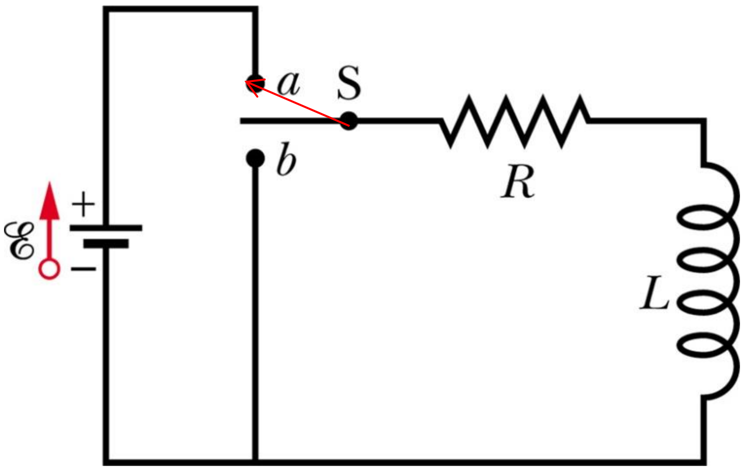
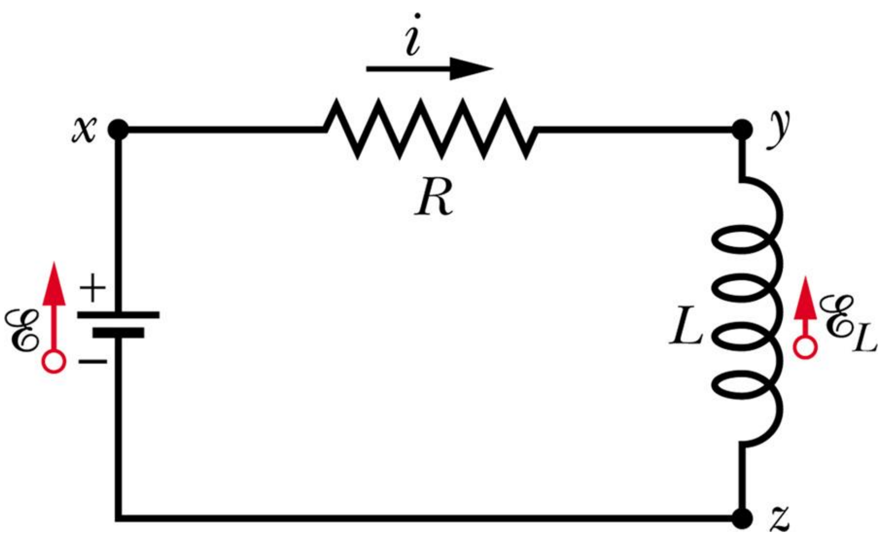
Copyright statement

- The images and the pictures in this lecture are provided by the CDs accompanied by the books
  1. University Physics, Bauer and Westfall, McGraw-Hill, 2011.
  2. Principles of Physics, Halliday, Resnick, and Walker, Wiley, 8th and 9th Ed.
- The rest is made by me.

RL circuit





$$-iR - L\frac{di}{dt} + \mathcal{E} = 0$$

$$L\frac{di}{dt} + Ri = \mathcal{E}$$

$$i(t) = \frac{\mathcal{E}}{R}\left(1 - e^{-Rt/L}\right)$$

time constant $\quad \tau_L = \dfrac{L}{R}$

$$\mathrm{H}/\Omega = \mathrm{H}/\Omega \frac{\mathrm{V}\cdot\mathrm{s}}{\mathrm{H}\cdot\mathrm{A}}\frac{\Omega\cdot\mathrm{A}}{\mathrm{V}} = \mathrm{s}$$

$$\mathcal{E}_L = -L\frac{di}{dt}$$

$$V = iR$$

Energy stored in a magnetic field

$$\mathcal{E} = L\frac{di}{dt} + iR$$

$$\mathcal{E}i = Li\frac{di}{dt} + i^2R$$

기전력이 회로에 공급하는 일률

저항에서 열에너지로 방출되는 비율

자기장에 저장되는 에너지의 비율

$$\frac{dU_B}{dt} = Li\frac{di}{dt} \longrightarrow dU_B = Lidi$$

$$\boxed{U_B = \frac{1}{2}Li^2}$$

Example

$$L = 53\text{mH}, \quad R = 0.53\Omega, \quad E = 12\text{V}$$

1. Magnetic energy

$$U_B = \tfrac{1}{2} L i_\infty^2 = \tfrac{1}{2} L (E / R)^2 = 31\text{J}$$

2. 에너지가 반으로 줄어드는 시간

$$U_B = \tfrac{1}{2} U_{B\infty}$$

$$\tfrac{1}{2} L i^2 = \tfrac{1}{2}\left(\tfrac{1}{2} L i_\infty^2\right)$$

$$\therefore i = i_\infty / \sqrt{2}$$

$$i = \frac{E}{R}\left(1 - e^{-\frac{t}{L/R}}\right)$$

$$= \frac{i_\infty}{\sqrt{2}} = \frac{1}{\sqrt{2}}\left(\frac{E}{R}\right)$$

$$t$$

$$= -\ln\left(1 - \frac{1}{\sqrt{2}}\right)\tau_L$$

$$= 1.2\tau_L$$

Energy density of a magnetic field

단면적 A, 길이 l인 솔레노이드를 고려하자.

$$u_B = \frac{U_B}{Al}$$

$$U_B = \frac{1}{2}Li^2$$

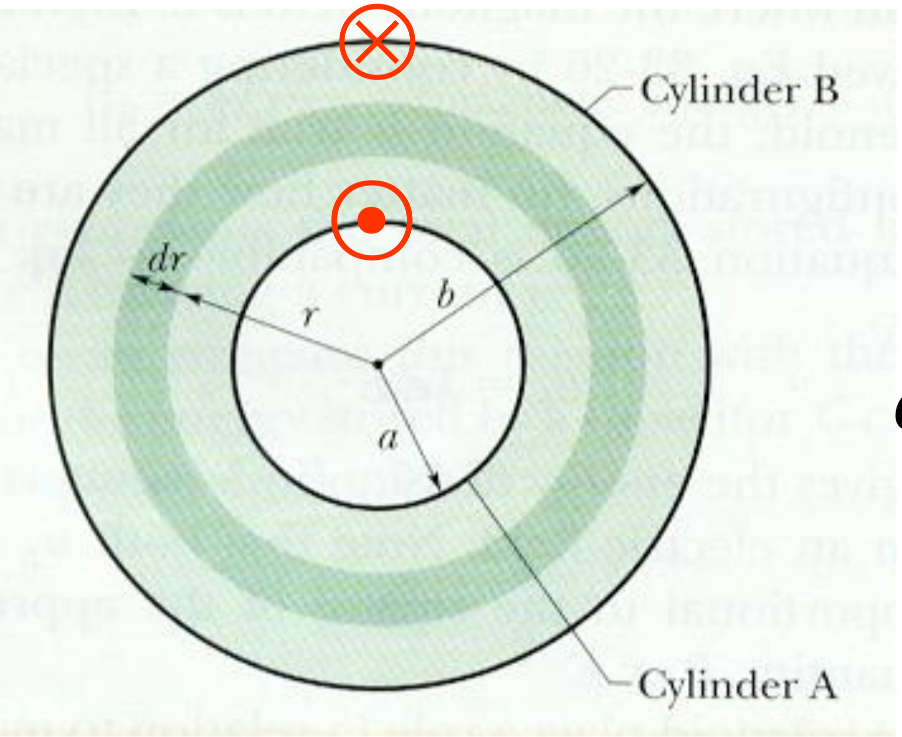
$$u_B = \frac{Li^2}{2Al} = \frac{L}{l}\frac{i^2}{2A} = \frac{1}{2}\mu_0 n^2 i^2$$

$$B = \mu_0 n i$$

$$\boxed{u_B = \frac{B^2}{2\mu_0}}$$

$$u_E = \frac{1}{2}\epsilon_0 E^2$$

Example



$$\boxed{u_B = \frac{B^2}{2\mu_0}} = \frac{1}{2\mu_0}\left(\frac{\mu_0 i}{2\pi r}\right)^2$$

$$dU_B = u_B dV = \frac{\mu_0 i^2}{8\pi^2 r^2}(2\pi r)dr$$

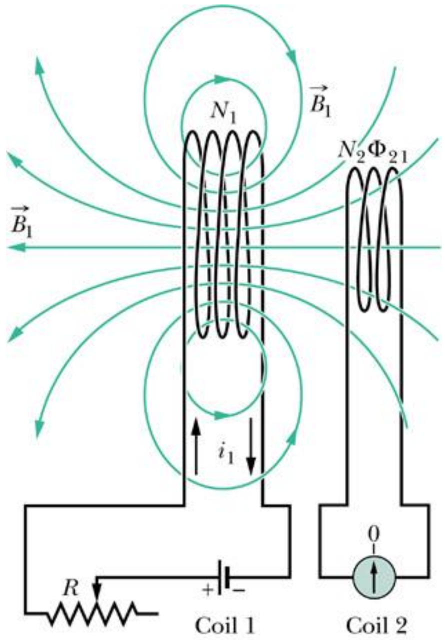
$$U_B = \int dU_B = \frac{\mu_0 i^2 l}{4\pi}\int_a^b \frac{dr}{r}$$

$$= \frac{\mu_0 i^2 l}{4\pi}\ln\frac{b}{a}$$

$$\oint \mathbf{B} \bullet d\mathbf{A} = \mu_0 i$$

$$B(2\pi r) = \mu_0 i$$

Mutual inductance

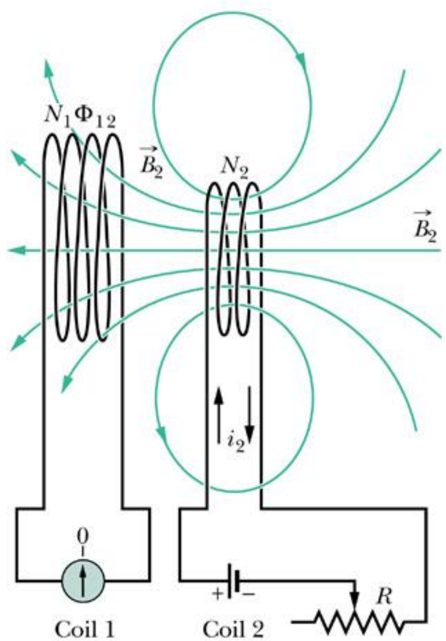


(a)

코일 1에 대한 코일 2의 상호유도용량 $$M_{21} = \frac{N_2\Phi_{21}}{i_1}$$

$$M_{21}i_1 = N_2\Phi_{21}$$

$$M_{21}\frac{di_1}{dt} = N_2\frac{d\Phi_{21}}{dt} \qquad \mathcal{E}_2 = -M_{21}\frac{di_1}{dt}$$



(b)

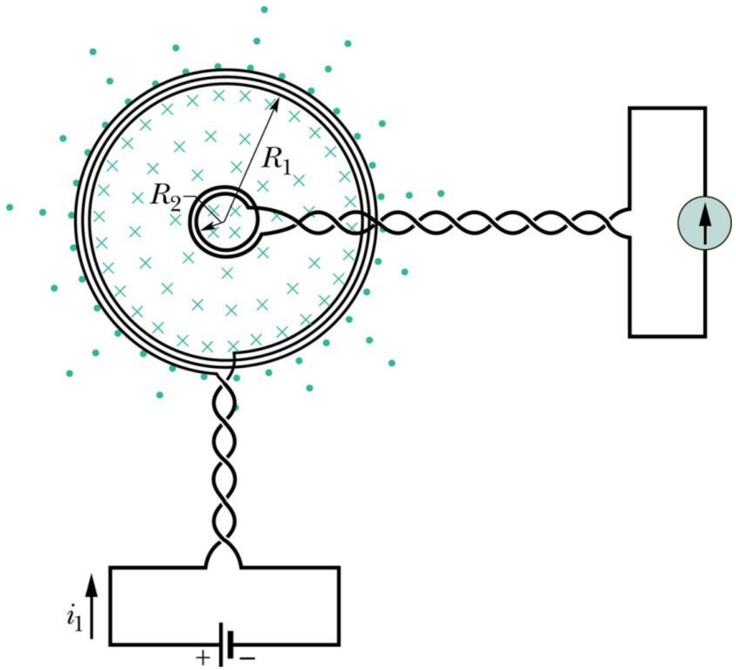
Likewise

$$\mathcal{E}_1 = -M_{12}\frac{di_2}{dt}$$

$$M_{12} = M_{21} = M$$

$$\mathcal{E}_2 = -M\frac{di_1}{dt}, \ \mathcal{E}_1 = -M\frac{di_2}{dt}$$

Example



$$M = \frac{N_2 \Phi_{21}}{i_1} \qquad \Phi_{21} = B_1 A_2$$

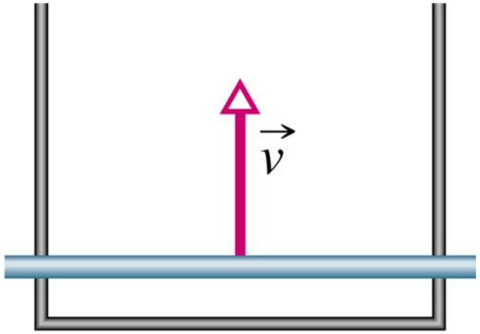
$$B(z) = \frac{\mu_0 i R^2}{2(R^2 + z^2)^{3/2}}$$

$$B_1 = N_1 \frac{\mu_0 i_1}{2R_1}$$

$$N_2 \Phi_{21} = \frac{\pi \mu_0 N_1 N_2 R_2^2 i_1}{2R_1}$$

$$M = \frac{N_2 \Phi_{21}}{i_1} = \frac{\pi \mu_0 N_1 N_2 R_2^2}{2R_1}$$

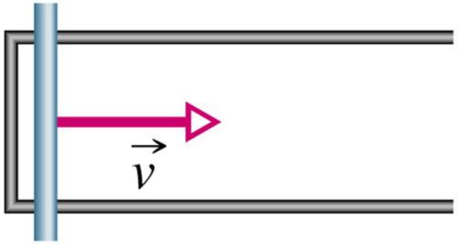
Question



$2L$

(1)

L

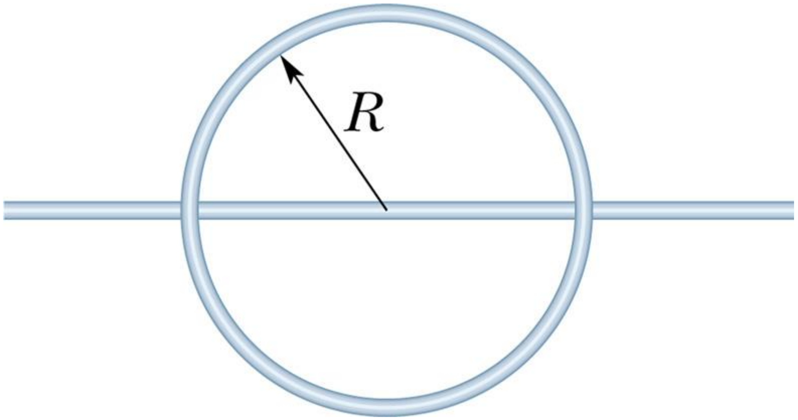


(2)

(1) Counterclockwise induced current

(a) Direction of the magnetic field?
(b) Direction of the current in Circuit 2?
(c) Emf in 1, and 2. Which is larger?

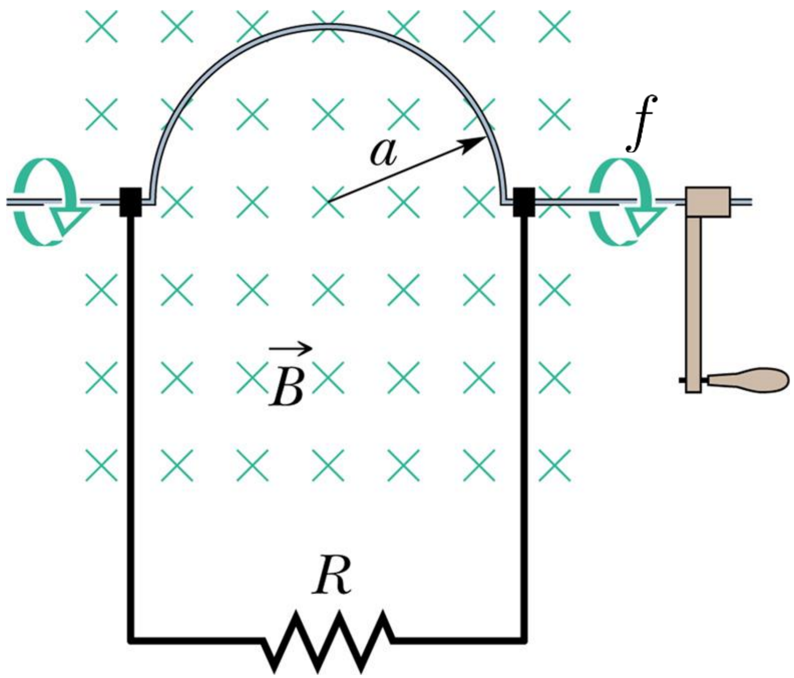
Problem



$$R = 2.0 \text{ m}, \; 4.0\Omega$$

$$i(t) = 5.0 \text{ A} - (2.0 \text{ A/s}^2)t^2$$

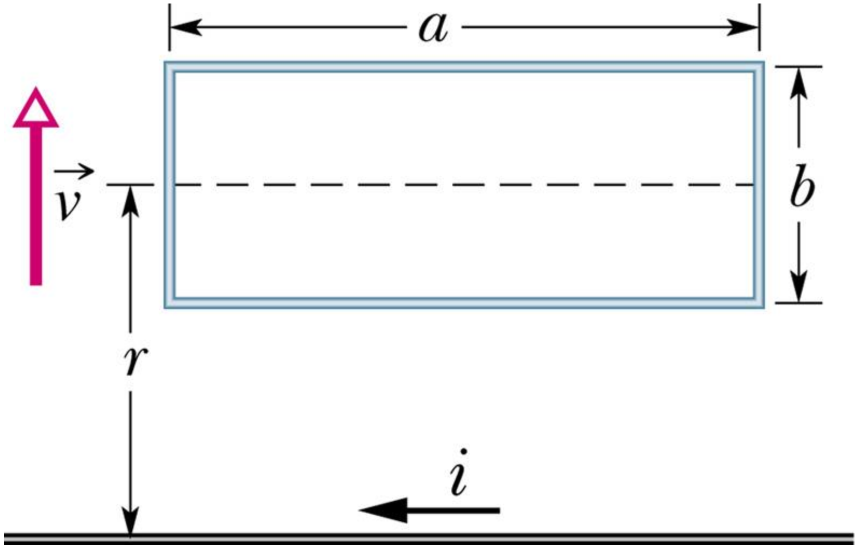
Problem



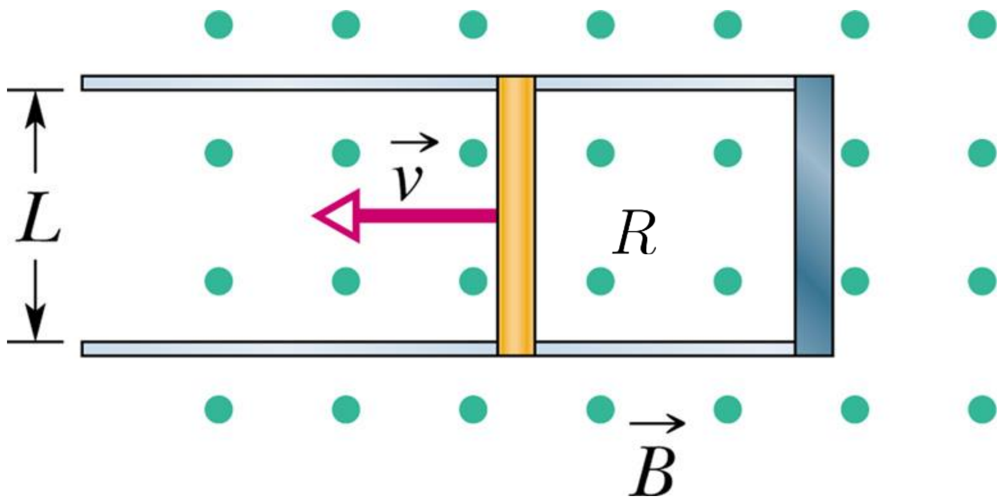
$a = 2.0\ \text{cm},\ \ B = 20\ \text{mT}$

(a) frequency
(b) amplitude of the EMF

Problem

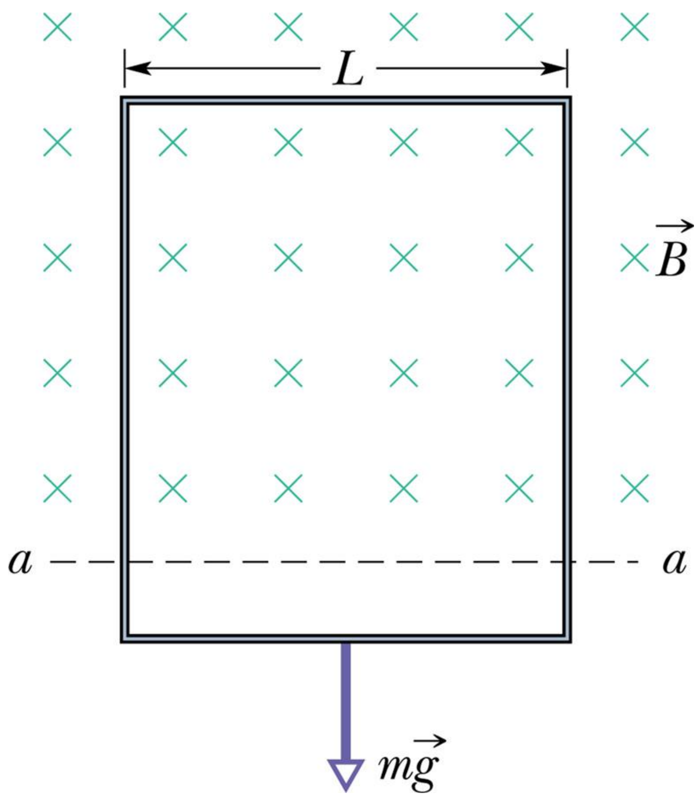


Problem

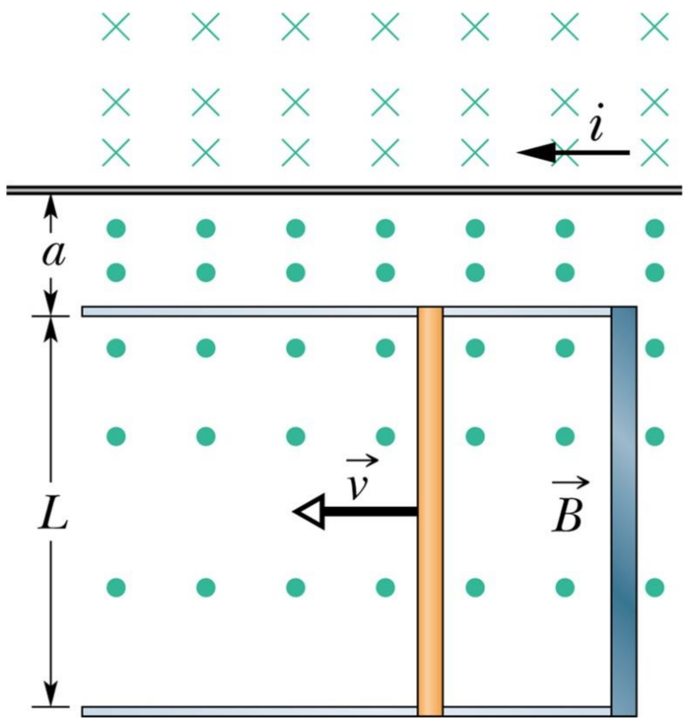


(a) Emf
(b) Current
(c) Thermal energy per unit time

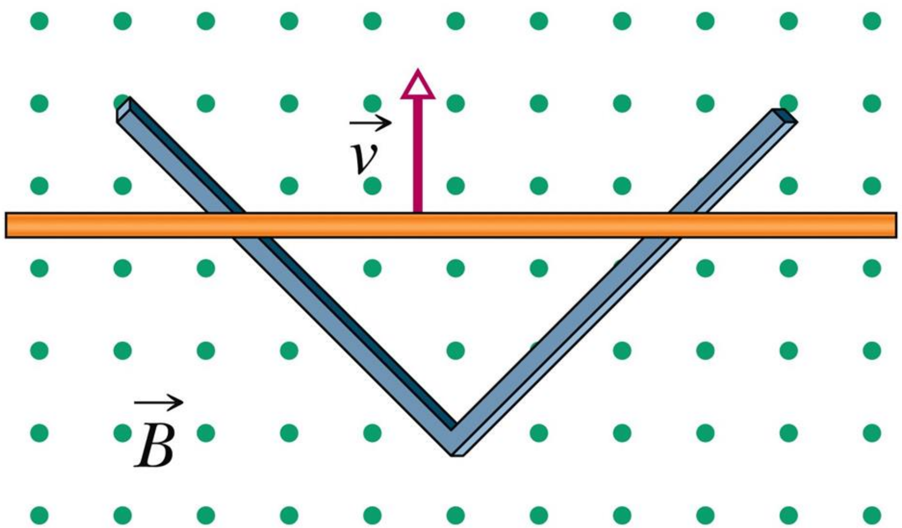
Problem



Problem

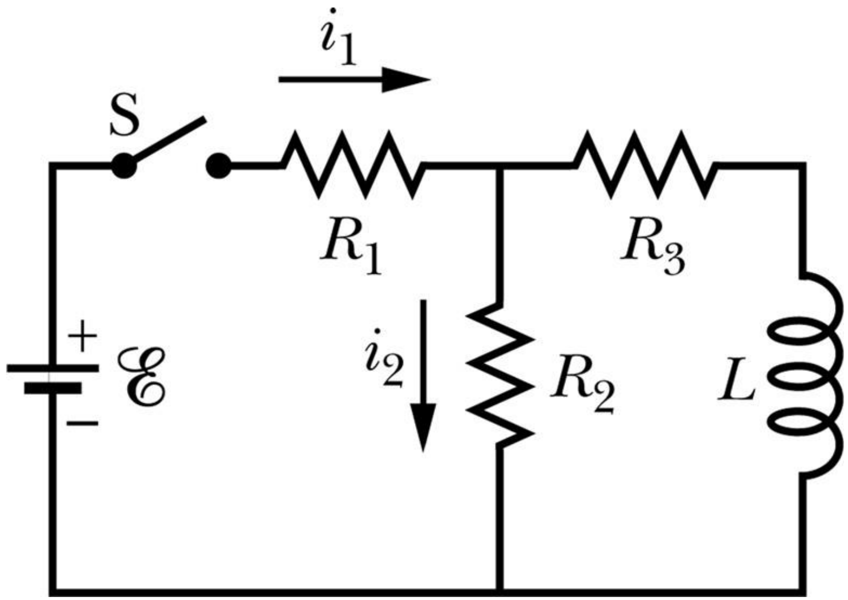


Problem



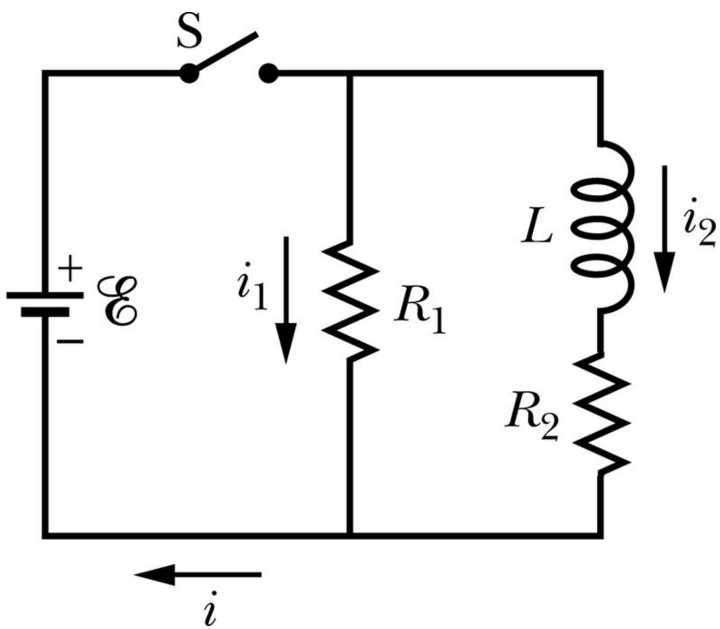
$$\mathcal{E} = at^n,\ n = ?$$

Problem

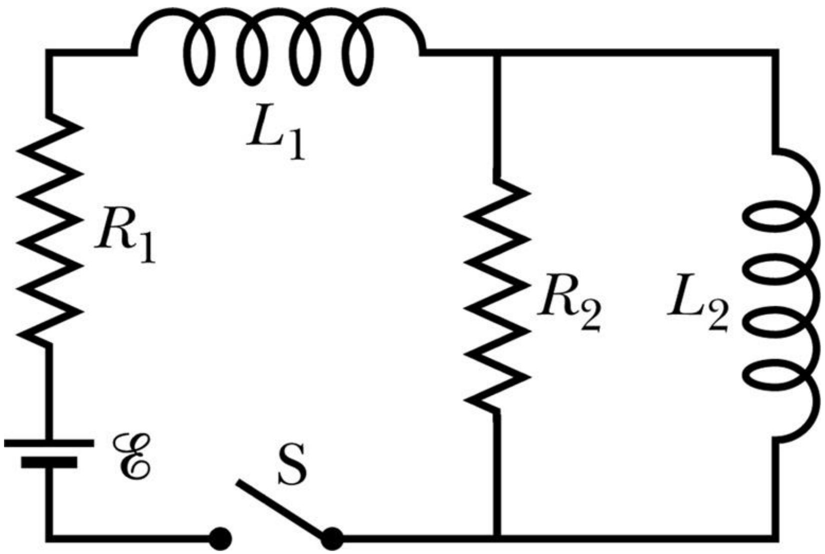


(a) Switch closed
(b) Long time after
(c) Switch opened
(d) Long time after

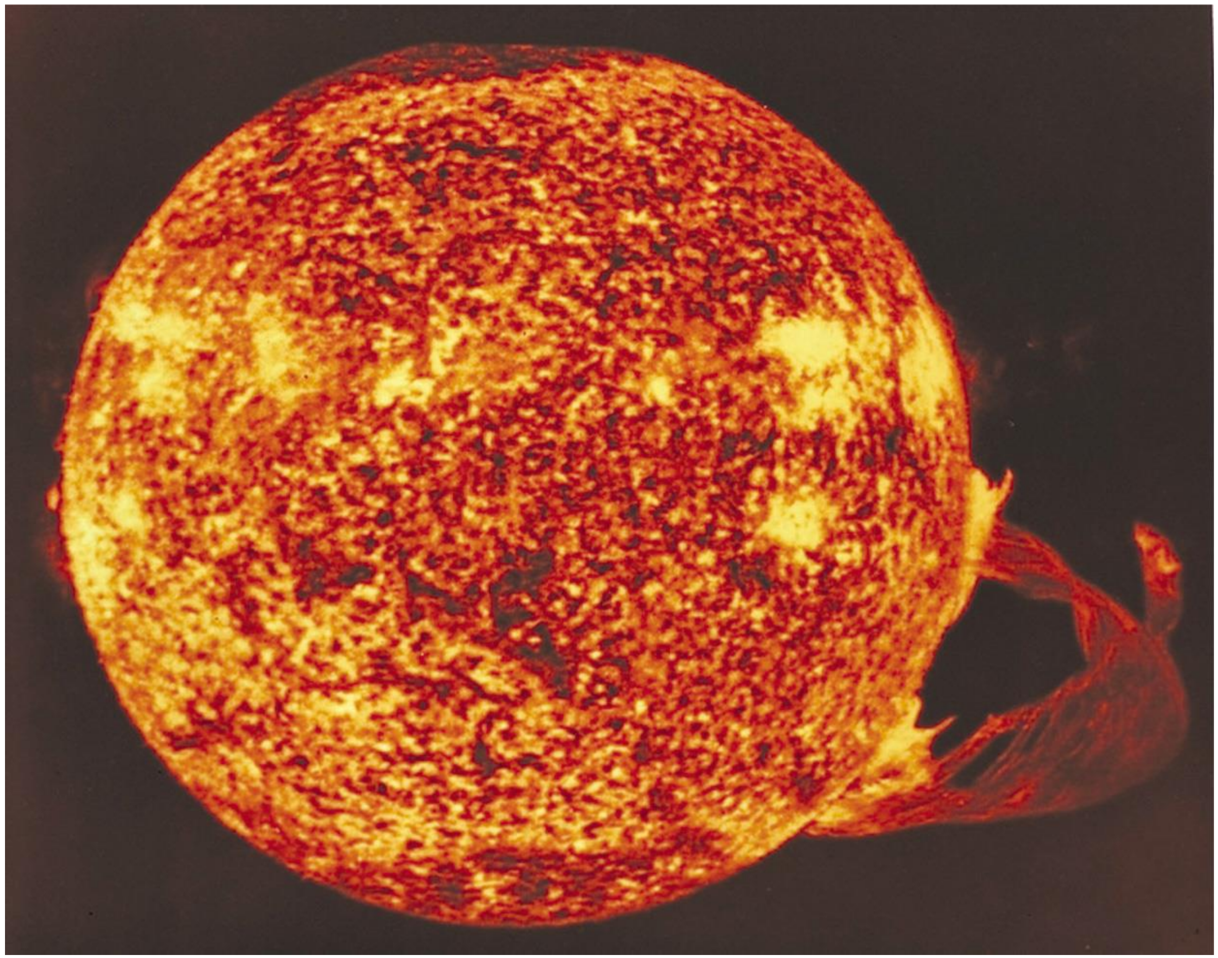
Problem



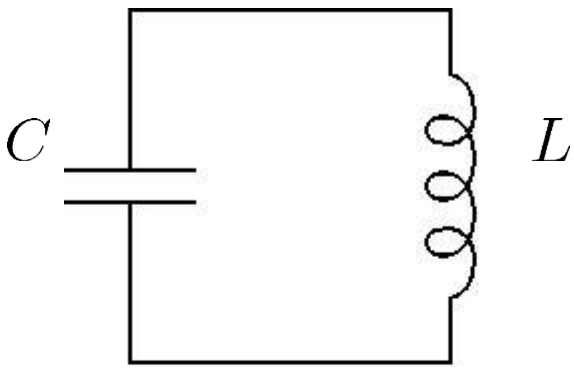
Problem



Chapter 30 Electromagnetic oscillations and currents



LC circuits



Energy stored in E and B fields

$$U_E = \frac{q^2}{2C}, \quad U_B = \frac{Li^2}{2}$$

Total energy is conserved.

electromagnetic oscillation

N. B. potential and kinetic energies of a spring

$$U = \frac{1}{2}kx^2, \quad T = \frac{1}{2}mv^2$$

퍼텐셜에너지와 운동에너지 사이의 교환

-> <u>용수철의 진동</u>

LC oscillation