$Q_i\ V_i \qquad\qquad P_{ij}\ Q_i Q_j$

$$U = \frac{1}{2}\sum I_i \phi_i = \frac{1}{2}\sum M_{ij} I_i I_j$$

$$= \frac{1}{2}\int \vec{J}\cdot\vec{A}\,dV = \frac{1}{2}\int \vec{B}\cdot\vec{H}\,dV$$

$\rho V \qquad\qquad E\cdot D$

$$U = \frac{1}{2} L I^2$$

CV^2

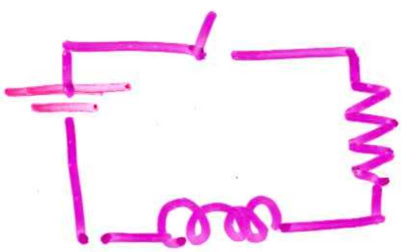
ϕ & I : careful with rhr sign convention

↑ flux

if currents constant $\quad F_x = +\frac{d}{dx}U$

$\tau = +\frac{d}{d\theta}U$

starting point: LR circuit

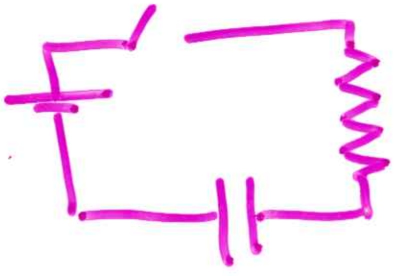


$$I = \frac{V}{R}\left(1 - e^{-t/\tau}\right)$$

$\tau = L/R$

$$VI = I^2 R + I L \frac{dI}{dt}$$

power in — heat — magnetic energy $\frac{d}{dt}\left(\frac{1}{2}LI^2\right)$

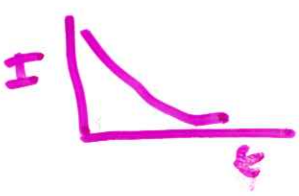


$$V = IR + \frac{\int I\,dt}{C}$$

$$0 = \dot{I}R + \frac{1}{C}I$$

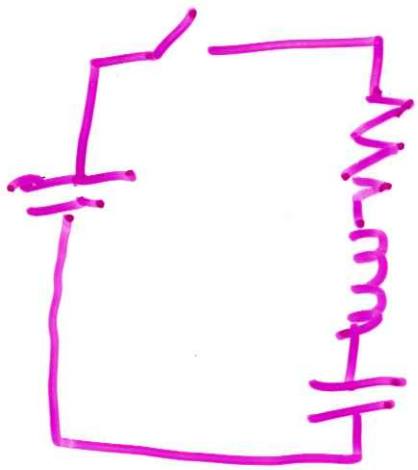
$$\dot{I} = -\frac{1}{RC}I \rightarrow I = I_0 e^{-t/\tau}$$

$I_0 = V/R$, $\tau = RC$



$$VI = I^2 R + \frac{IQ}{C}$$

electric energy $\frac{d}{dt}\left(\frac{1}{2}Q^2/C\right)$



$$V = IR + L\frac{dI}{dt} + \frac{\int I\,dt}{C}$$

$$0 = \dot{I}R + L\ddot{I} + \frac{I}{C}$$

$$0 = \ddot{I} + \underbrace{\frac{R}{L}}_{2B}\dot{I} + \underbrace{\frac{1}{LC}}_{\omega_0^2} I$$

$$I = I_0 e^{rt}$$

$$\dot{I} = rI$$

$$\ddot{I} = r^2 I$$

$$0 = \ddot{I} + 2B\dot{I} + \omega_0^2 I$$

$$0 = r^2 + 2Br + \omega_0^2$$

$$r = \frac{-2B \pm \sqrt{(4B)^2 - 4\omega_0^2}}{2}$$

$$= -B \pm i\underbrace{\sqrt{\omega_0^2 - B^2}}_{\omega'}$$

$$I = Ae^{-Bt}e^{+i\omega' t} + Be^{-Bt}e^{-i\omega' t} = \tilde{A}e^{-Bt}\cos(\omega' t + \phi)$$

"R" = $i\omega L$

"R" = $\frac{1}{i\omega C}$

$R = R$

$V_0 = |V_0| e^{i\phi}$

 $\omega = 2\pi f$

↑

$e^{i\omega t}$

$\cos(\omega t + \phi)$

$V = V_0 e^{i\omega t}$

$\sim V_{rms} = \frac{V_0}{\sqrt{2}}$

$$V = RI + L\frac{dI}{dt} + \frac{\int I\,dt}{C}$$

$$I = I_0 e^{i\omega t}$$

$L\frac{dI}{dt} \rightarrow i\omega L I$

$\frac{\int I\,dt}{C} \rightarrow \frac{\frac{1}{i\omega} I}{C}$

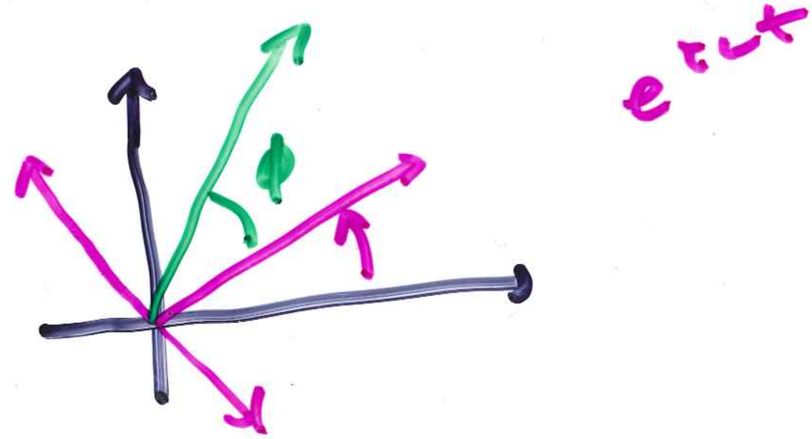
$$V = \left(R + i\omega L + \frac{1}{i\omega C}\right) I$$

$V \leftarrow V_0 e^{i\omega t}$, $\quad I \leftarrow I_0 e^{i\omega t}$, $\quad i \rightarrow e^{i\pi/2}$, $\quad \frac{1}{i} \rightarrow e^{-i\pi/2}$

$$V_0 = \underbrace{\left(R + i\omega L + \frac{1}{i\omega C}\right)}_{Z = |Z| e^{i\phi}} I_0$$

$$|V_0| = |Z|\,|I_0|$$

$$V = |Z|\, I_0\, e^{i(\omega t + \phi)}$$



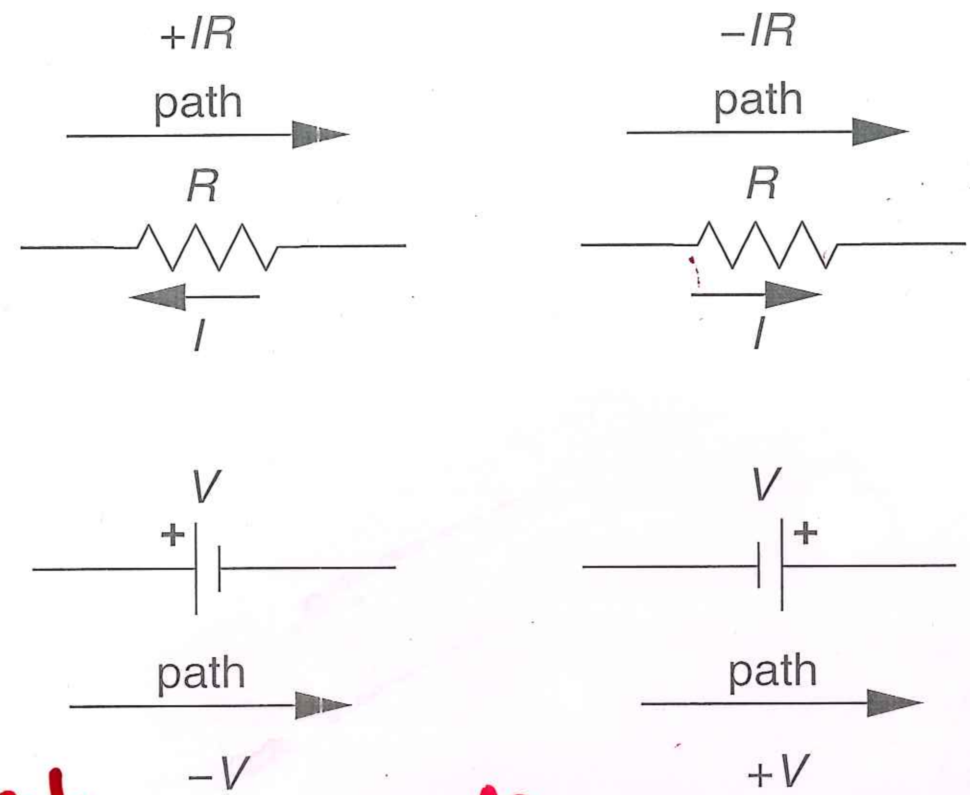
$$\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}} \leftarrow \frac{1}{i\omega C}$$

$$i\omega L$$

$$C = C_1 + C_2$$

$$\frac{1}{1/i\omega C} = \frac{1}{1/i\omega C_1} + \frac{1}{1/i\omega C_2}$$

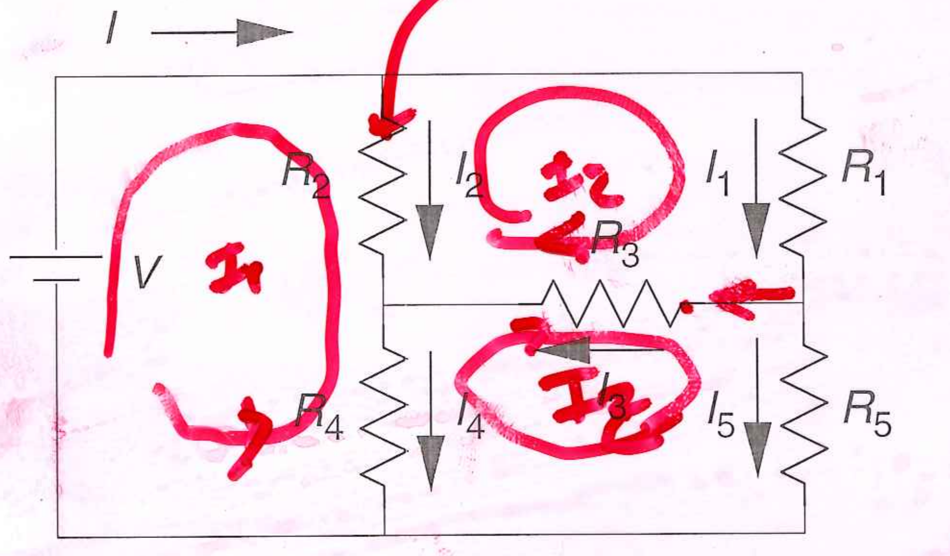
$$C = C_1 + C_2$$



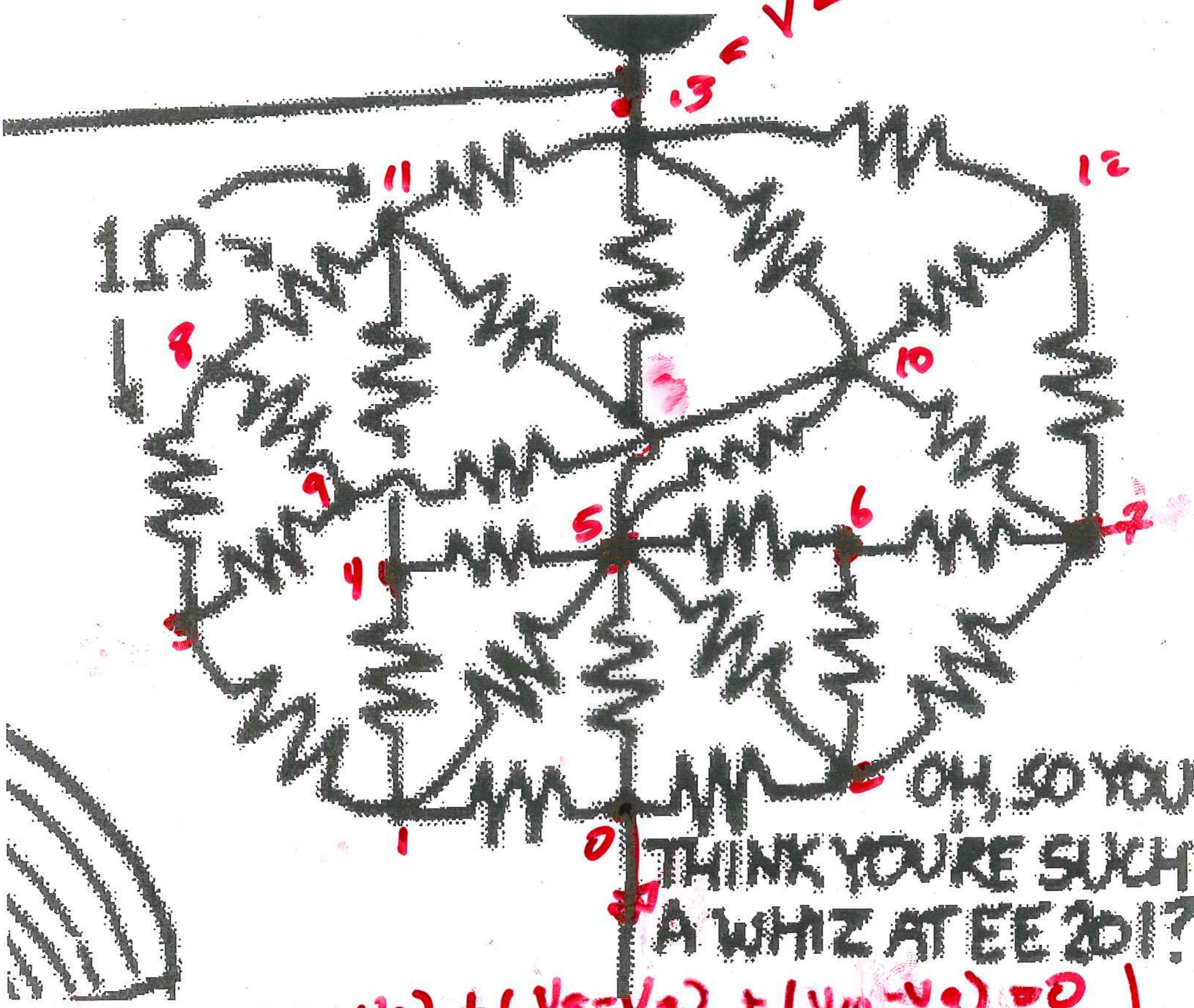
mesh
Laws

node Kirchh

+R2 (I2+I1)



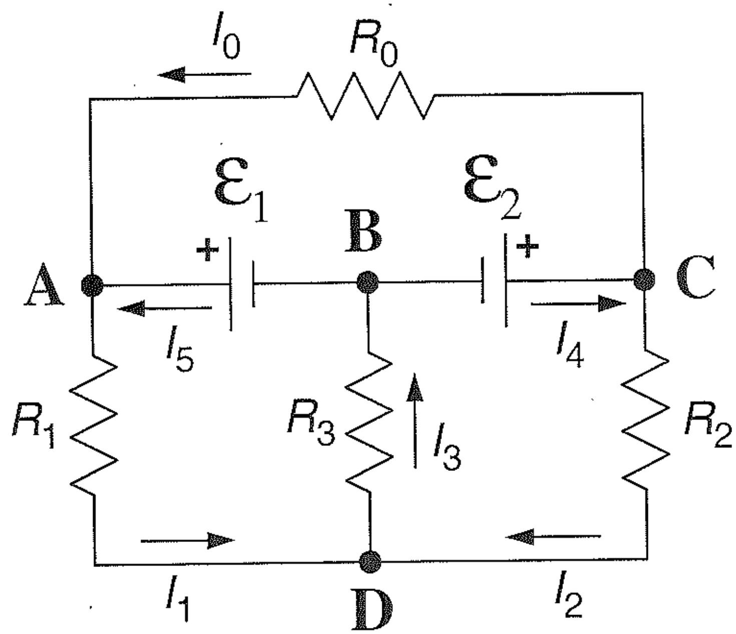
R3 (-I2 + I3)



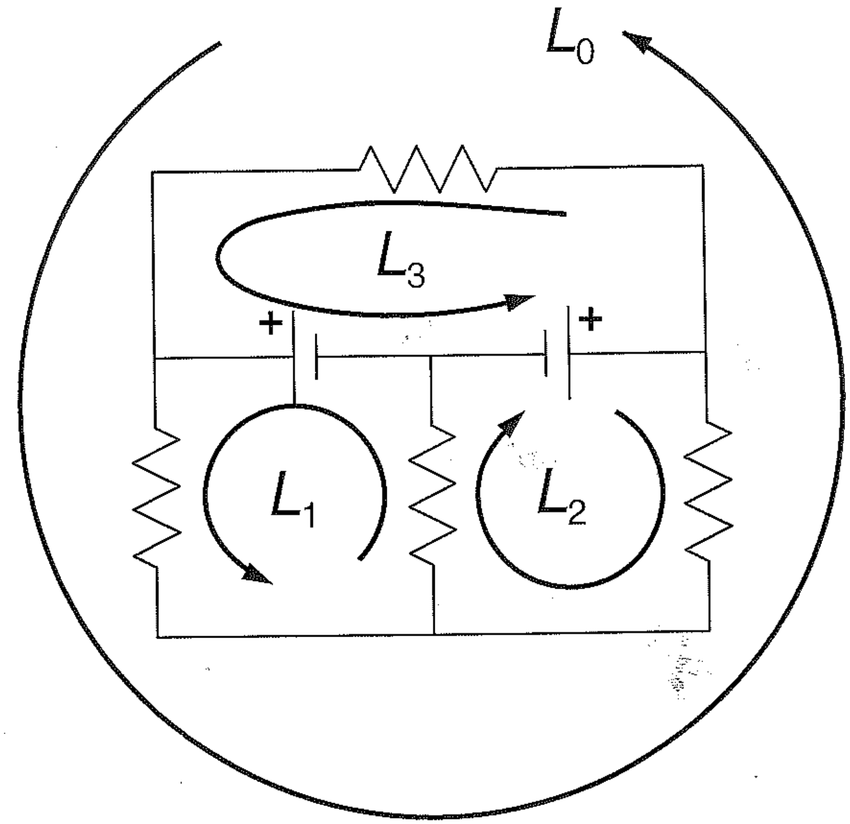
$(V_3 - V_a) + (V_5 - V_a) + (V_{10} - V_a) = 0$

$(0 - V_5) + (V_1 - V_5) + (V_4 - V_5) + (V_{11} - V_5)$
$+ (V_{10} - V_5) + (V_6 - V_5)$
$+ (V_{12} - V_5)$
$+ (V_2 - 0) = 0$

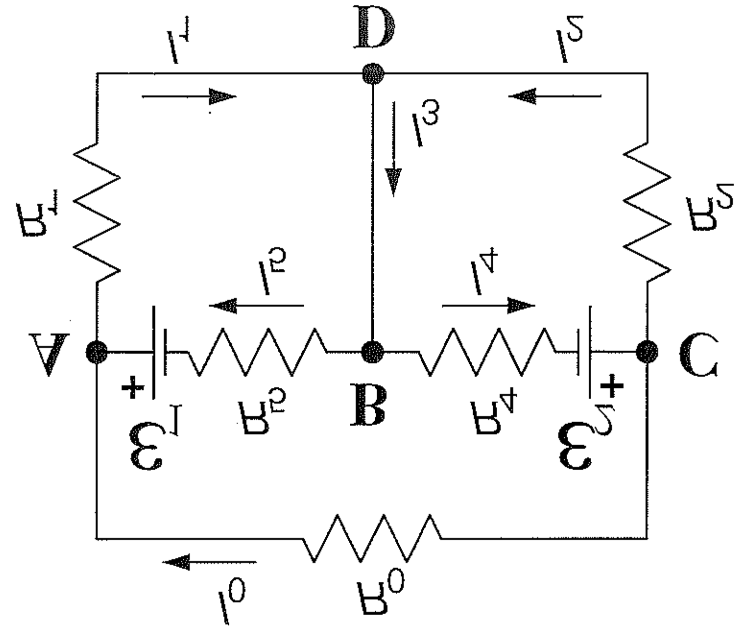
$R = \frac{V}{I} = (V_1 - 0) + (V_5 - 0) + (V_2 - 0)$



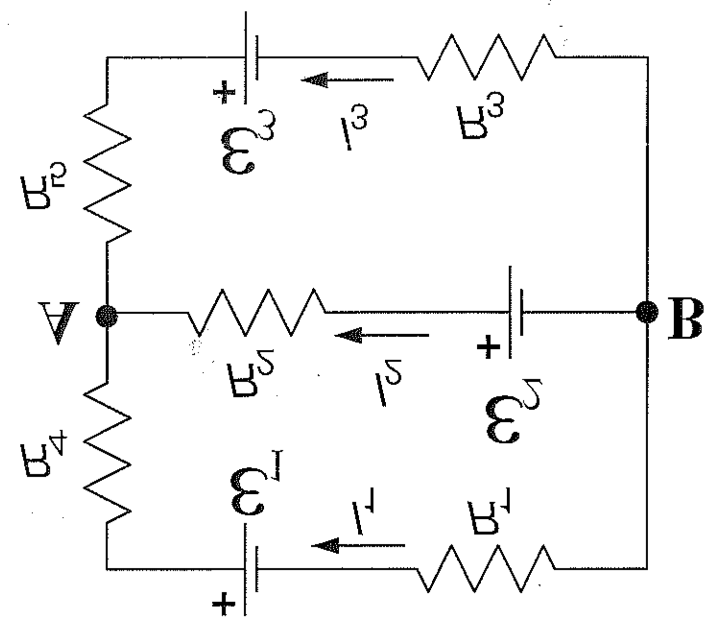
I0
R0
ε1
ε2
B
A
C
+
+
I5
I4
R1
R3
I3
R2
I1
D
I2



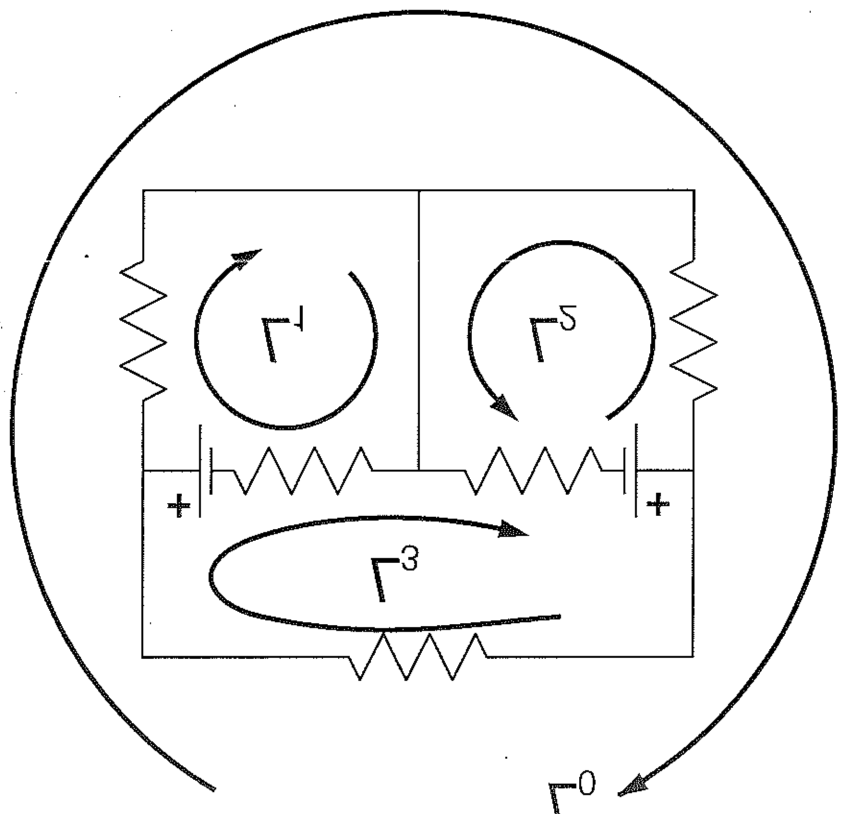
L0
L3
+
+
L1
L2



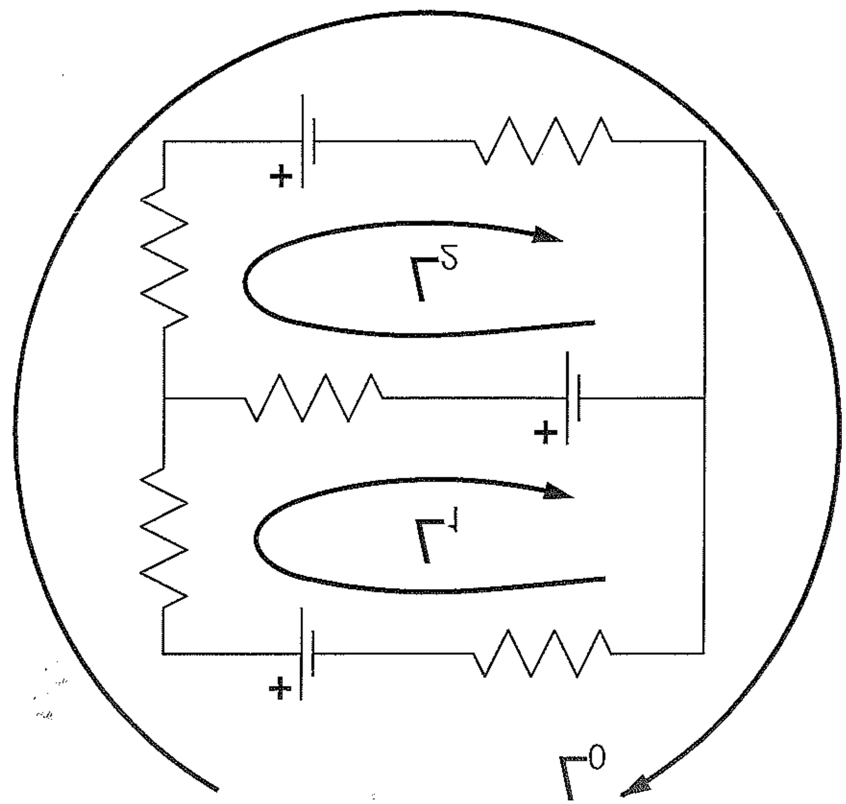
A
B
C
D
R_0
R_1
R_2
R_4
R_5
I_0
I_1
I_2
I_3
I_4
I_5
$\mathcal{E}_1$
$\mathcal{E}_2$



A
B
R_1
R_2
R_3
R_4
R_5
I_1
I_2
I_3
$\mathcal{E}_1$
$\mathcal{E}_2$
$\mathcal{E}_3$



L_0
L_1
L_2
L_3



L_0
L_1
L_2