = qV = (\gamma - 1)mc^2$$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$\therefore R = \gamma\frac{mv}{qB} = \left[\frac{(\gamma+1)mV}{qB^2}\right]^{1/2}$$

* non-relativistic

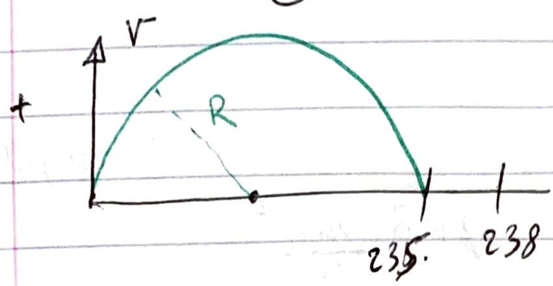
$\gamma \approx 1$ $v \lll c$

Mass - spectrometer

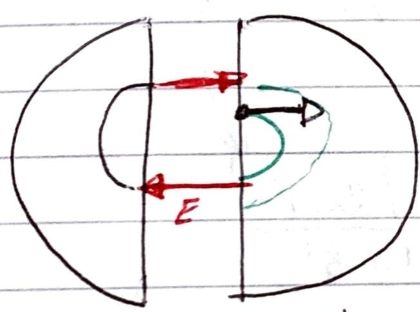
$^{235}U_{146}$ $^{238}U_{143}$

99.3% electrons   0.7% electrons

⊙ B



B ⊙
1T   1MeV.



20kV.

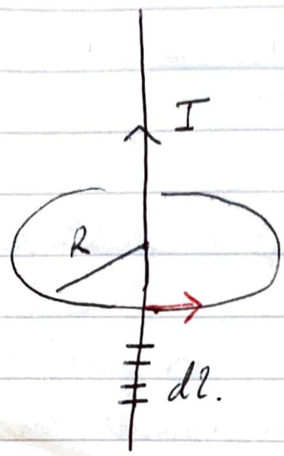
* Time is independent of speed.

substitute

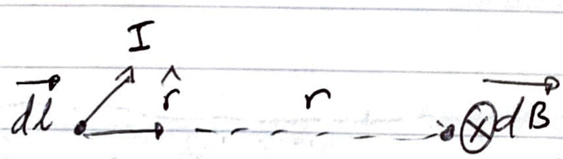
$$T = \frac{2\pi R}{\text{speed}} = \frac{2\pi \cdot m}{qB}(\gamma)$$

Lect 14

- Bio-Savart, div $B=0$, High voltage Power Lines, Leyden Jar



$$B \propto \frac{I}{R}$$

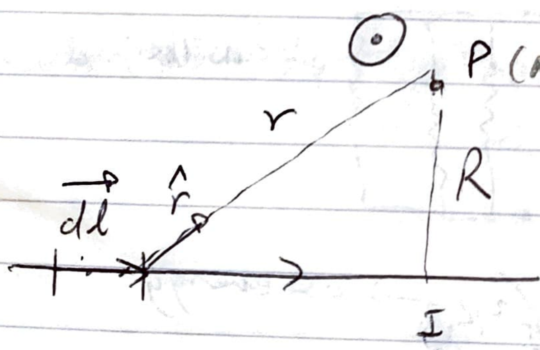


constant   length 1

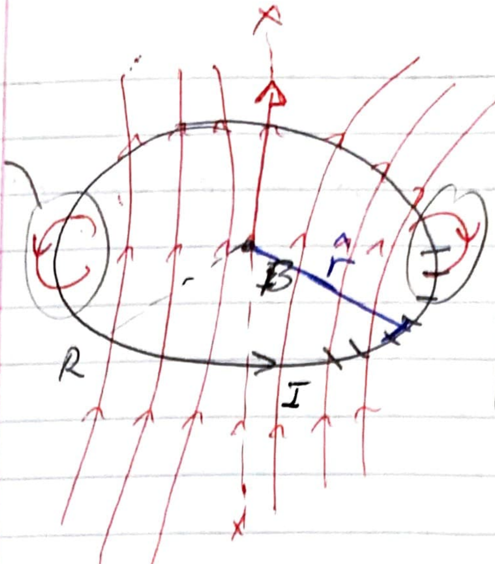
$$\vec{dB} = \frac{C\,I\,(\vec{dl} \times \hat{r})}{r^2}$$

only do that to get the direction right

$C = 10^{-7} = \frac{\mu_0}{4\pi}$ } permeability of free space.



$$B = \frac{\mu_0 I}{2\pi R}$$



$\int dl$ = circumference of circle

$B = \int d\vec{B} = \frac{\mu_0}{4\pi} \frac{I}{R^2} \cdot 2\pi R$

entire loop

$$\boxed{B = \frac{\mu_0 I}{2R}}$$

(Maxwell eq.)

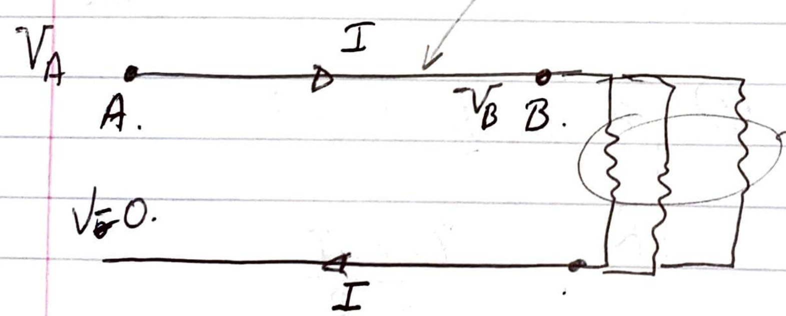
$$\oint \vec{B} \cdot d\vec{A} = 0$$ → Because there are no magnetic monopoles

close surface.

× Power-Lines

$V_A - V_B = I R$

$V_B = V_A - IR$



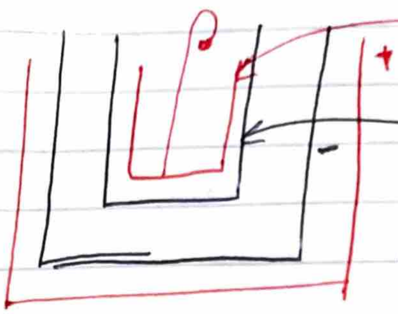
∴ Power: $V_B I = V_A I - I^2 R$ → loss energy

energy per second consuming

energy per second provided.

$R = \frac{\rho l}{A}$

- Leyden Jar (Experiment.)



$\frac{1}{2} Q_{free} V$

$\sigma_i = \left(1 - \frac{1}{K}\right) \sigma_{free}$

eg $K = 5$ (glass) $\quad \sigma_i \simeq 0.8 \sigma_{free}$.

* ~~that~~ See x spark → energy left → impossible

Reason:

↳ some charge on glass → how? → corona discharge

$E_{air} = 3 \cdot 10^6$ V/m ✗ corona

$E_{glass} = 10^7$ V/m < corona } discharge

30 kV

cond. — 11.5×10^6 1mm) 11.5 kV • $V = E \cdot d$ $\quad E_{gl} = \frac{E_{air}}{K(5)}$

glass — 2.3×10^6 3mm) 7 kV

cond. — 11.5×10^6 1mm) 11.5 kV

$$\left(2 \times E_{air} \cdot 10^{-3}\right) + \underbrace{\left(\frac{E_{air}}{5}\right)}_{E_{glass}} \cdot 3 \times 10^{-3} = 30 \cdot 10^3$$

$3 \cdot 10^6$) 3 kV

$8 \cdot 10^6$) 24 kV

$3 \cdot 10^6$) 3 kV

Lect 15

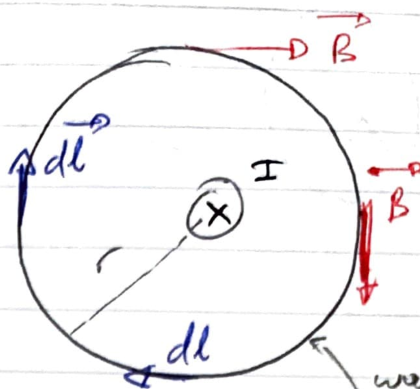
- Ampere's law, Solenoids, Kelvin Water Dropper

Note.

- Biot & Savart

$$\vec{dB} = \frac{\mu_0}{4\pi r^2} I \, (\vec{dl} \times \hat{r})$$

small wire goes into page that carries a current.

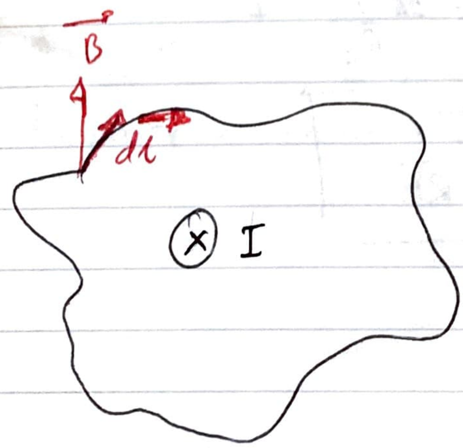


walk around the loop

$$B = \frac{\mu_0 I}{2\pi r}$$

$$\oint_{\text{close loop}} \vec{B} \cdot \vec{dl} = B \cdot 2\pi r = \mu_0 I$$

*

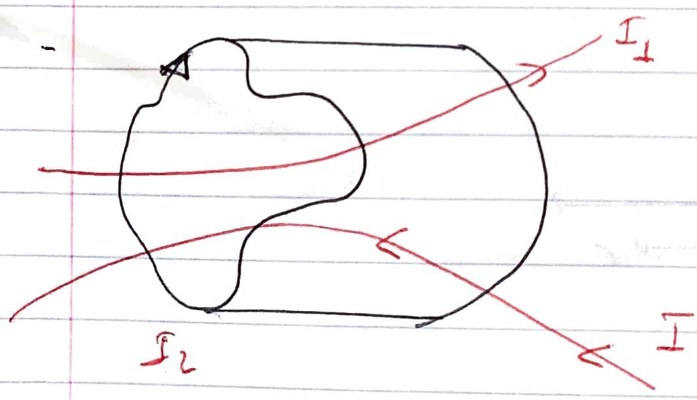


$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_{enclosed} /$$

penetration

* What do we mean by enclosed?

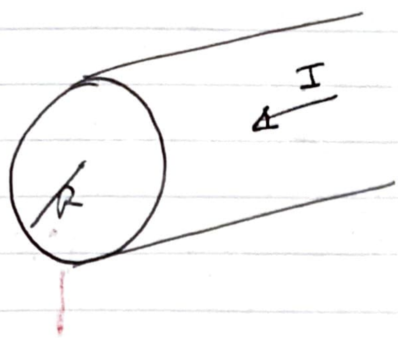
-

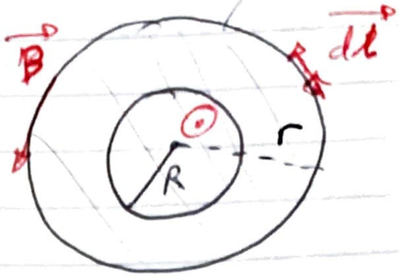


$I_1 > 0$; $I_2 < 0$ CW

$I_1 < 0$; $I_2 > 0$ CCW

$r > R$





$$B \cdot 2\pi r = \mu_0 I_{penetrating}$$

$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

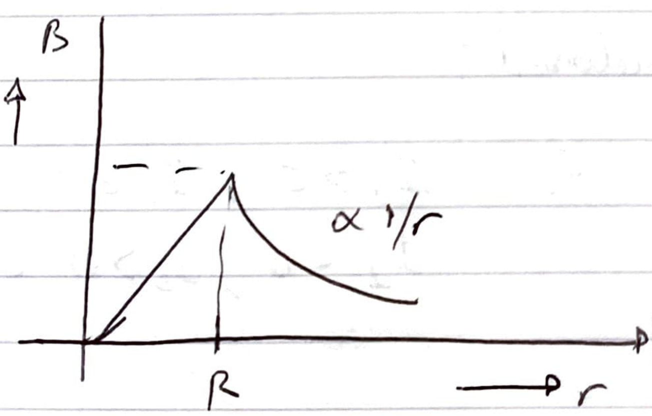
$r < R$

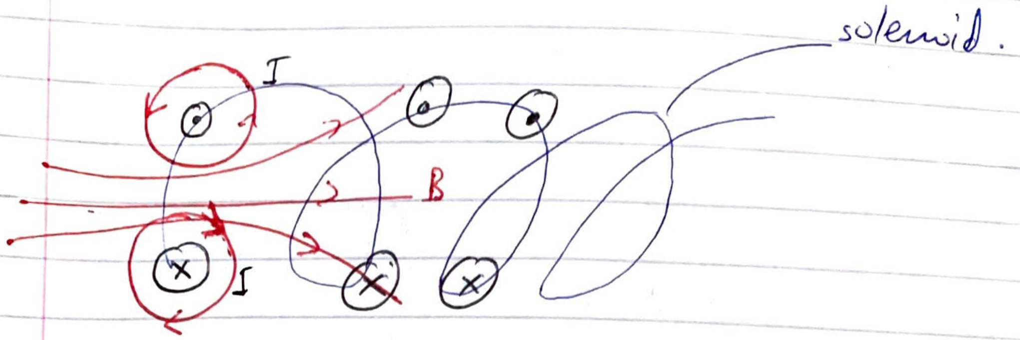
ratio

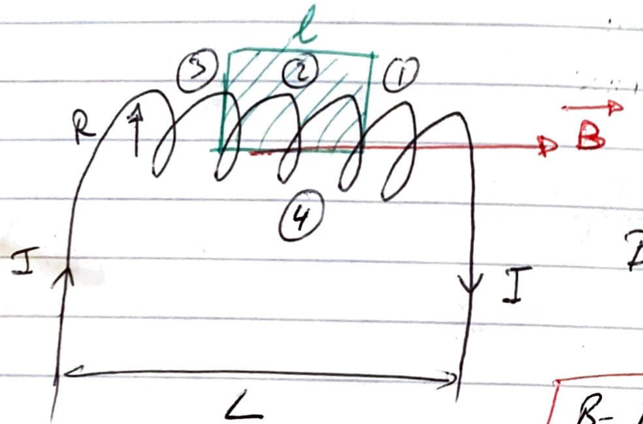
$$B\, 2\pi r = \mu_0 \cancel{I} \frac{r^2}{R^2} I$$

$$\boxed{B = \frac{\mu_0 I r}{2\pi R^2}}$$

$r = R$







N: # of windings

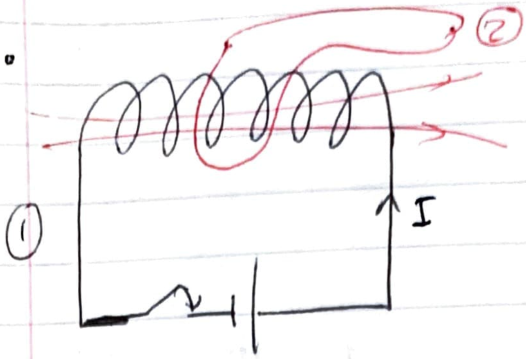
→ # of time of (I) penetration

$$Bl = \boxed{\frac{l}{L} N} \mu_0 I.$$

$$\boxed{B = \frac{\mu_0 I \cdot N}{L}} \quad (L >> R)$$

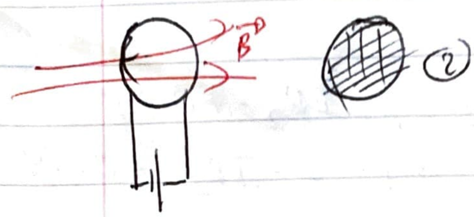
Lect 16

- Electromagnetic Induction, Faraday's Law, Lenz's Law



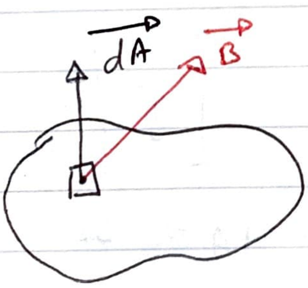
* A changing magnetic field is causing current (#2).
[Lenz's law)

* ($\mathcal{E}_{ind} = I_{ind} \cdot R$)



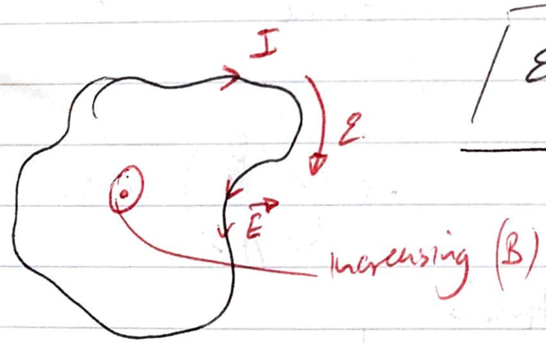
$\mathcal{E}_2 \propto \frac{dB_\perp}{dt}$

$\mathcal{E}_2 \propto$ area ②.



$\phi_B = \int \vec{B} \cdot \vec{dA}$

open surface.



$$\boxed{\mathcal{E} = -\frac{d\phi_B}{dt}} = -\frac{d}{dt}\int \vec{B} \cdot \vec{dA} = \int \vec{E} \cdot \vec{dl}$$

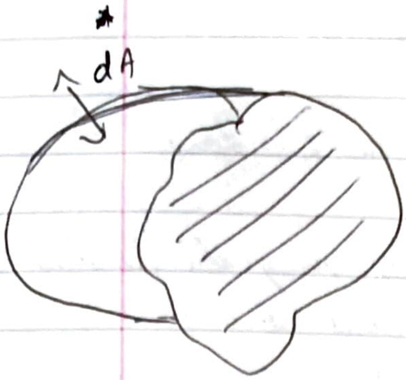
open surface. close loop.

(Faraday)

$$\Rightarrow \oint \vec{E} \cdot \vec{dl} = -\frac{d}{dt}\int \vec{B} \cdot \vec{dA}$$

closed loop

open surface.



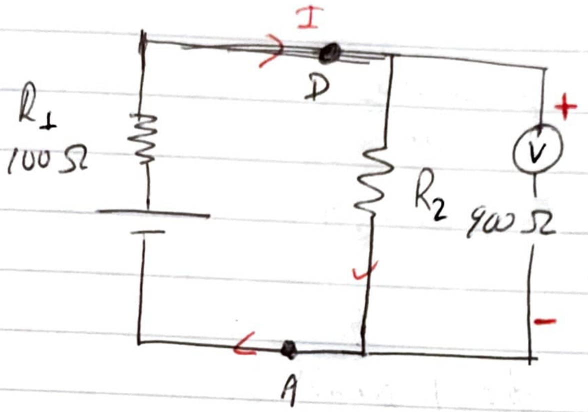
C.W $\vec{dA}$ ⊗

C.C.W dA ⊙.

(* Non-Conservative fields)

$\mathcal{E} = 1V = I(R_1 + R_2)$

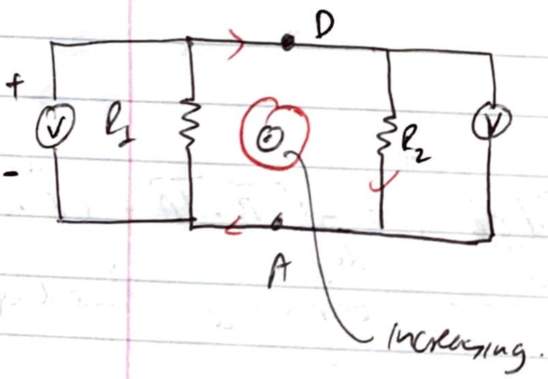
$I = 10^{-3}A$.



- $V_D - V_A = IR_2 = +0.9V$
- $V_D - V_A = 1 - IR_1 = +0.9V$

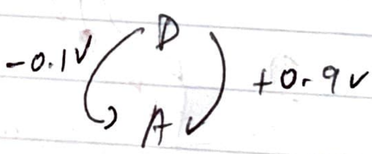
[?]

⇕



- $V_D - V_A = -IR = -0.1V$

$$\int_A^D \vec{E} \cdot \vec{dl}$$



* Faraday's law always holds

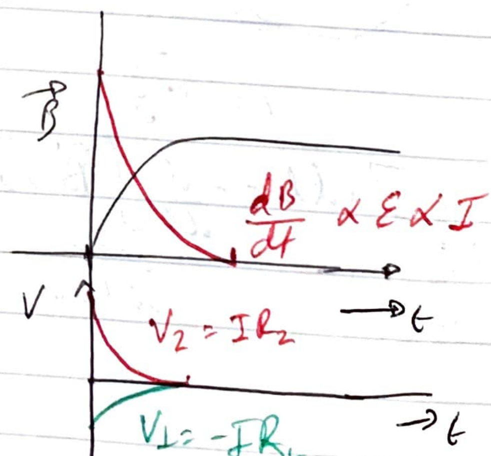
$V_D - V_A = +0.9V$

$V_A - V_D = +0.1V$ +

$= +1V$

$\Rightarrow \frac{dB}{dt} = 10T/s$ Area $= 10cm^2$ $10^{-2}m^2$

$\boxed{\frac{d\phi}{dt} \approx 0.1V}$



Lect 17

- Motional EMF, Dynamos, Eddy Currents, Magnetic Braking

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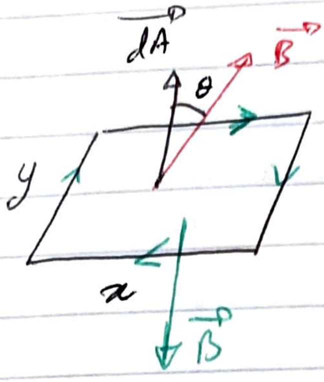

$\phi_B = \int_{\text{open surface}} \vec{B} \cdot \vec{dA}$ [scalar]

$= \underbrace{xy}_{A} . B\cos\theta.$

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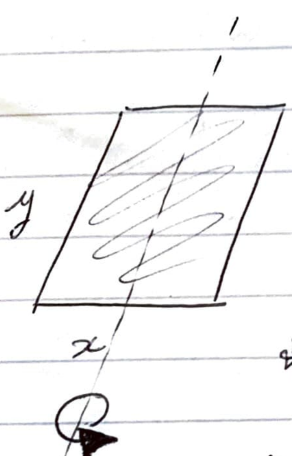


$\omega = \frac{2\pi}{\text{period}}.$ $\theta = \theta_0 + \omega t$

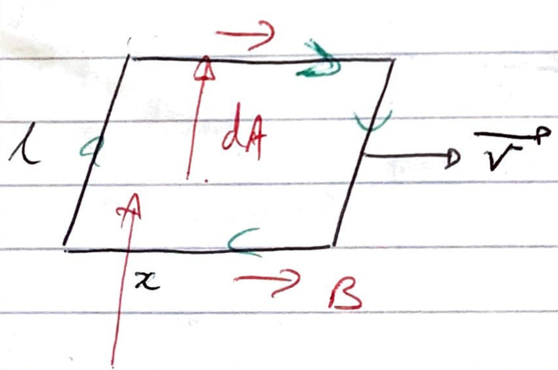
$t = 0 \quad \theta = 0$

$\phi_B = AB\cos(\omega t)$

$-\frac{d\phi}{dt} = +AB\omega\sin\omega t. = \mathcal{E}(t)$

$I(t) = \frac{\mathcal{E}(t)}{R_{TOTAL}}.$ AC

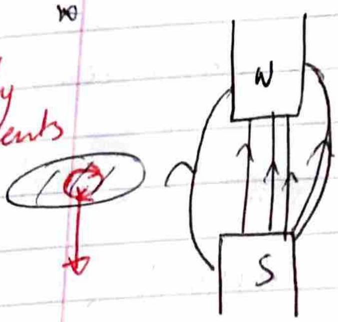
>



$\phi_B = lxB$

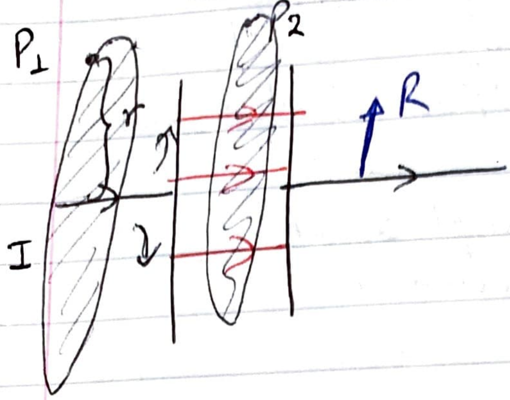
$\frac{d\phi}{dt} = lBv = |\mathcal{E}|$

Eddy currents



8.02x / Lect 18

- Displacement Current, Synchronous Motors, Explanation secret TOP



$$E = \frac{\sigma_{free}}{K\varepsilon_0} = \frac{Q_{free}}{\pi R^2 K}, \quad I = \frac{dQ_{free}}{dt}$$

$$\therefore \frac{dE}{dt} = \frac{I}{\pi R^2 K \varepsilon_0}$$

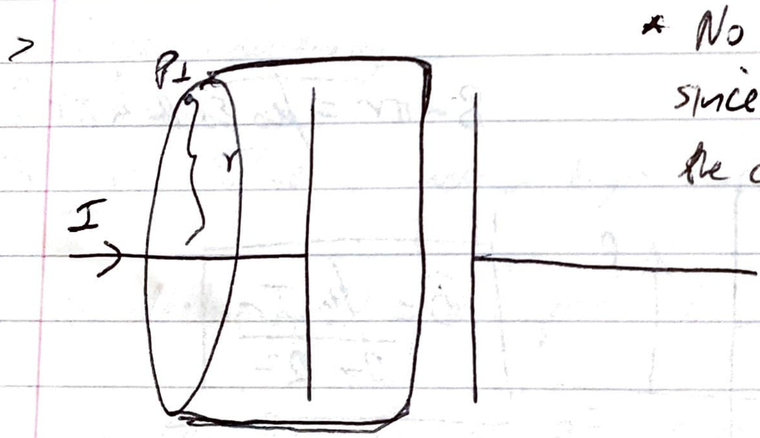
* Ampere's Law

$$B \times 2\pi r = \mu_0 (I_{pen} = I)$$

for P_1 $\boxed{B = \frac{\mu_0 I}{2\pi r}}$

for P_2 → not correct
need to have magnetic field.

* No penetration Current (I_{pen}) since no current flowing inside the capacitor



$$\phi_E = \int_{\text{open surface}} \vec{E} \cdot d\vec{A} \qquad \left(\frac{d\phi_E}{dt}\right)$$

Maxwells & Ampere's Law

$$\underset{\text{close loop}}{\oint} B\cdot dl = \mu_0 \left(I_{pen.} + \underbrace{\varepsilon_0 k \frac{d}{dt} \underset{\text{open surface}}{\int} \vec{E}\cdot d\vec{A}}_{\text{displacement current}} \right)$$

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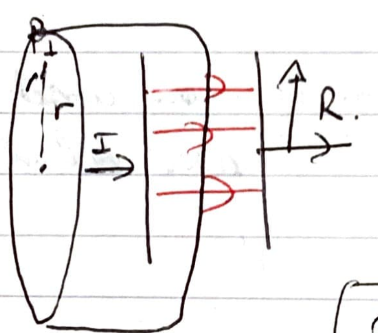
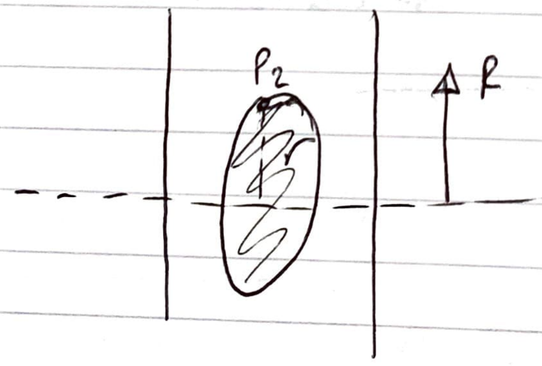


$$B 2\pi r = \mu_0 \varepsilon_0 \cancel{k}\, \underbrace{\cancel{\pi} R^2}_{A}\ \underbrace{\frac{I}{\cancel{\pi} R^2 \cancel{k} \varepsilon_0}}_{\frac{dE}{dt}} = \mu_0 I$$

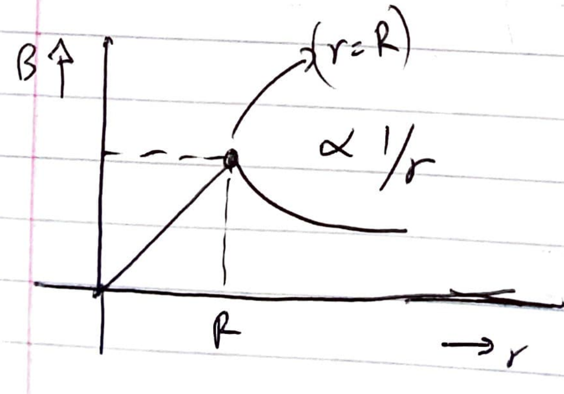
$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

>

$$B 2\pi r = \mu_0 \cancel{\varepsilon_0} \cancel{k} \cancel{\pi} r^2 \times \frac{I}{\cancel{\pi} R^2 \cancel{k \varepsilon_0}}$$



$$\boxed{B = \frac{\mu_0 I r}{2\pi R^2}}$$

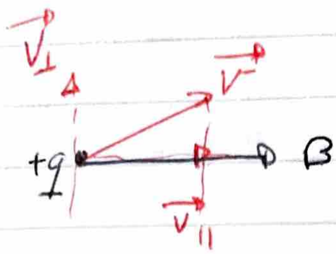


Lect 19

- Magnetic Levitation, Superconductivity, Aurora Borealis

* Very ~~m~~ nice information on medical devices → cardiogram.

- Aurora Borealis (Northern lights) ~ caused from plasma from sun

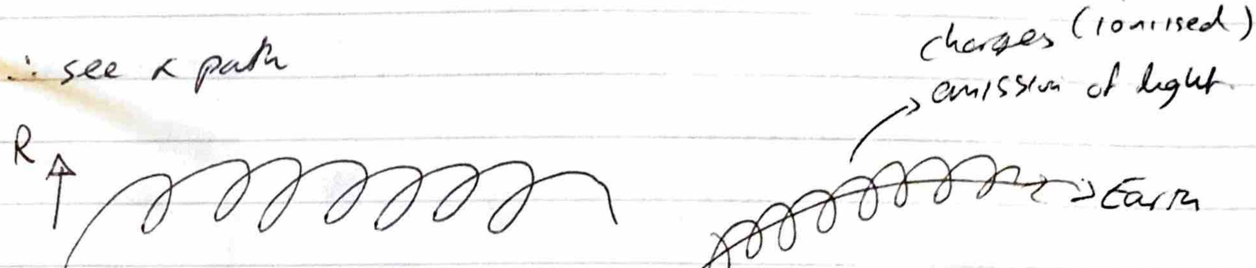


$\vec{F} = q(\vec{v} \times \vec{B})$

$F = q(\vec{v}_{\parallel} + \vec{v}_\perp) \times \vec{B}$ $\theta = 0 \therefore \phi$

$F = q\vec{v}_\perp \times \vec{B}$

∴ see a path



$R = \frac{m v_\perp}{qB}$

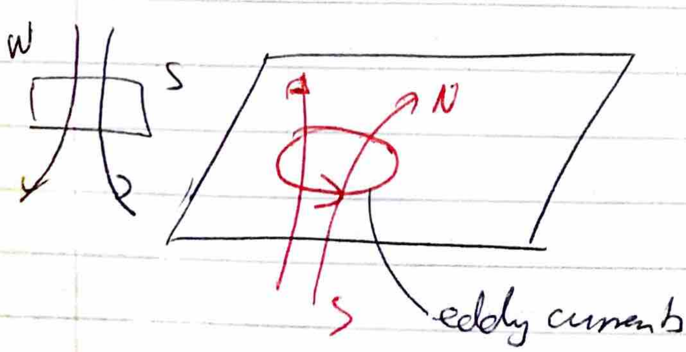
- Superconductivity

{* Note: There is also a high temperature superconductivity.}

* No electric field in a superconductor. ($\uparrow V = I \uparrow R = 0$ ∞

* Magnetic Pressure: $P = \frac{B^2}{2\mu_0}$ $\left[\frac{N}{m^2}\right]$

(* squeezed magnetic field.)



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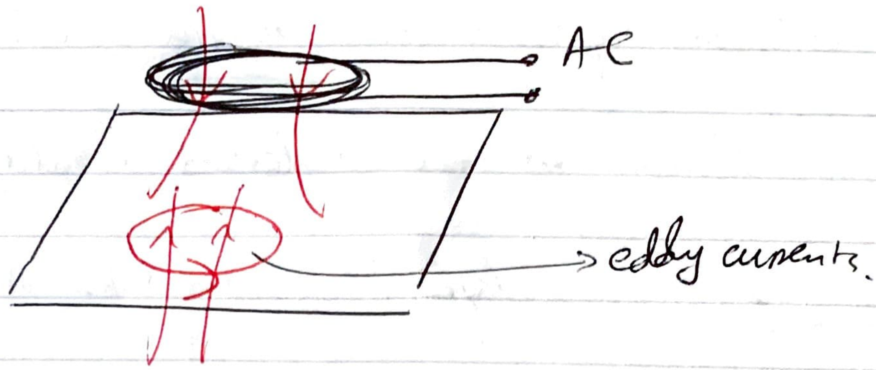


» Magnetic levitation.

Lect 20

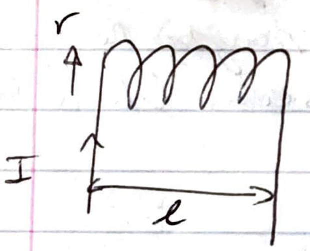
- Inductance, RL Circuits, Magnetic Field Energy

* L - self-inductance: inductance as current passes, $\therefore$ magnetic field is created / $\frac{\Delta Q}{\Delta t}$ } causing $\propto \Delta \vec{B}$

* $\phi_B = LI$

* $\mathcal{E}_{ind} = -\frac{d\phi_B}{dt} = -L\frac{dI}{dt}$.

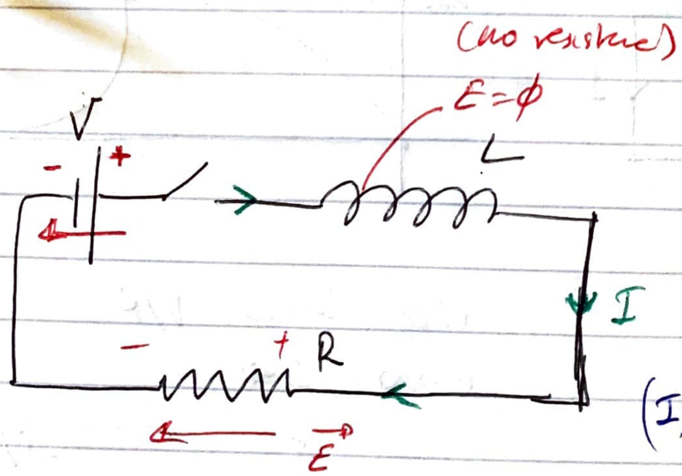
Self inductance of solenoid



$B = \mu_0 I \frac{N}{l}$

$\phi_B = \underbrace{\pi r^2}_{A} N^2 \mu_0 I / l = LI$

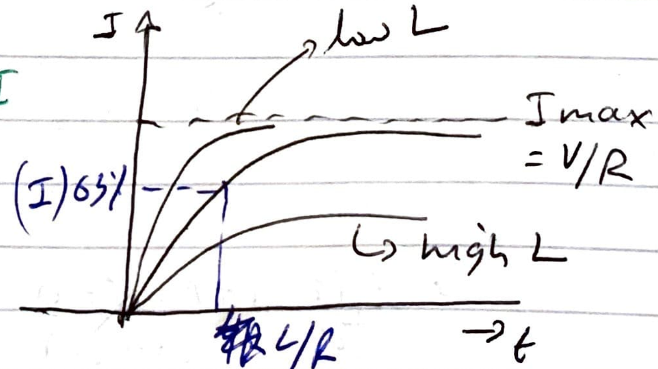
$\boxed{\therefore L = \frac{\pi r^2 N^2}{l} \mu_0}$ $[H] = \left[\frac{V sec}{A}\right]$



$t = L/R$; $I = 63\%\ I_{max}$

$t = 0$; $I = 0$

(self inductance)



(*Supplement found on link below video)

* $\oint \vec{E}\cdot d\vec{l} = -\frac{d\Phi_B}{dt} = -L\frac{dI}{dt}$ * Faradays

- Going around the loop (direction of I)

$$\boxed{0 + IR - V = -L\frac{dI}{dt}}$$ * Fordays Law

$V - L\frac{dI}{dt} = IR$ → Lenz's Law.

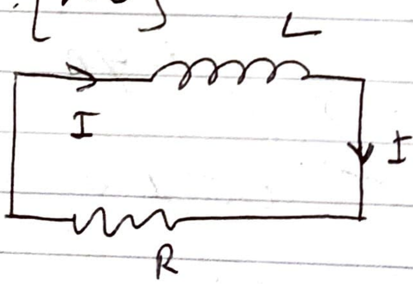
- $L\frac{dI}{dt} + IR - V = 0$

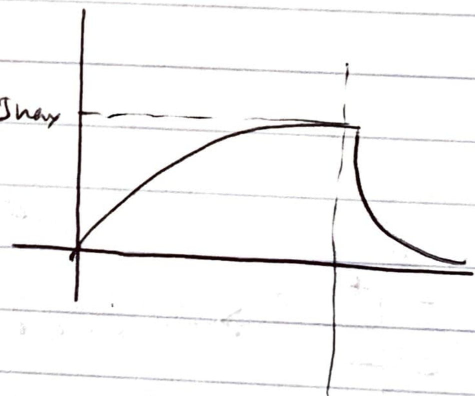
* That is not Kirchhoff Rule
→ It Faradays
→ but ~~rearranging~~ rearranging the equation makes it seems like is Kirchhoffs

Solution

- $I = I_{max}(1 - e^{-R/L\,t})$
  $I_{max} = V/R$

- Now: $[V=0]$





$t=0$ $I_{max} = V/R$
$t\to\infty$ $I\to 0$.

* $L\frac{dI}{dt} + IR - \cancel{V} = 0$ $(V=0)$ → Solution: $\boxed{I = I_{max}e^{-R/L\,t}}$.

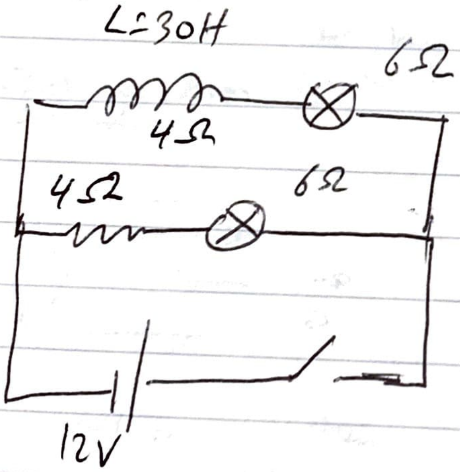
→ Energy (heat from resistor) (as $I \to 0$)

↳ $\int_0^\infty I^2 R\,dt = I_{max}^2 R \int_0^\infty \underbrace{e^{-2R/Lt}\,dt}_{L/2R}$

$$\boxed{= \frac{1}{2} L I_{max}^2}$$

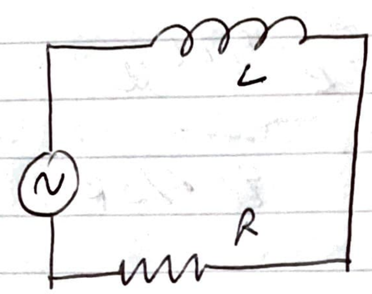
$= \frac{1}{2} L I^2 = \frac{B^2}{2\mu_0} \pi r^2 l$ → volume sol.

magnetic field Energy density = $B^2/2\mu_0$ [J/m^3]



$\frac{L}{R} = \frac{30}{10} = 3$ sec

∞ Self inductance is fighting ΔI



$V = V_0 \cos \omega t$.

Using Faraday's Law.

$$I = \frac{V_0}{\sqrt{R^2 + (\omega L)^2}} \cos(\omega t - \phi)$$

phase lag

Imax.

[Resistance]

$(j\omega L)$.

$$\tan\phi = \frac{\omega L}{R}.$$