Physics II: 1702
Gravity, Electricity, & Magnetism

Professor Jasper Halekas
Van Allen 70 [Clicker Channel #18]
MWF 11:30-12:30 Lecture, Th 12:30-1:30 Discussion

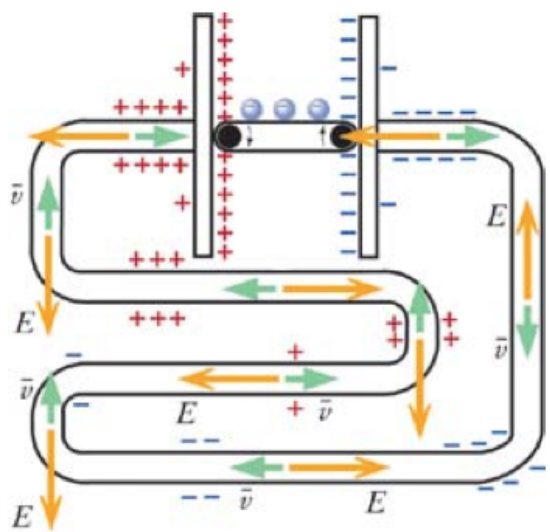
Announcements

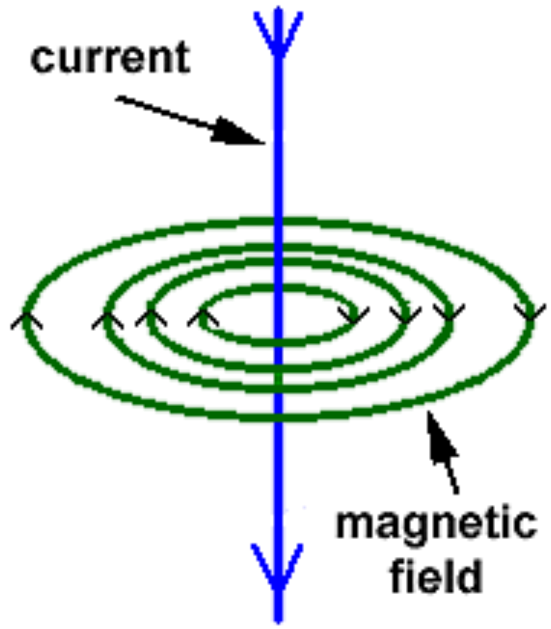
- Midterm II Wednesday 4/6 in class
  - Closed book
  - Bring pen/pencil
  - Bring 8.5x11 index card cheat-sheet (one-sided)
  - No calculator needed!

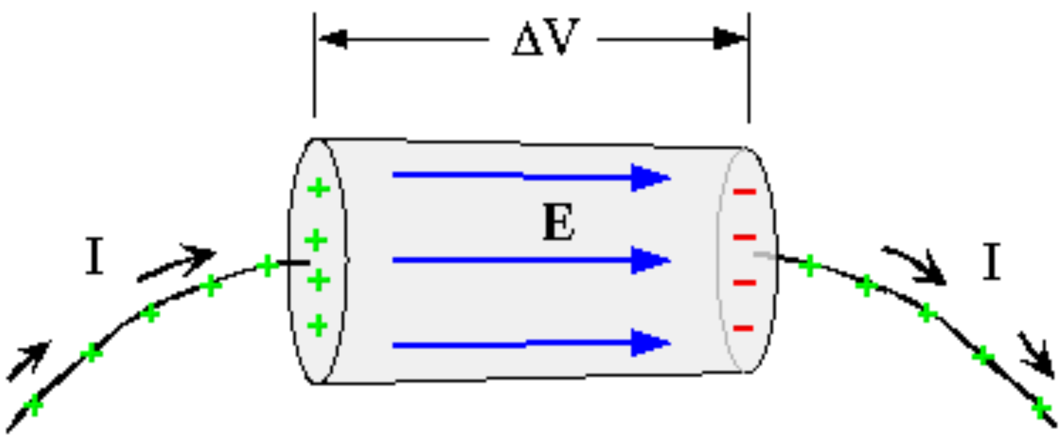
Review: Four Most Important Things

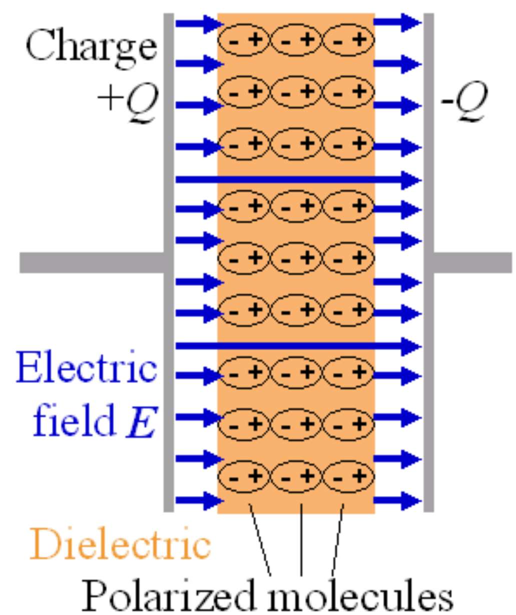
1. Understand how resistors and capacitors work and how they behave in series and parallel
2. Be able to analyze voltages and currents through circuits
3. Know how to compute magnetic forces and torques on moving charges, currents, and magnetic moments
4. Know how to calculate the magnetic field from the current

Midterm II Review!



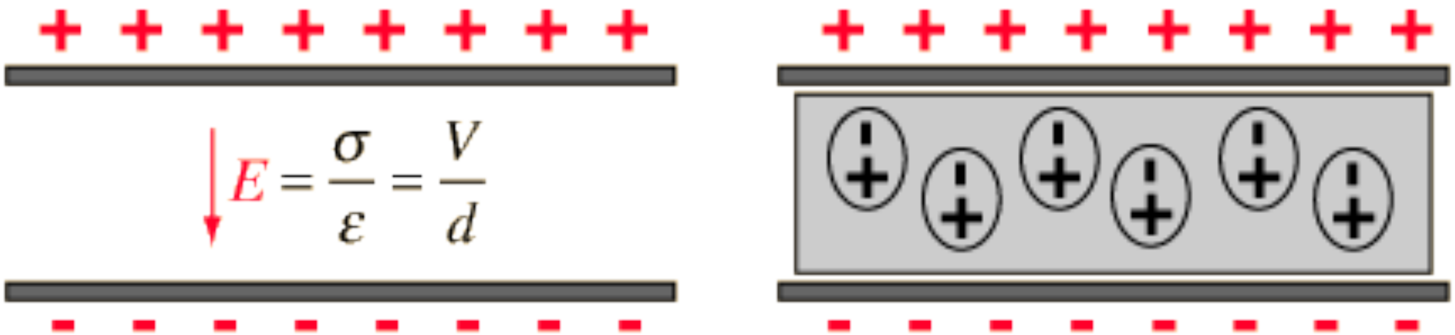






Capacitor

- C = Q/V (always)



For air, $\varepsilon \approx \varepsilon_0$

$E_{effective} = E - E_{polarization} = \frac{\sigma}{k\varepsilon_0}$

$$C = \frac{\varepsilon_0 A}{d}$$

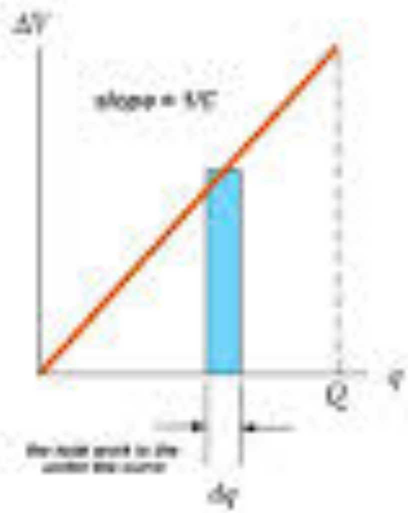
The capacitance is increased by the factor k.

$$C = \frac{k\varepsilon_0 A}{d}$$

Energy Storage

Energy Stored in a Charged Capacitor

$$dW = \Delta V dq = \frac{q}{C} dq$$



$$W = \int_0^Q \frac{q}{C} dq = \frac{1}{C} \int_0^Q q\, dq = \frac{Q^2}{2C}$$

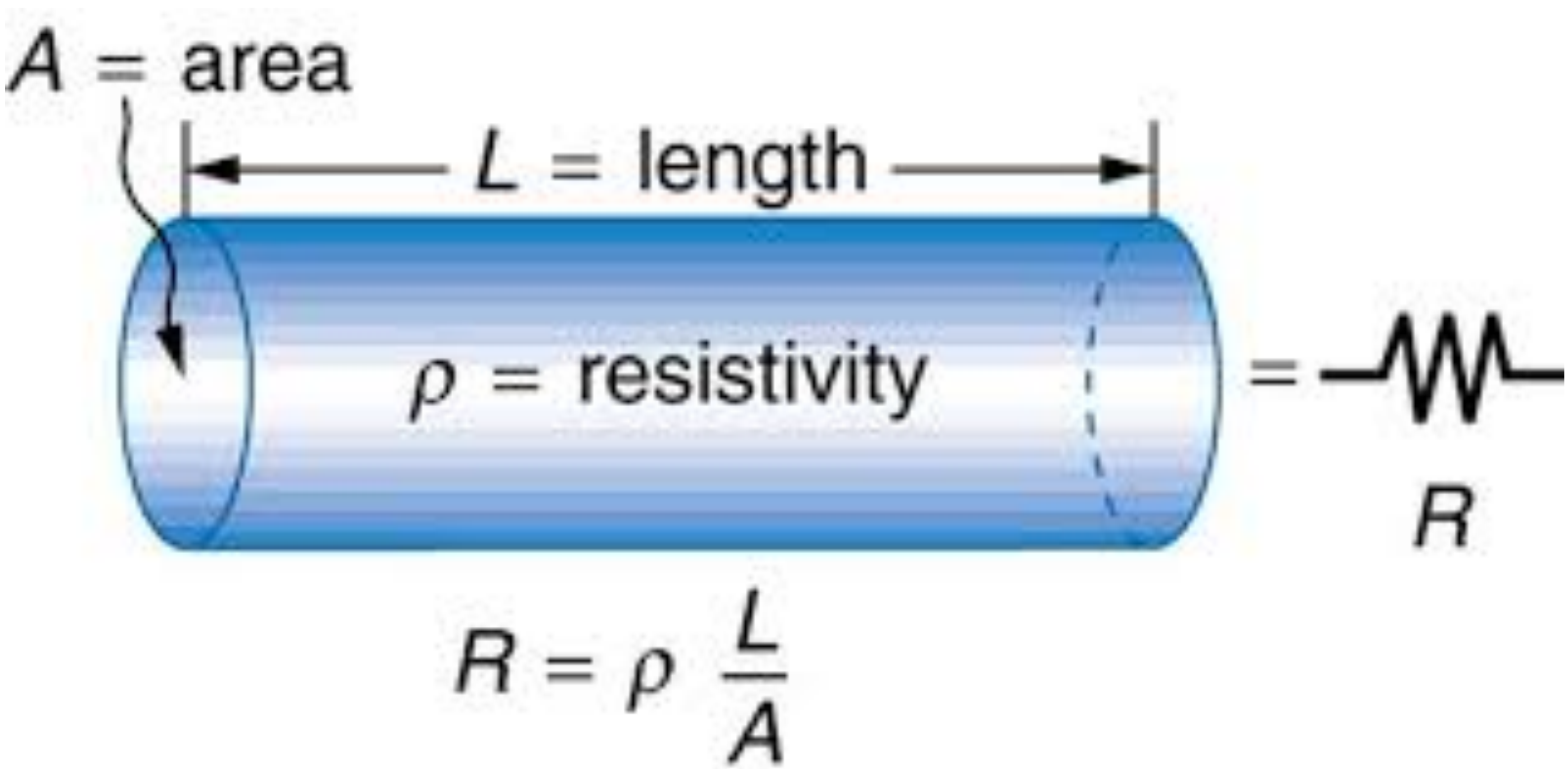
$$U = \frac{Q^2}{2C} = \frac{1}{2} Q \Delta V = \frac{1}{2} C (\Delta V)^2$$

Concept Check

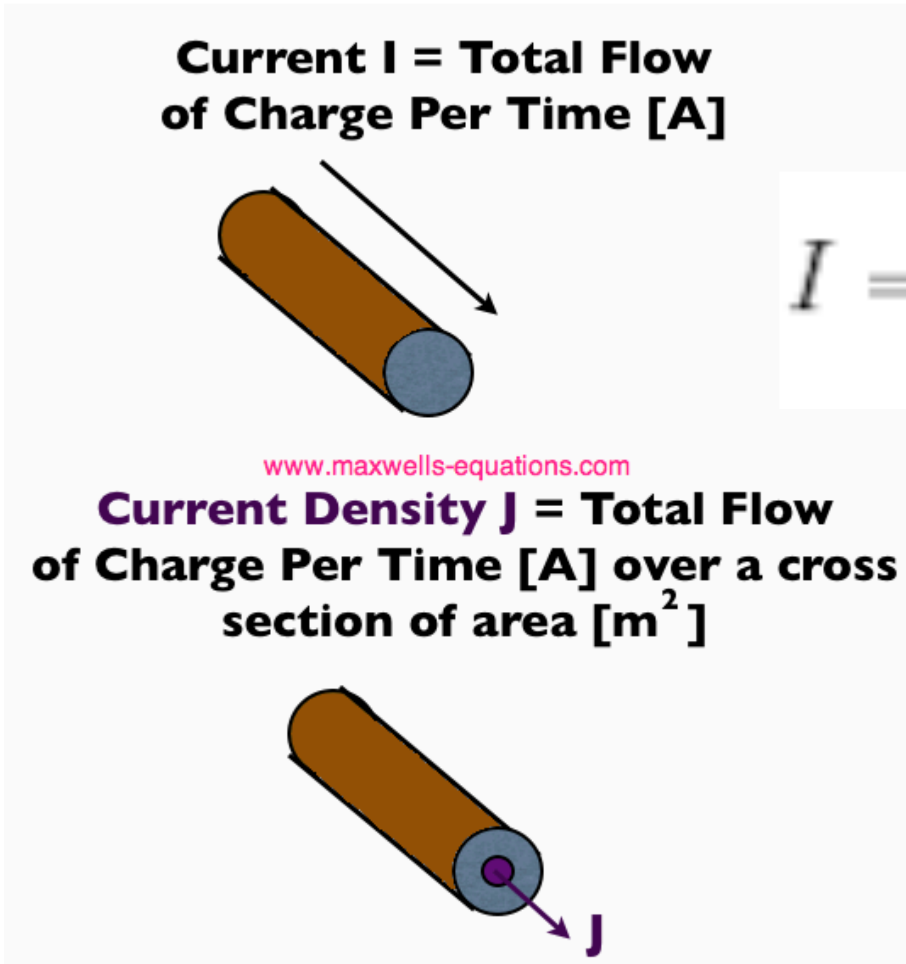
A parallel-plate capacitor with a dielectric between the plates is charged so that +Q resides on one plate, –Q on the other. With the plates isolated and the charge Q constant, the dielectric is pulled out from between the plates. The energy stored in the capacitor …

1) increases
2) decreases
3) stays the same.

Resistor



Current and Current Density



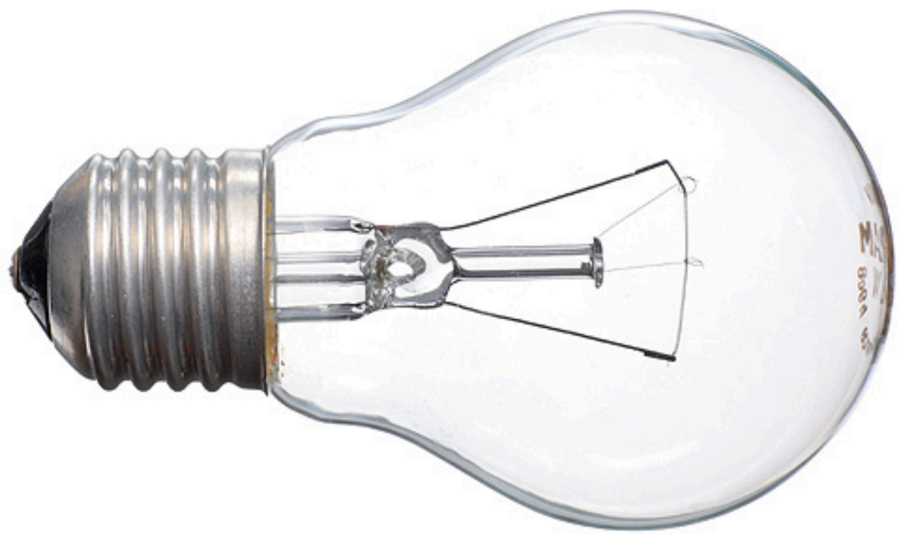
$$I = \int_S \mathbf{J} \cdot \mathrm{d}\mathbf{A}$$

Macroscopic Quantities Vs. Fields

- $V = IR$
- Equivalent to $E = \rho J = J/\sigma$
- For resistor $V = I\rho L/A$
  - $\Rightarrow V/L = E = \rho I/A = \rho J$

Power Dissipation

- $P = VI$ (always)
  - $= I^2R = V^2/R$ for ohmic materials (resistors, light bulbs)

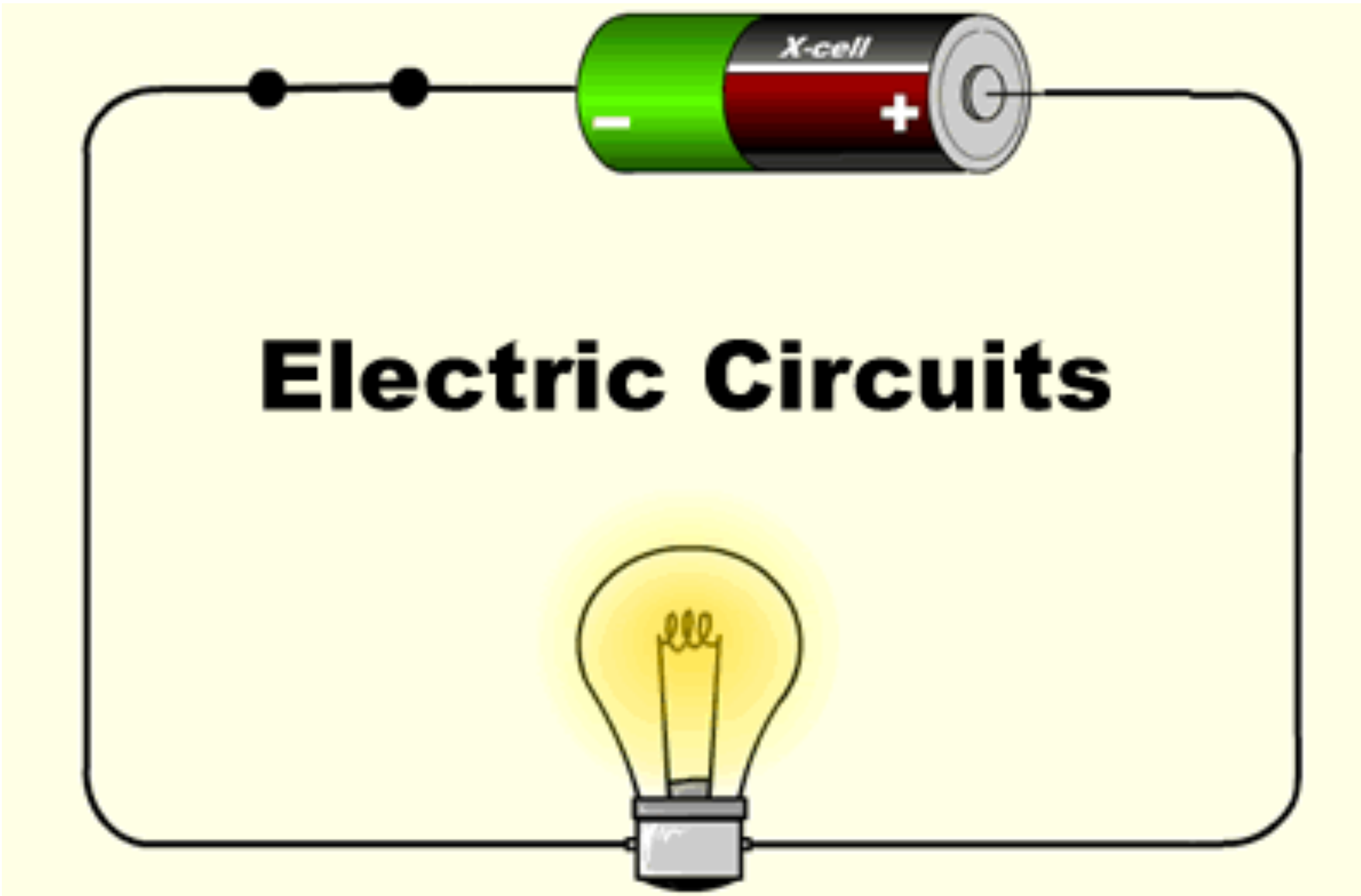


Concept Check

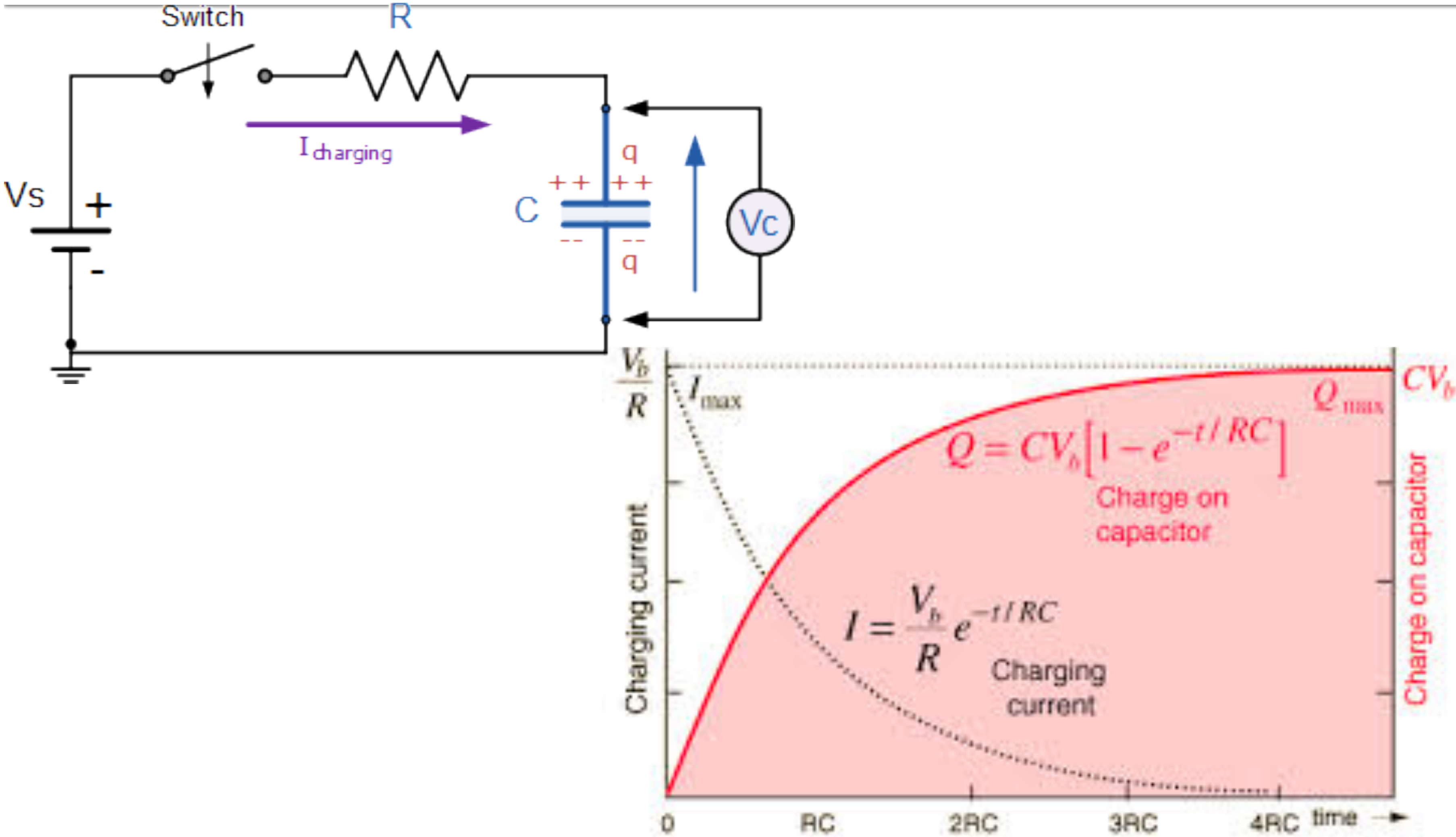
You wish to double the rate of energy dissipation in a heating device. You could:

1) double the potential difference keeping the resistance the same
2) double the current keeping the resistance the same
3) double the resistance keeping the potential difference the same
4) double the resistance keeping the current the same
5) double both the potential difference and the current

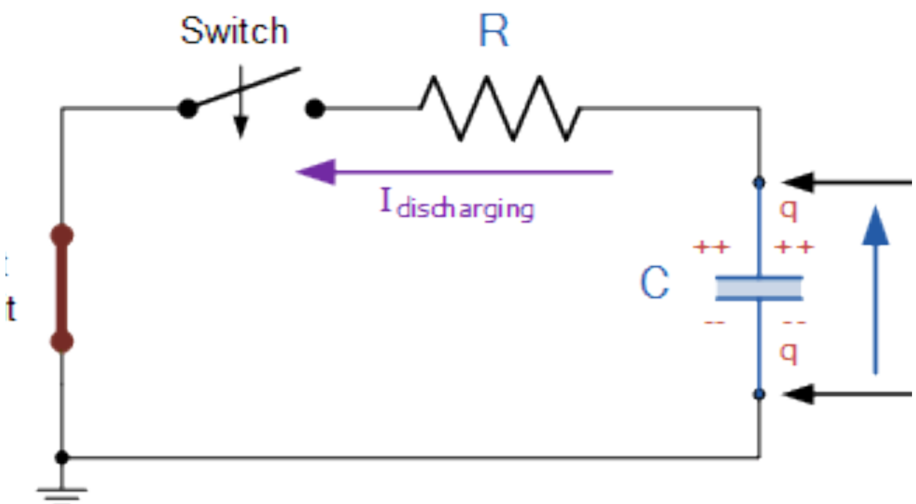
Circuits

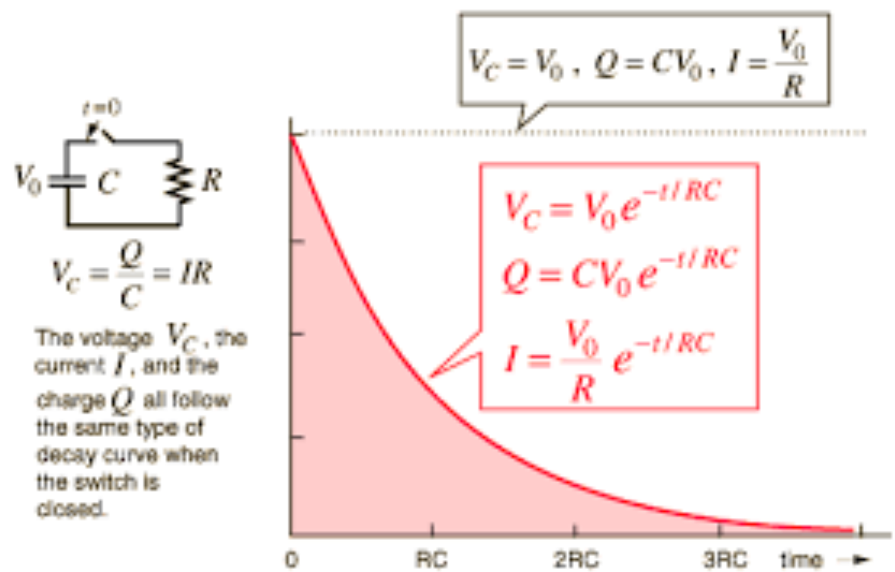


Capacitor Charging

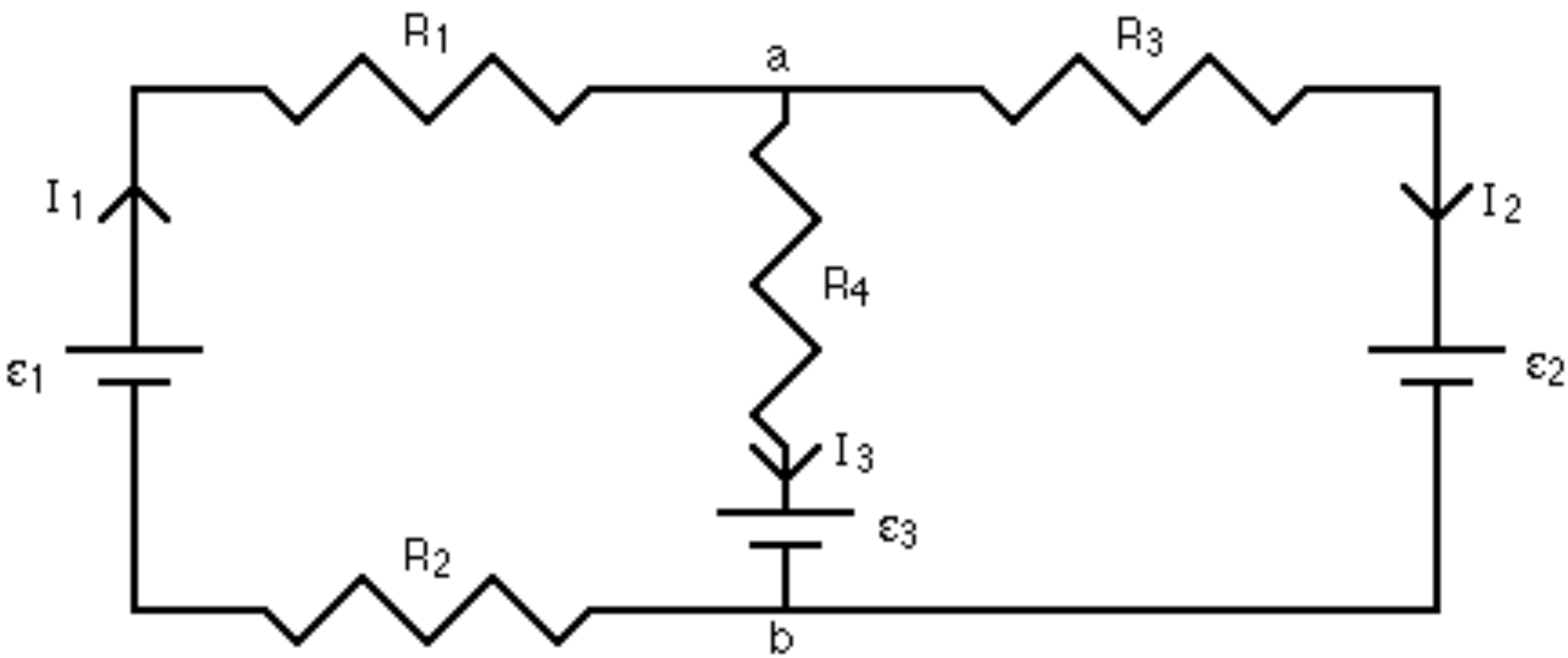


Capacitor Discharging



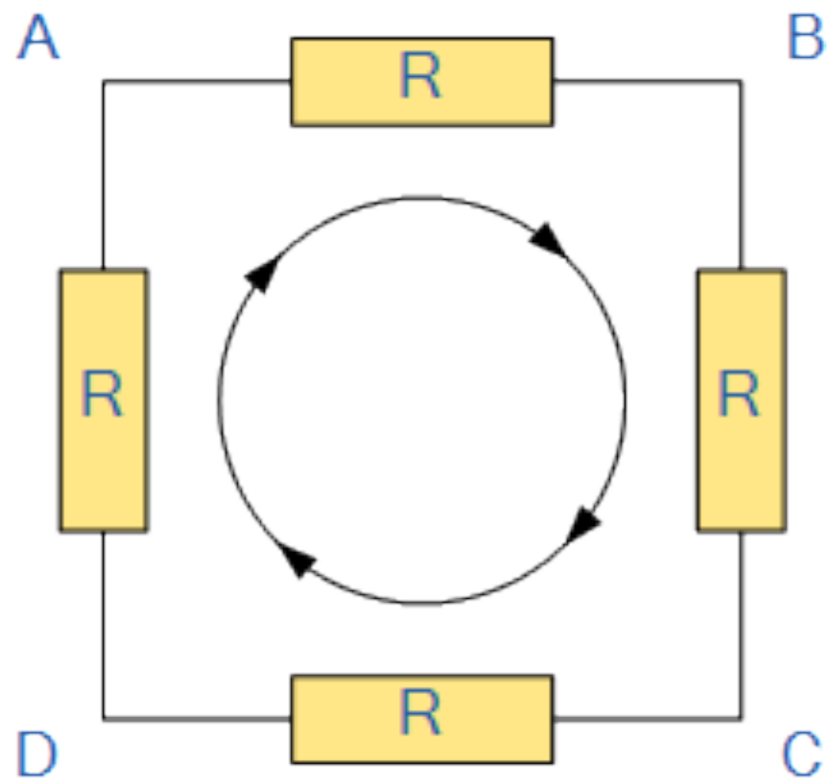


Multi-Loop Circuits



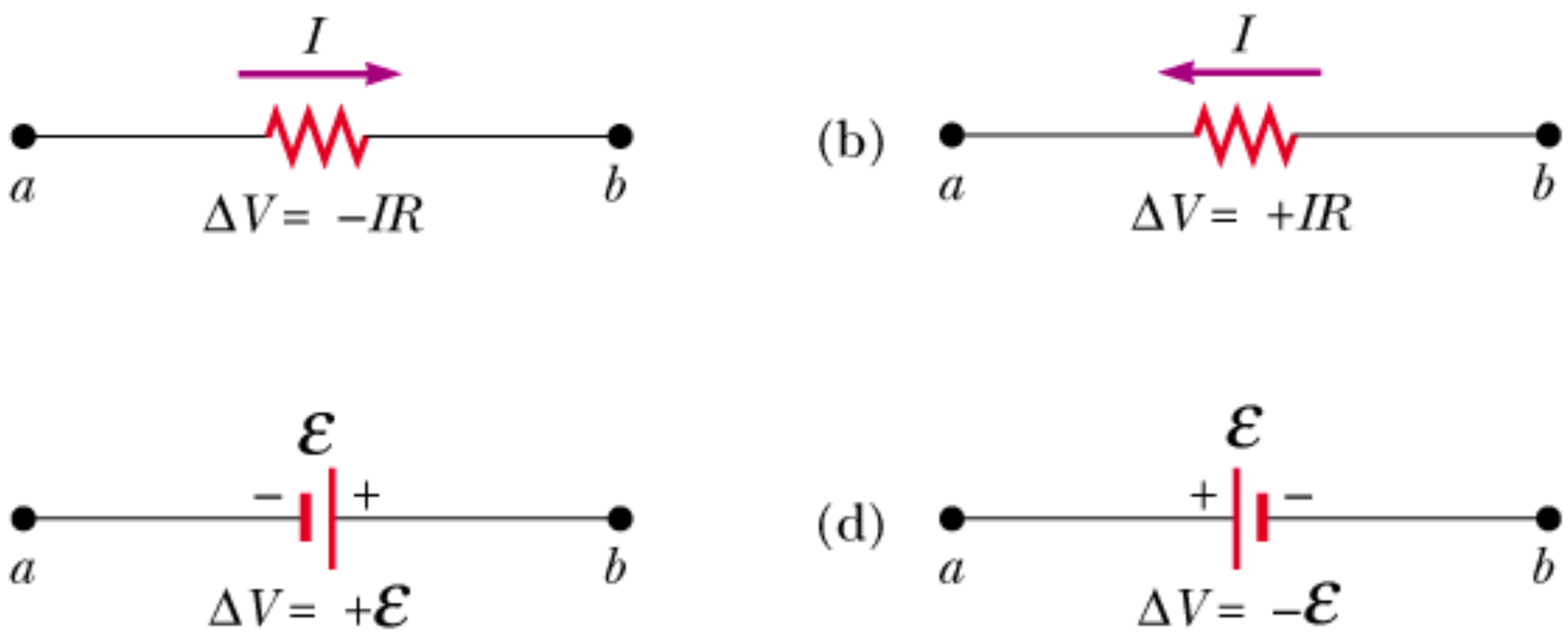
Loop Rule

The sum of all the Voltage
Drops around the loop
is equal to Zero

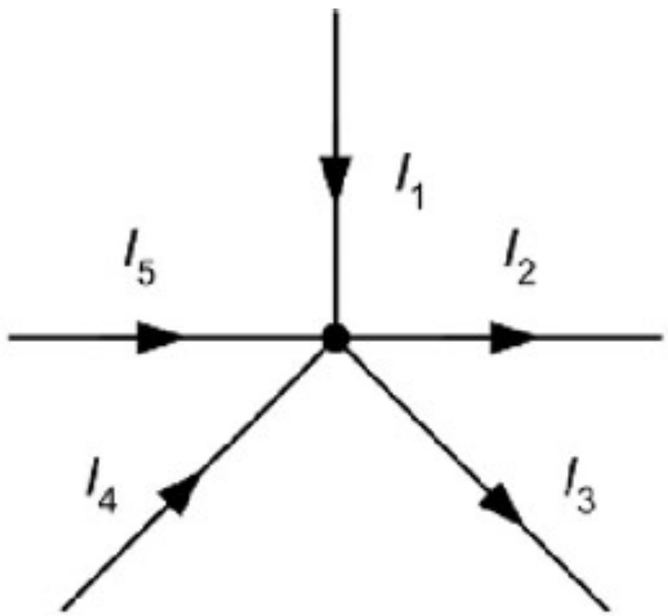


$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

Loop Rule Signs



Junction Rule



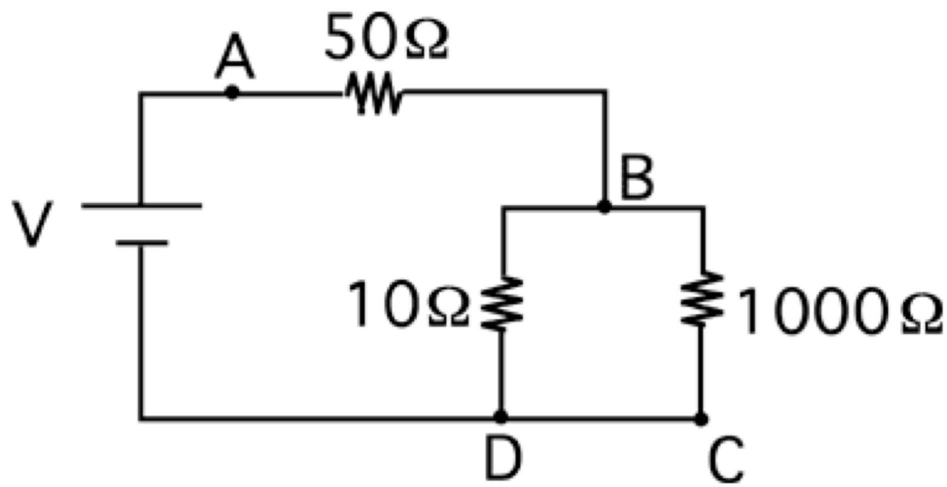
$$I_1 - I_2 - I_3 + I_4 + I_5 = 0$$

Convention:
Current flowing towards the junction is positive (+)
Current flowing away from the junction is negative (–)

Concept Check

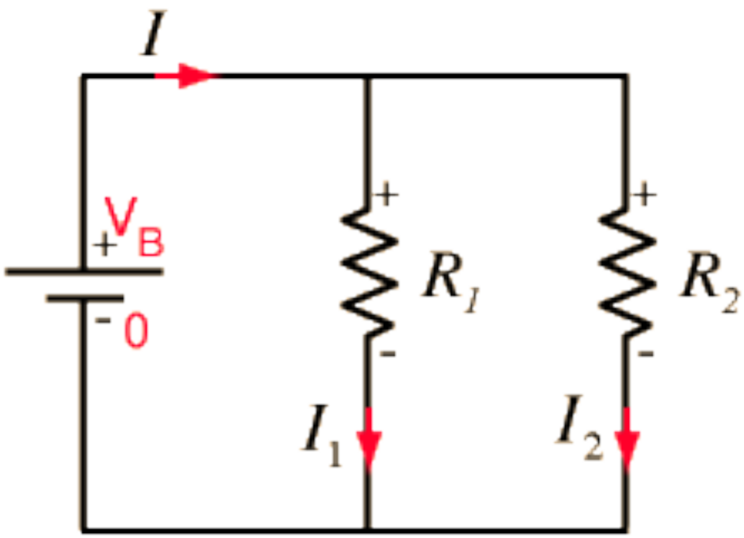
Q37) Consider the circuit below. Which statement(s) is correct?

- 1: IAB = IBD + IBC
- 2: IBC < IBD
- 3: IBC > IBD



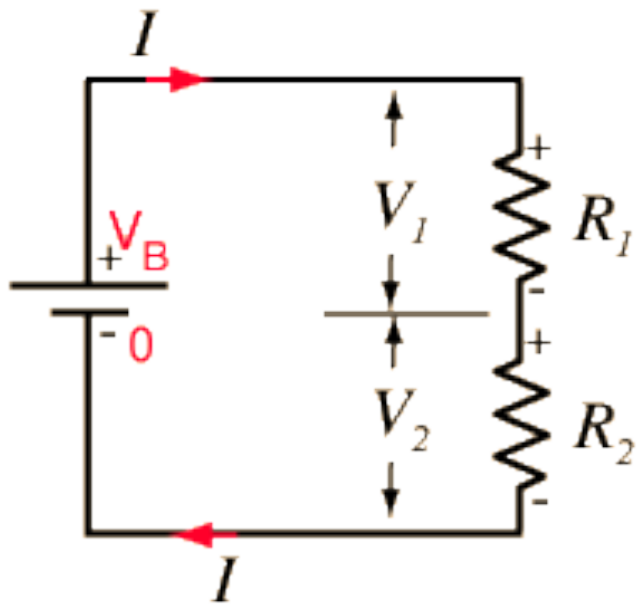
1) 1 only
2) 2 only
3) 3 only
4) 1 and 2
5) 1 and 3

Resistors in Parallel and Series



Parallel resistors

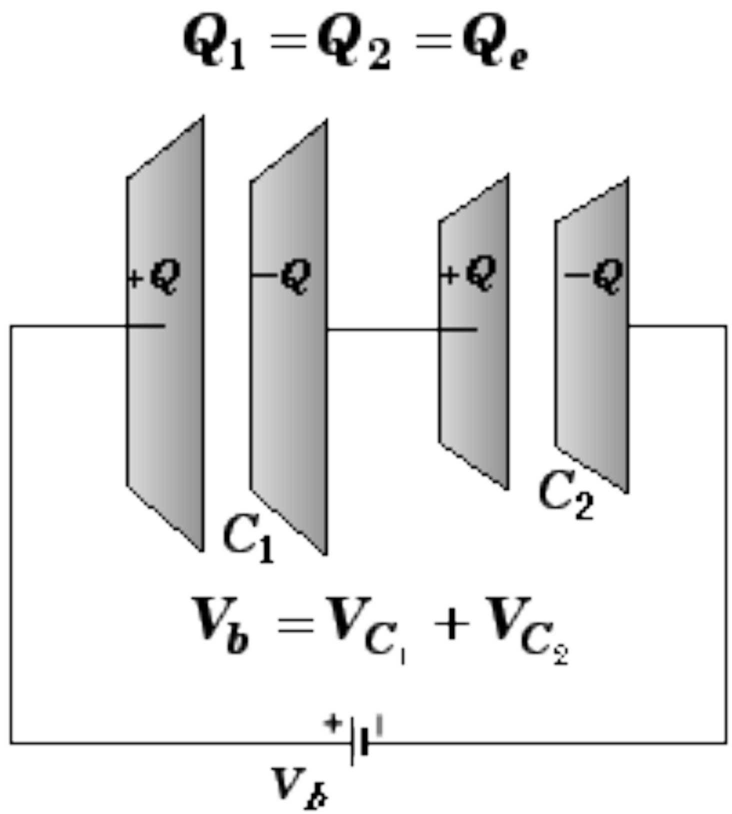
$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2}$$

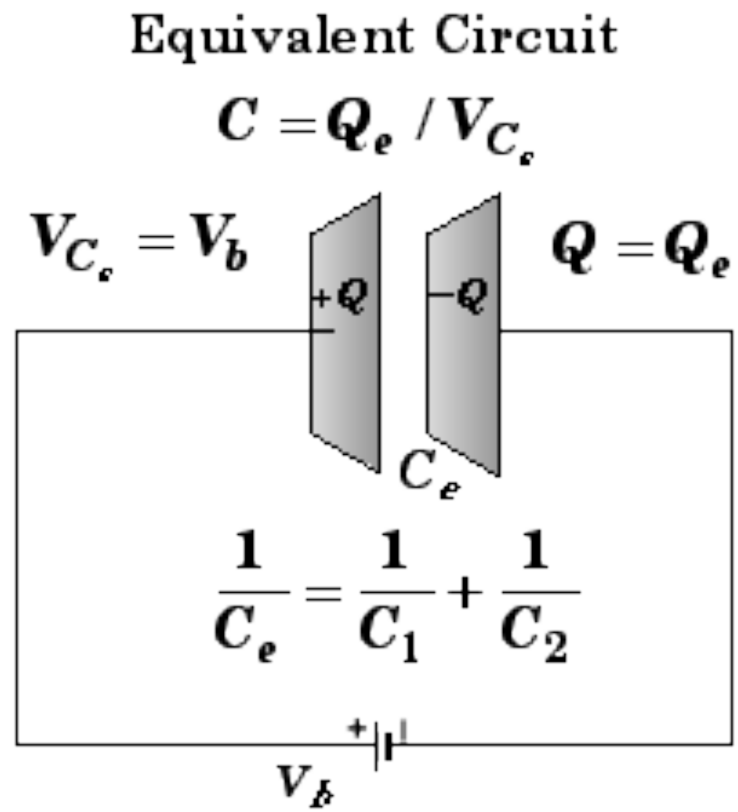


Series resistors

$$R_{equivalent} = R_1 + R_2$$

Capacitors in Parallel and Series





Two Ways to Get Magnetic Field

Magnetic field of a current element

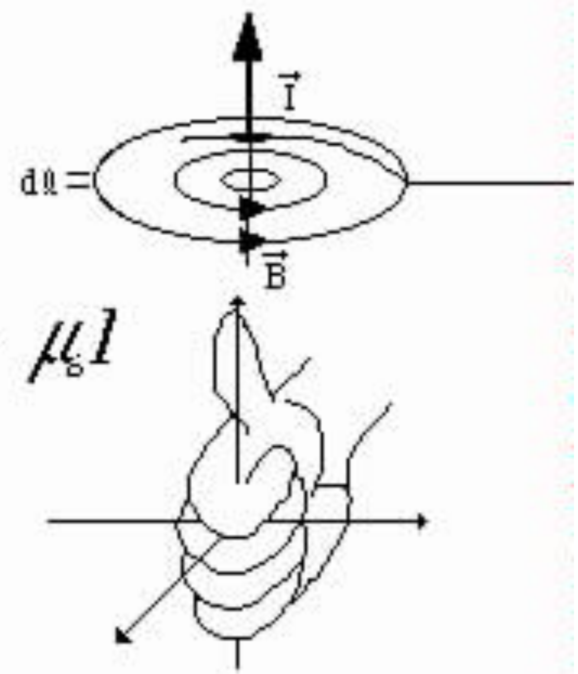
$$d\vec{B} = \frac{\mu_0 I d\vec{L} \, x \, \vec{1}_r}{4\pi r^2}$$

where

$d\vec{L}$ = infinitesmal length of conductor carrying electric current I

$\vec{1}_r$ = unit vector to specify the direction of the the vector distance r from the current to the field point.

$$\oint_C \vec{B} \bullet d\vec{\ell} = \mu_0 I$$

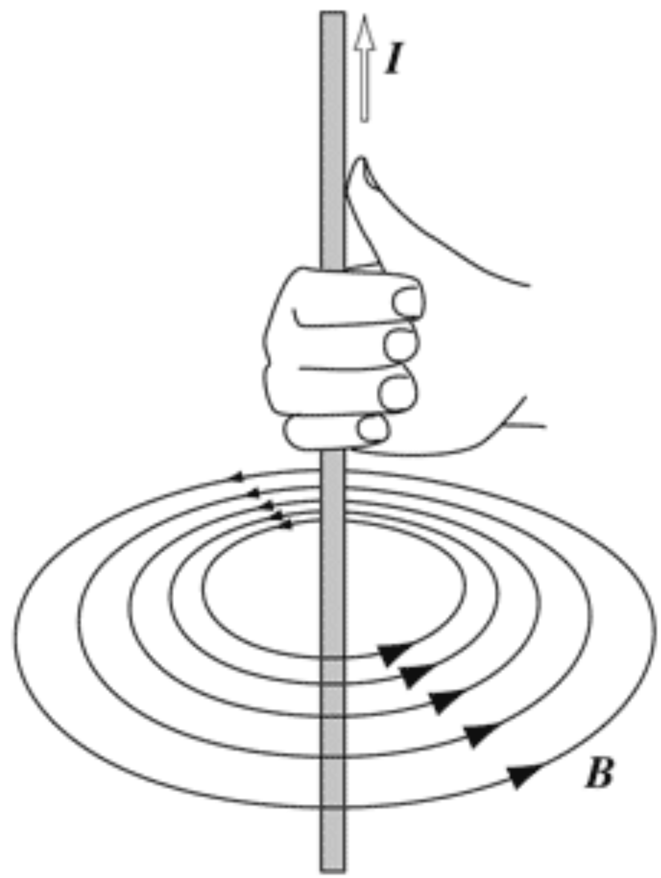


Magnetic Field of Wire

Magnetic Field of a Straight Current Carrying Wire

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

B = magnetic field strength at distance **d**
I = current
μ_0 = pemeability of free space ($4\pi \times 10^{-7}$ T m/A)
d = distance from the wire



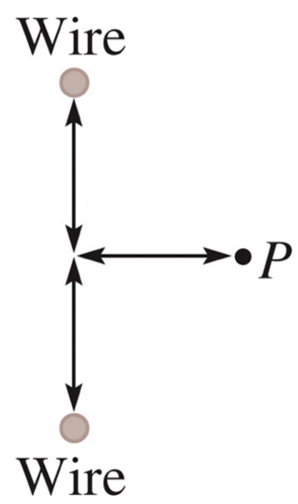
Ampere's Law

For any closed loop path, the sum of the products of the length elements and the magnetic field in the direction of the length elements is proportional to the electric current enclosed in the loop (magnetic permeability, μ_0, is the constant of proportionality).

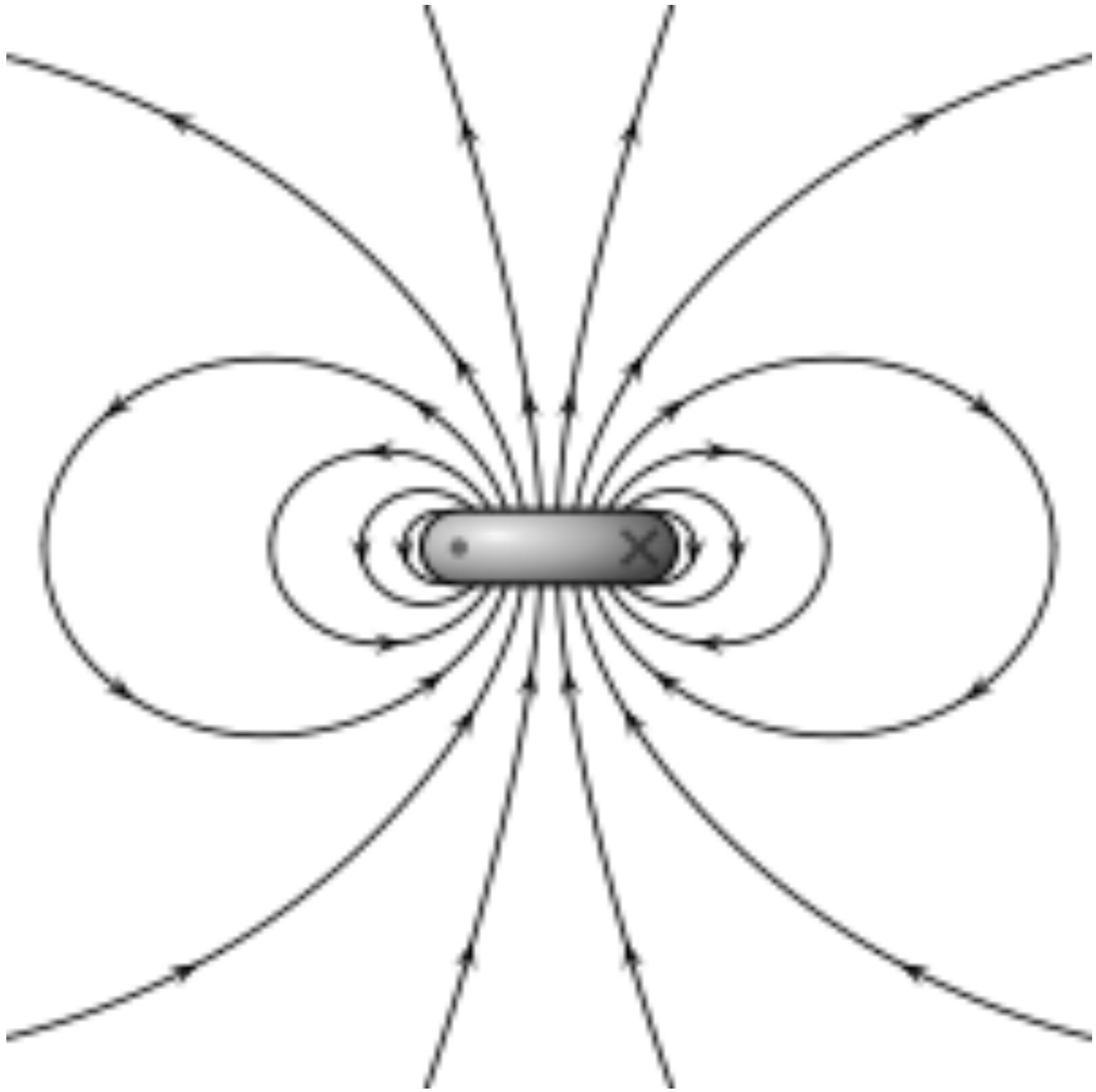
Concept Check

Q6) Two conducting wires perpendicular to the page are shown in cross section as gray dots in the figure. They each carry a current **out of** the page. What is the direction of the magnetic field at point *P*?

1) up
2) down
3) right
4) left
5) none of the above



Magnetic Field of Loop



$\mu = iA$

Magnetic Field of Solenoid

The Magnetic Field of a Solenoid

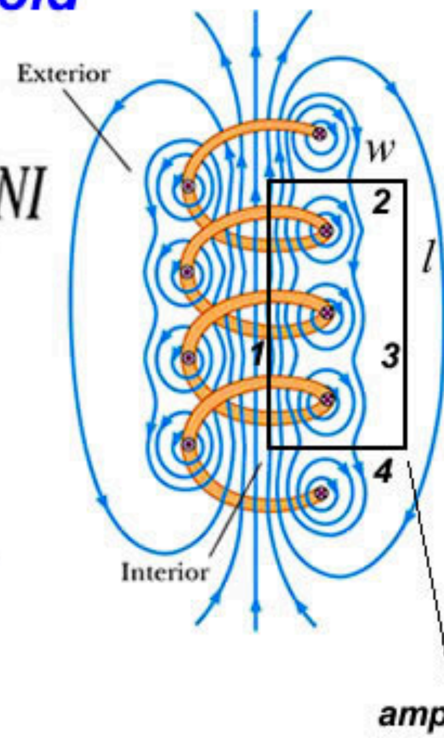
$$\oint B \cdot ds = \int_{path1} B \cdot ds = B \int_{path1} ds = Bl = \mu_o NI$$

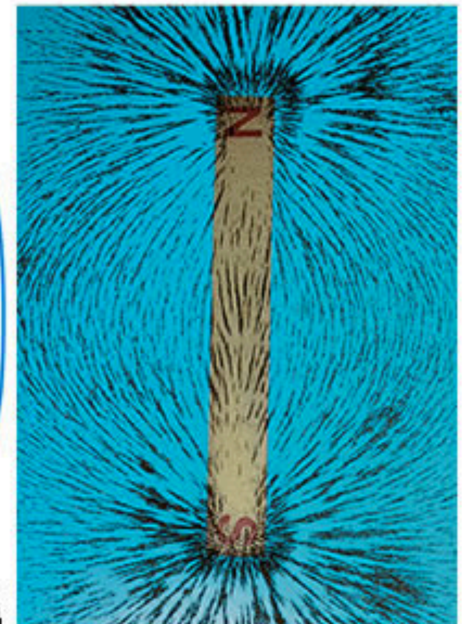
$$B = \mu_o \frac{N}{l} I = \mu_o n I$$

On sides 2 and 4   B is perpendicular to ds

so $\oint B \cdot ds = 0$

On side 3 the B-field is nearly zero



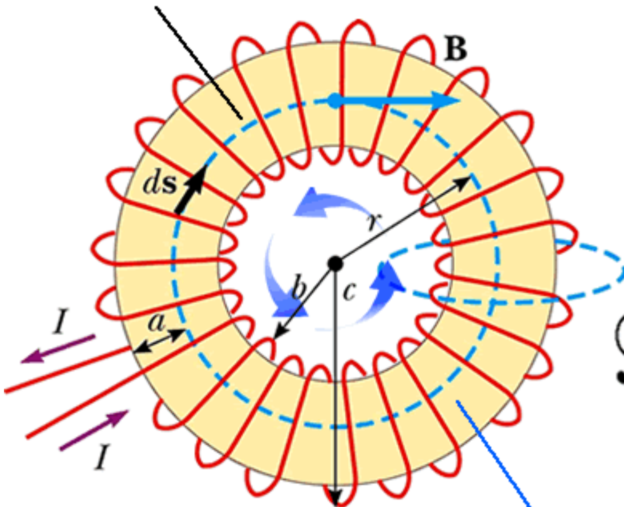


Magnetic Field of Toroid

The Magnetic Field created by a Toroid

"TOKAMAK"

amperian Loop



The Current is traveling around the Toroid in the red wire in a counterclockwise direction

The magnetic field in inside the doughnut. It is nonuniform inside the red wire.

B is constant and tangent to ds

$$B \bullet ds = Bds\cos\theta = Bds$$

We can pull B outside the integral

$$\oint ds = 2\pi r$$

$$\oint B \bullet ds = B\oint ds = B(2\pi r) = \mu_o NI$$

The wire passes thru the loop N times

$$B = \frac{\mu_o NI}{2\pi r}$$

The B-Field is the same as that around a straight wire except that each turn of the wire produces more B-Field

The Magnetic Field seems to be confined to the inside of the toroid.

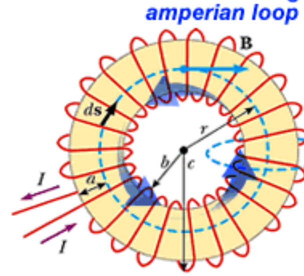
If the amperian loop shown is smaller than the dimension b or larger than the dimension c than there would be zero net current thru the amperian loop. So,

B is not equal to 0

$$\oint B \bullet ds = 0$$

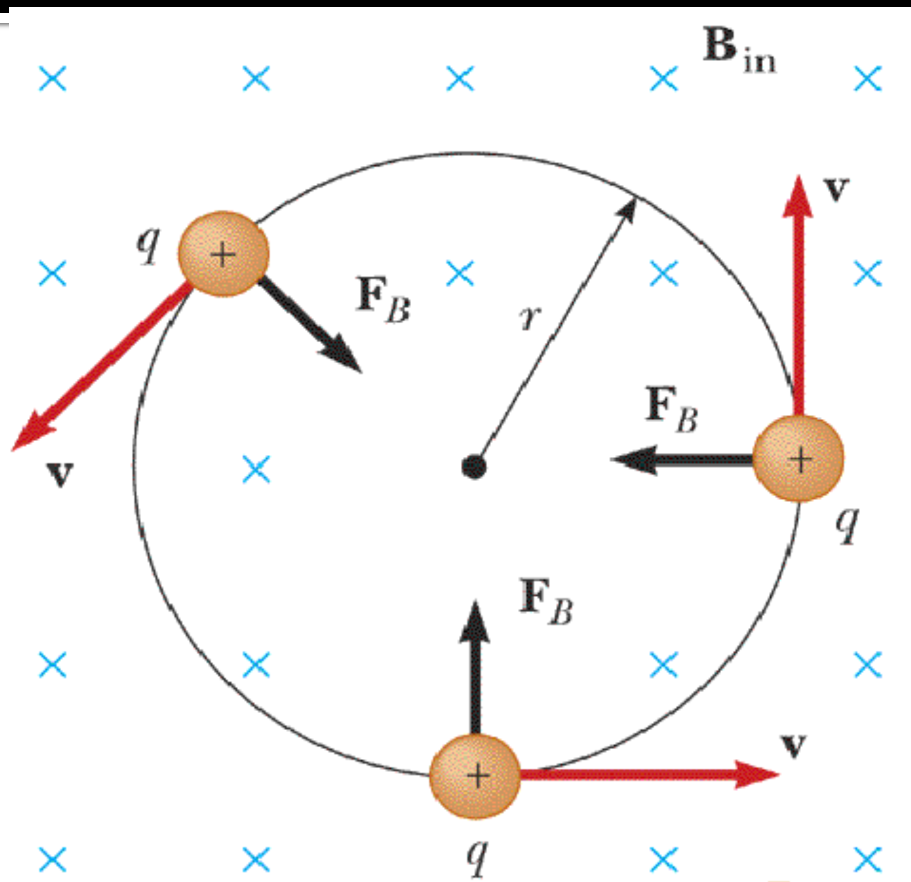
B is perpendicular to ds

There is a current travelling thru the 2nd amperian loop

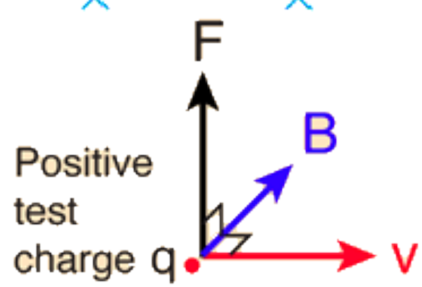


Which produces a B-Field perpendicular to the screen

Magnetic Force



$$\vec{F} = q\vec{v} \ x \ \vec{B}$$



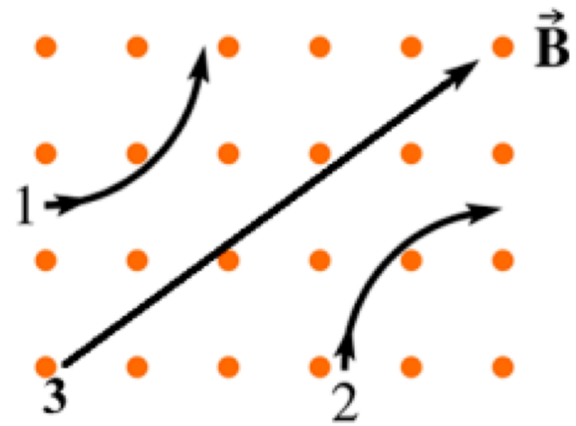
Electromagnetic Force

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

Electric force *Magnetic force*

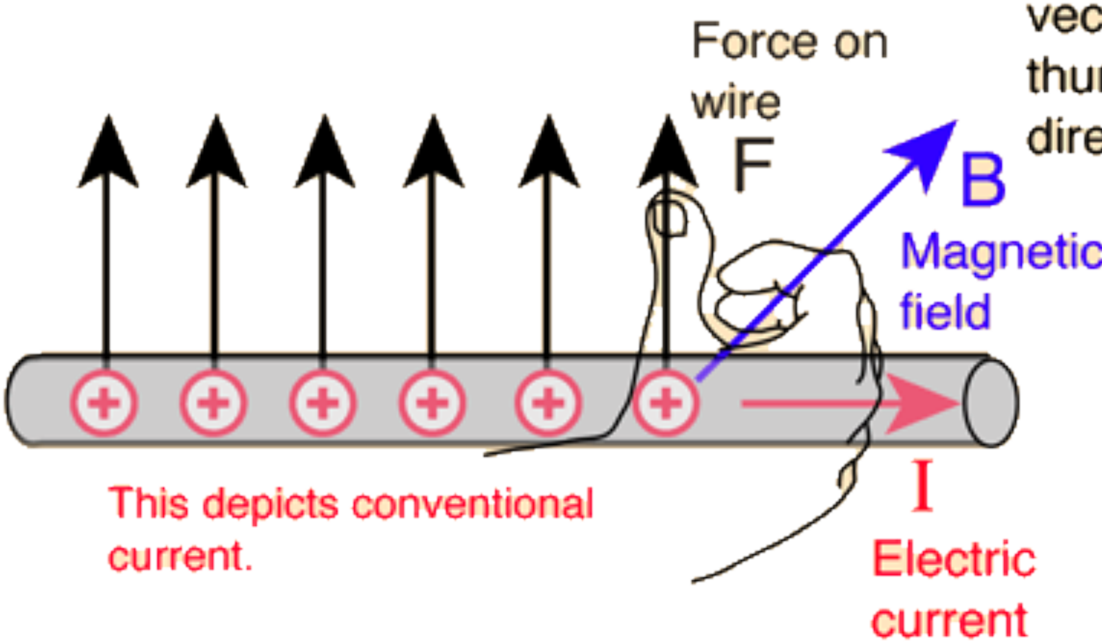
Concept Check

Q23) Three particles move through a region of uniform magnetic field pointed out of the plane and follow the trajectories shown. The charges on these particles are



1) $q_1 < 0$, $q_2 > 0$, $q_3 = 0$.
2) $q_1 > 0$, $q_2 = 0$, $q_3 < 0$.
3) $q_1 < 0$, $q_2 = 0$, $q_3 > 0$.
4) $q_1 = 0$, $q_2 > 0$, $q_3 < 0$.

Magnetic Force on Wire

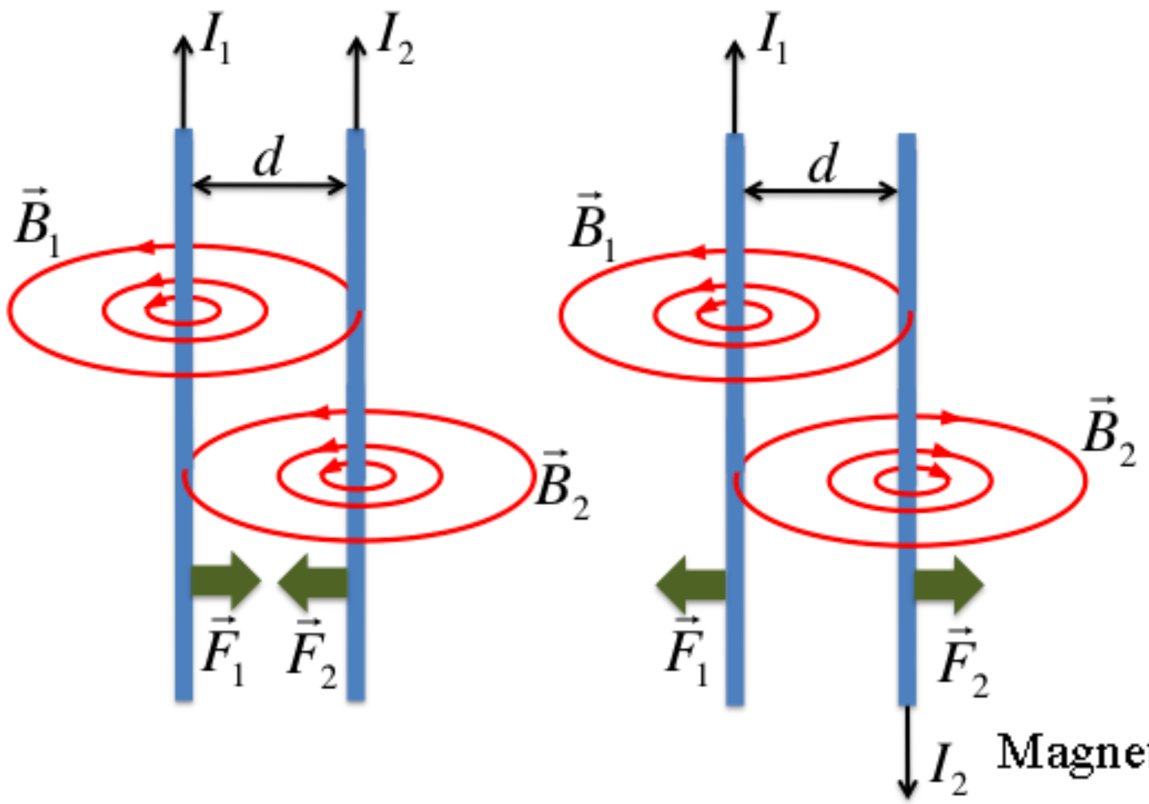


Curl fingers as if rotating vector I into vector B. The thumb is then in the direction of the force F

$$\vec{F} = \vec{I}L \times \vec{B}$$

Force on straight wire of length L

Force Between Two Wires

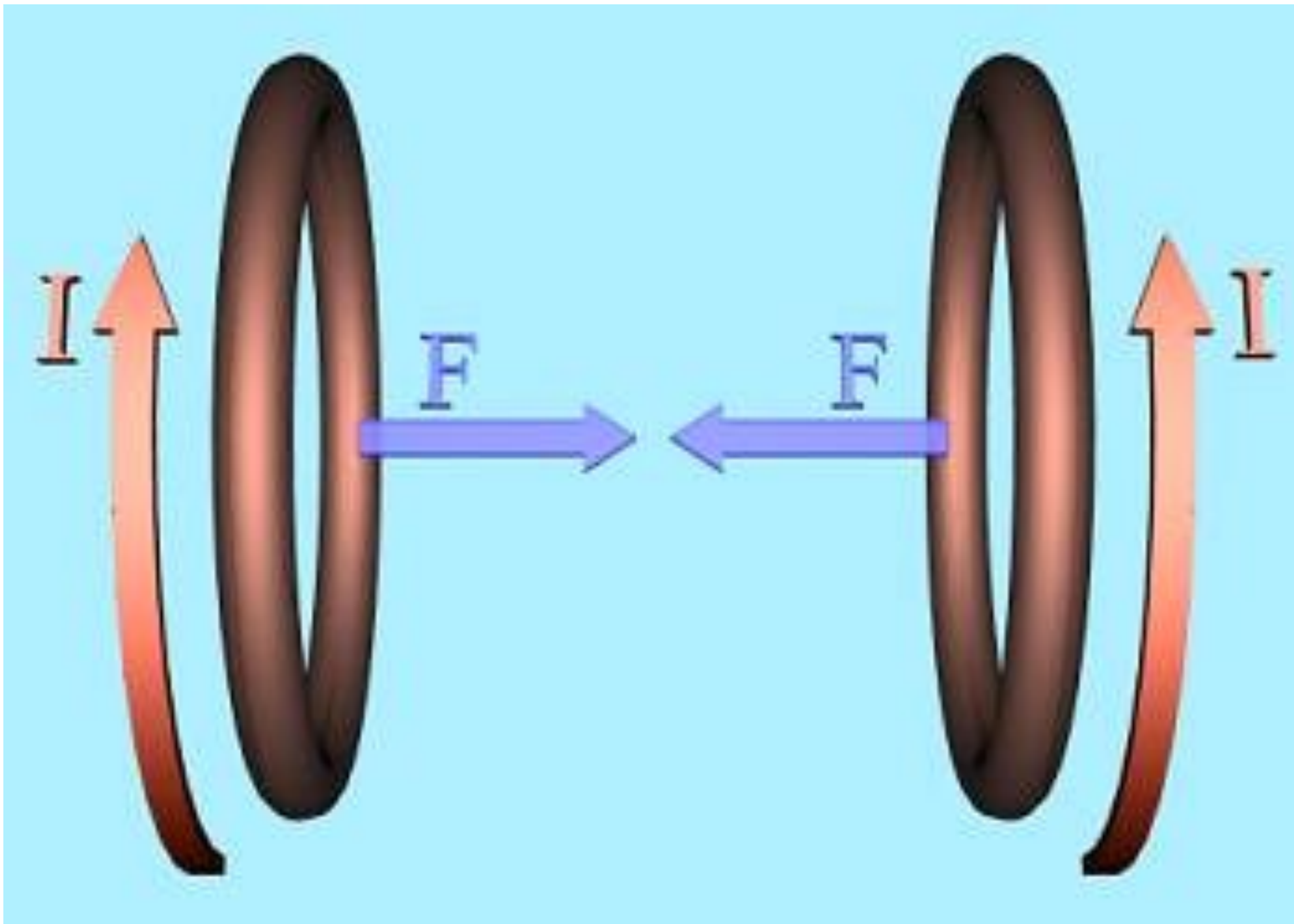


Magnetic Force of Wire 1 on Wire 2

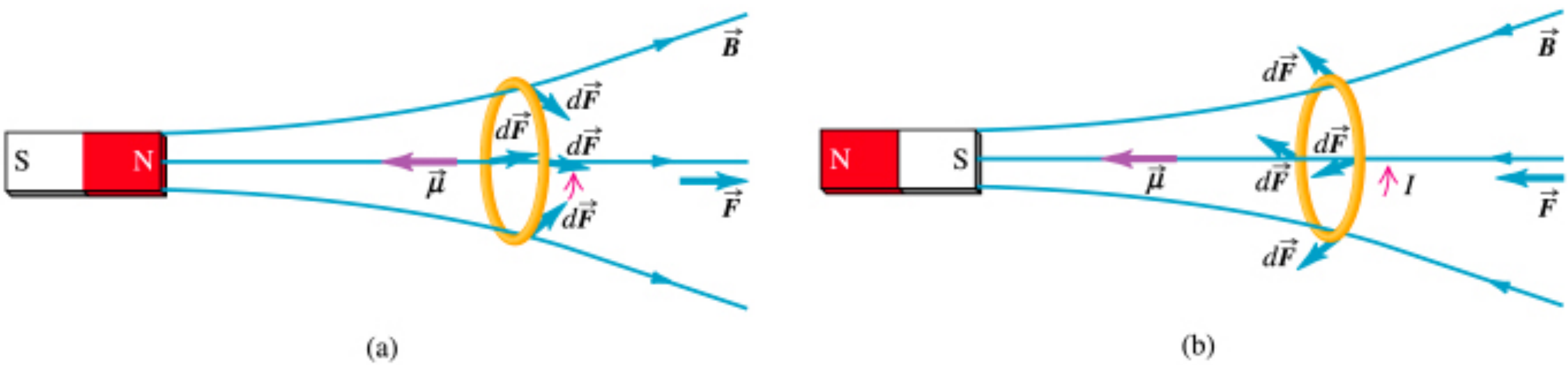
$$F_{1on2} = I_2 \ell_2 B_1 = I_2 \ell_2 \left(\frac{\mu_0 I_1}{2\pi d} \right)$$

$$= \frac{\mu_0 I_1 I_2 \ell_2}{2\pi d}$$

Force Between Two Current Loops



Force Between Magnet and Loop



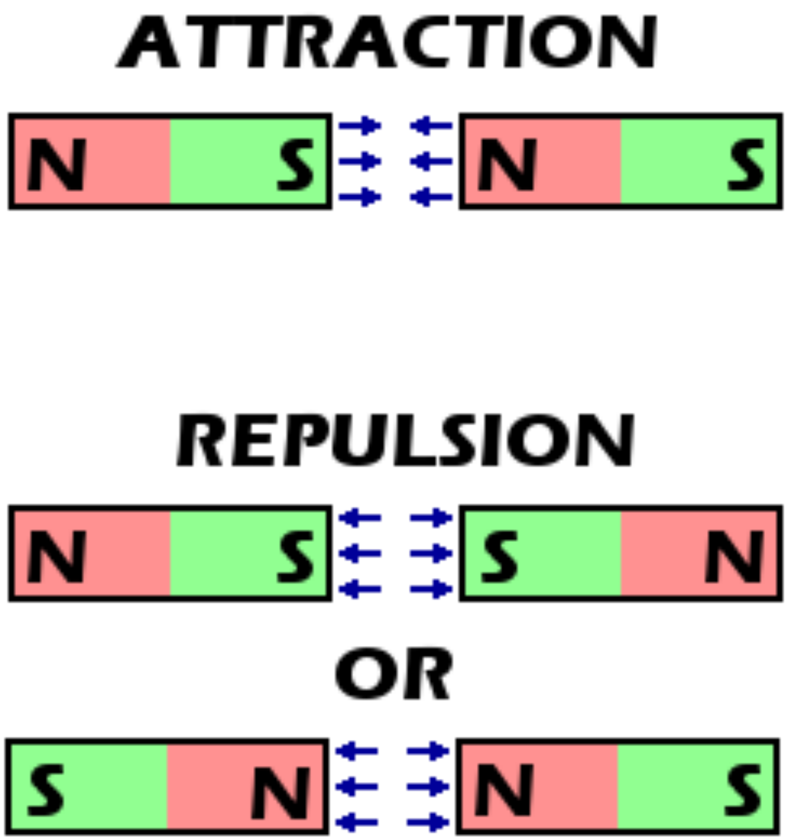
Force on Magnetic Moment

$$\vec{F}_{mag} = \nabla(\boldsymbol{\mu} \cdot \vec{B})$$

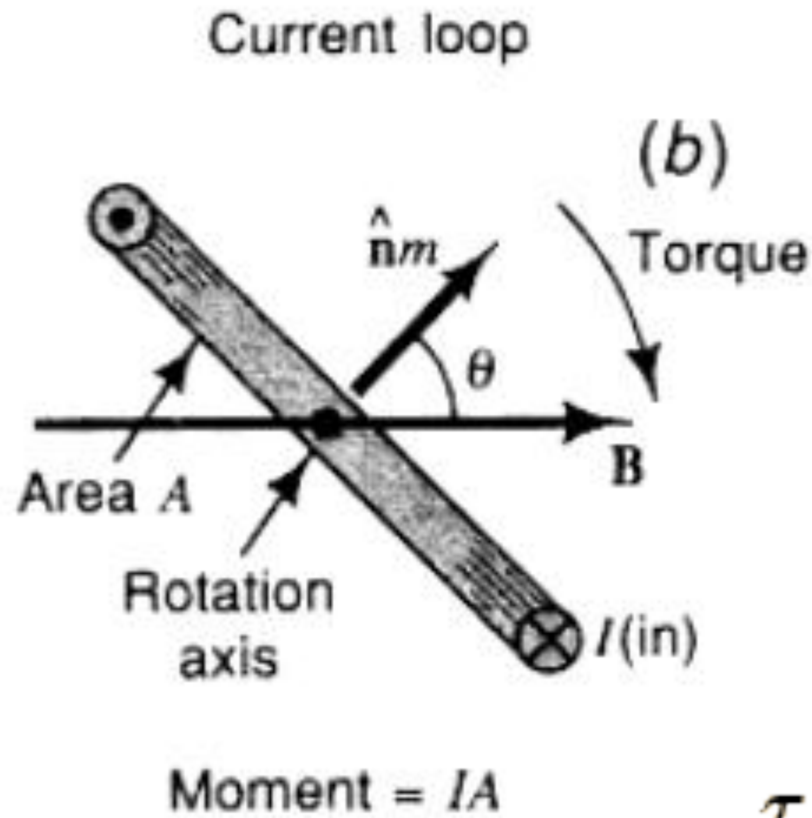
$$U(\theta) = -\mu \cdot B$$

F = -∇U

Force Between Two Magnets



Torque on Magnetic Moment



$$\tau = \mu \ x \ B$$