Electrostatics

Electric Fields

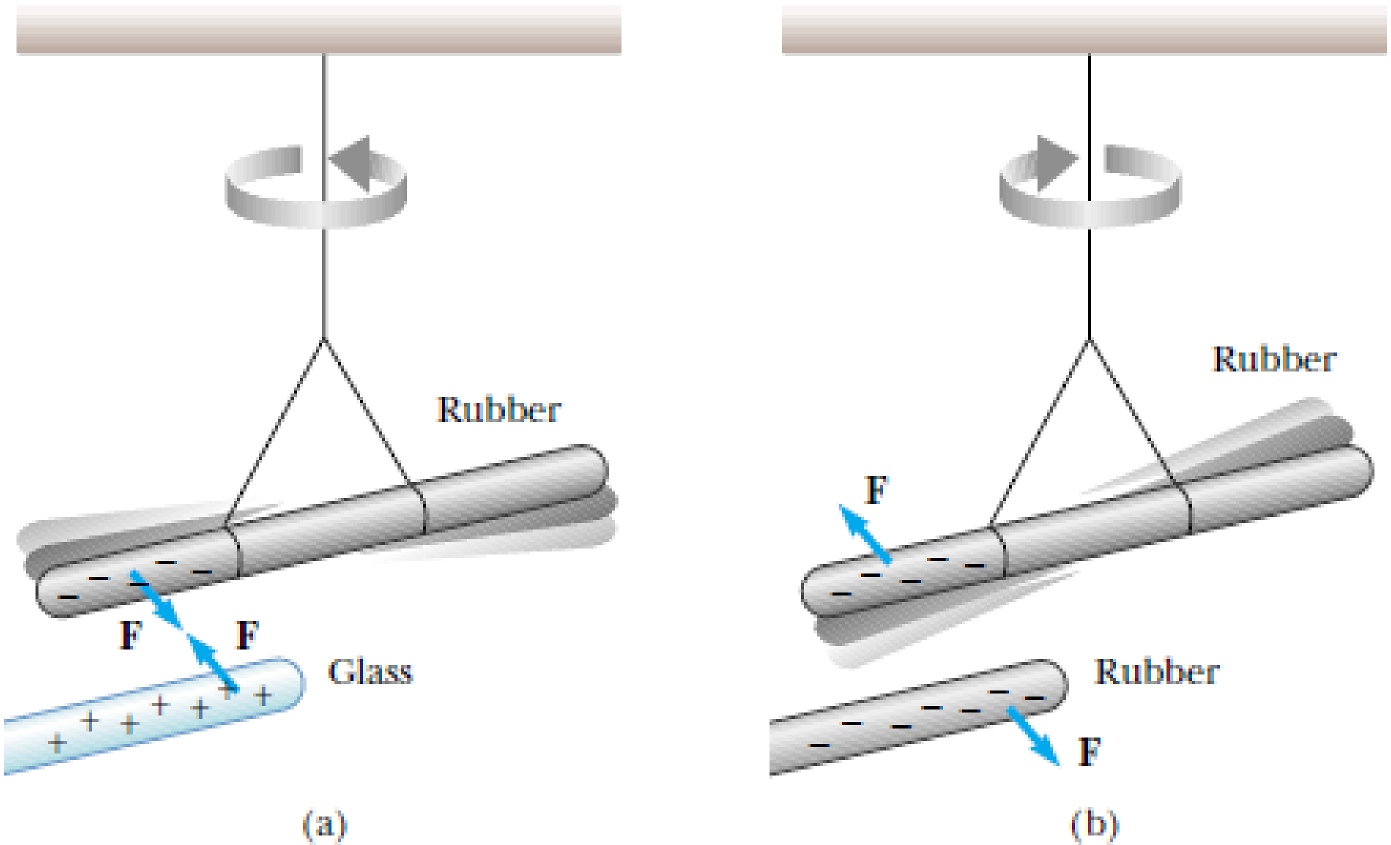
Properties of Electric Charges

- There are two kinds of charges in nature
  - Positive charge
  - Negative charge

Benjamin Franklin (1706–1790)

- Charges of the same sign repel one another
- Charges with opposite signs attract one another

Properties of Electric Charges



Properties of Electric Charges

- Total charge in an isolated system is conserved.
- Charge is quantized.
  - $q=Ne$

  Robert Millikan (1868–1953)

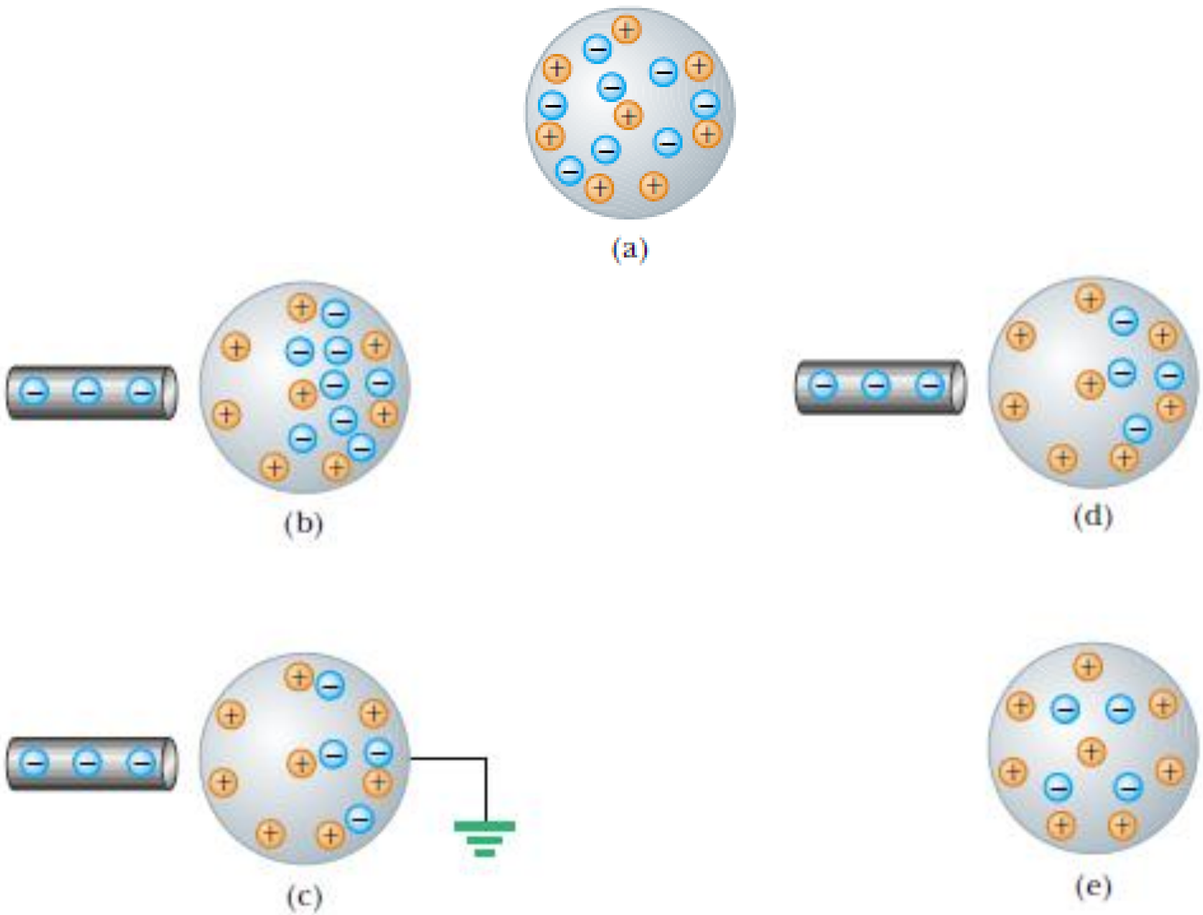
Charging Objects By Induction

- materials in terms of the ability of electrons to move through the material
  - Electrical conductors
    - materials in which some of the electrons are free electrons that are not bound to atoms and can move relatively freely through the material
      - copper, aluminum, silver
  - Electrical insulators
    - materials in which all electrons are bound to atoms and cannot move freely through the material
      - Glass, rubber, wood

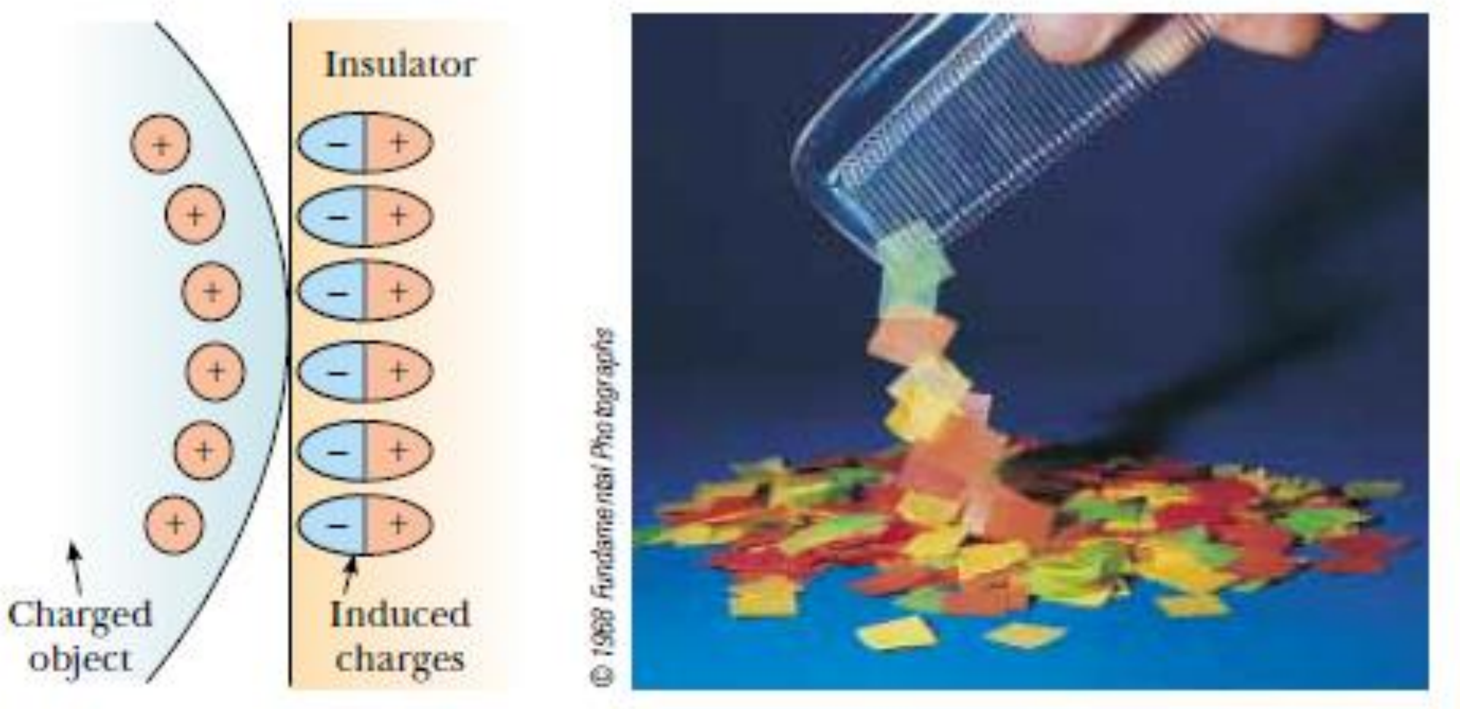
Materials

- materials in terms of the ability of electrons to move through the material
  - Semiconductors
    - Materials in which their electrical properties are somewhere between those of insulators and those of conductors
      - Silicon, germanium

Charging Objects By Induction



Charging Objects By Induction



(a) (b)

Coulomb's Law

- Properties of the electric force between two stationary charged particles

  Charles Coulomb (1736–1806)

  - inversely proportional to the square of the separation r between the particles and directed along the line joining them
  - proportional to the product of the charges q_1 and q_2 on the two particles
  - attractive if the charges are of opposite sign and repulsive if the charges have the same sign
  - a conservative force

Coulomb's Law

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

k_e = $1/(4\pi\varepsilon_o)$
Coulomb constant

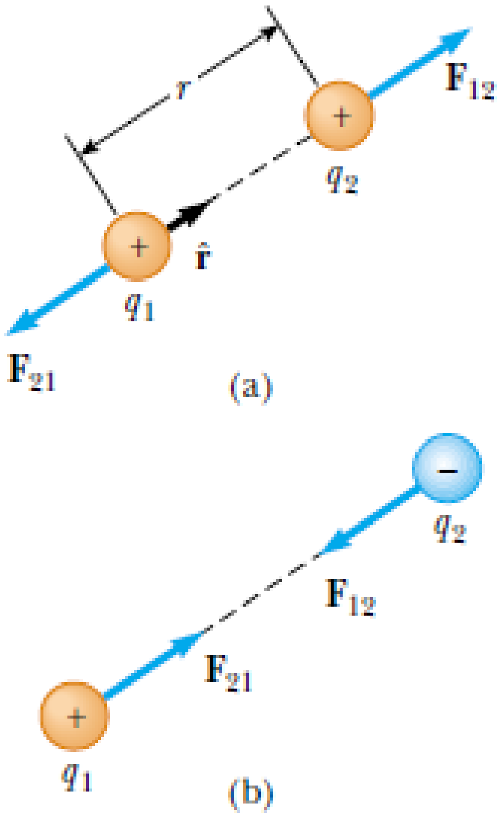
= 8.9875×10^{9} N.m^2/C^2

ε_o = 8.8542×10^{12} C^2/N.m^2
Permittivity of free space

Coulomb's Law

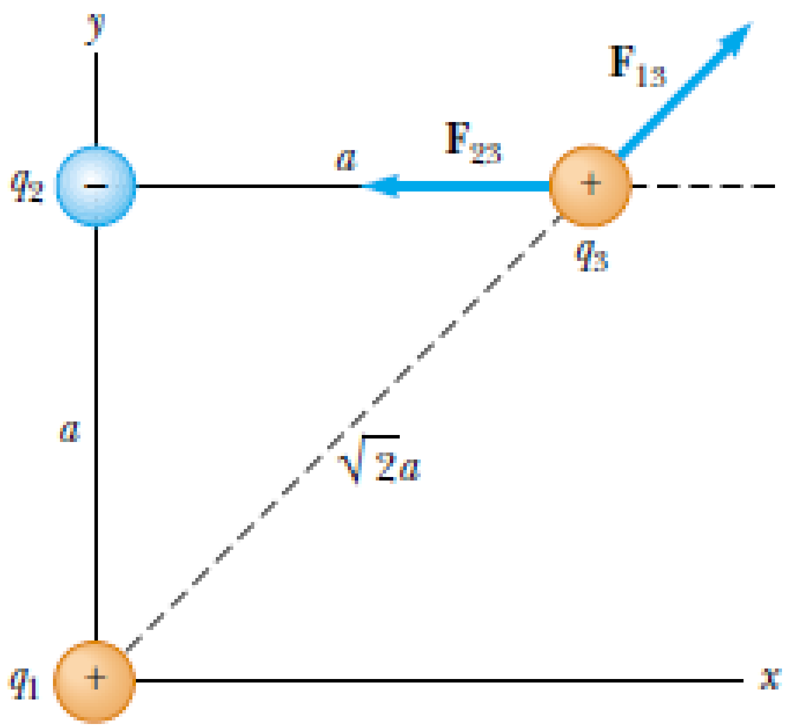
Charge and Mass of the Electron, Proton, and Neutron		
Particle	**Charge (C)**	**Mass (kg)**
Electron (e)	$-1.602\,191\,7 \times 10^{-19}$	$9.109\,5 \times 10^{-31}$
Proton (p)	$+1.602\,191\,7 \times 10^{-19}$	$1.672\,61 \times 10^{-27}$
Neutron (n)	0	$1.674\,92 \times 10^{-27}$

Coulomb's Law



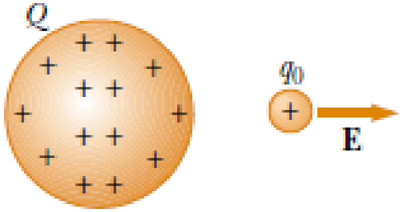
$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r}$$

Example #1



- Consider three point charges located at the corners of a right triangle as shown in the figure, where $q_1 = q_3 = 5.0$ μC, $q_2 = -2.0$ μC, and $a = 0.10$ m. Find the resultant force exerted on q_3

The Electric Field



The Electric Field

- The electric force acting on a positive test charge placed at that point divided by the test charge

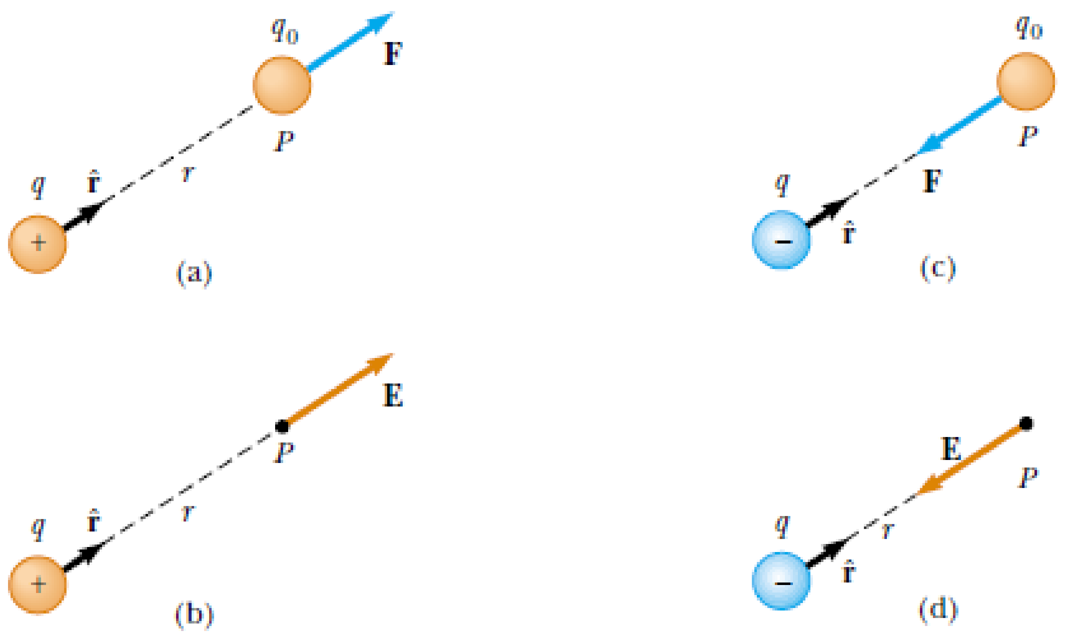
$$\vec{E} = \frac{\vec{F}_e}{q_0}$$

N/C

The Electric Field

$$\vec{F}_e = k_e \frac{q q_0}{r^2} \hat{r}$$

$$\vec{E} = \frac{\vec{F}_e}{q_0} = k_e \frac{q}{r^2} \hat{r}$$

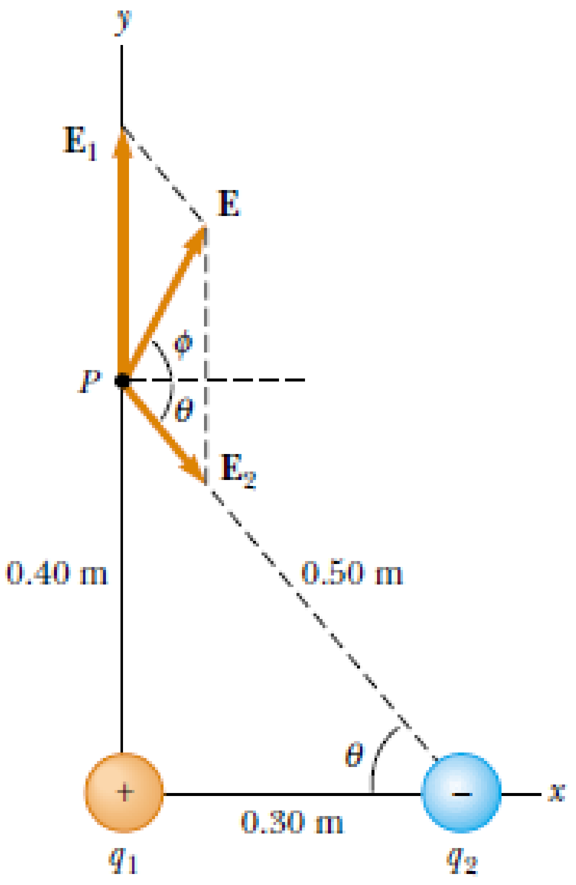


The Electric Field

- at any point *P*, the total electric field due to a group of source charges equals the vector sum of the electric fields of all the charges

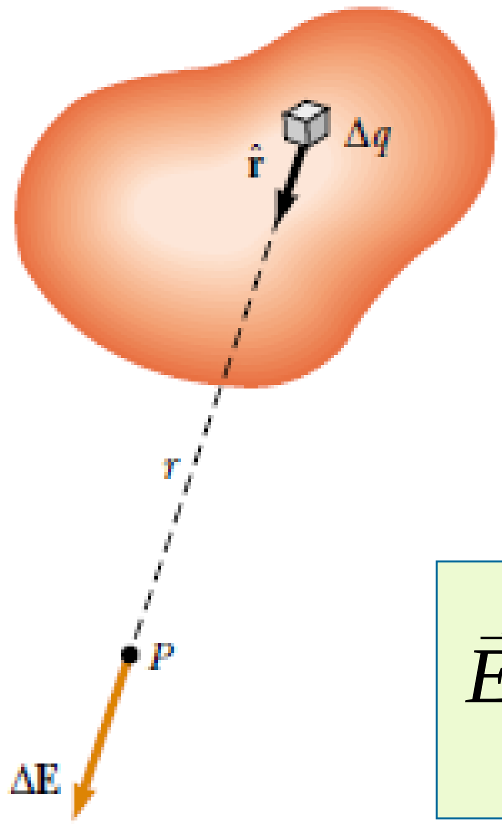
$$\vec{E} = k_e \sum_i \frac{q_i}{r_i^{\,2}} \hat{r}_i$$

Example #2



- A charge q_1=7.0 μC is located at the origin, and a second charge q_2=-5.0 μC is located on the *x* axis, 0.30 m from the origin as shown in the figure. Find the electric field at the point *P*, which has coordinates

Electric Field of a Continuous Charge Distribution



$$\Delta \vec{E} = k_e \frac{\Delta q}{r^2} \hat{r}$$

$$\vec{E} \approx k_e \sum_i \frac{\Delta q_i}{r_i^2} \hat{r}$$

Discrete

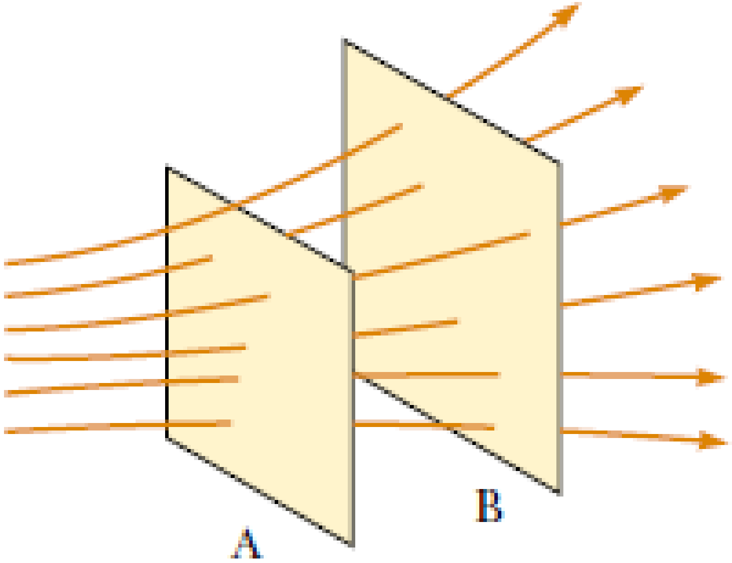
$$\vec{E} = k_e \lim_{\Delta q_i \to 0} \frac{\Delta q_i}{r_i^2} \hat{r}_i = k_e \int \frac{dq}{r^2}$$

Continuous

Electric Field of a Continuous Charge Distribution

- Charge density
  - The uniformly distribution of charges on a line, a surface, or throughout a volume
    - linear charge density *(λ)*
      - a charge Q is uniformly distributed along a line of length l ($\lambda = Q/l$)
    - surface charge density *(σ)*
      - a charge Q is uniformly distributed on a surface of area A ($\sigma = Q/A$)
    - volume charge density *(ρ)*
      - a charge Q is uniformly distributed throughout a volume V ($\rho = Q/V$)

Electric Field Lines

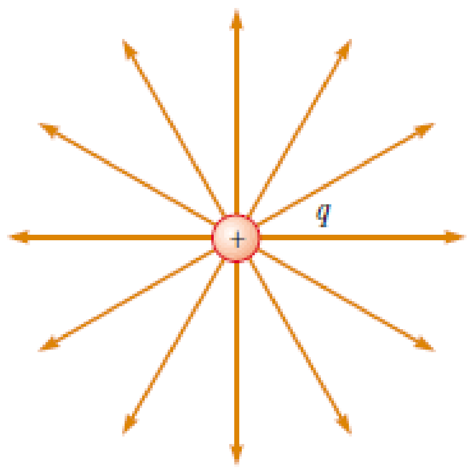


- Lines that are parallel to the electric field vector at any point in space

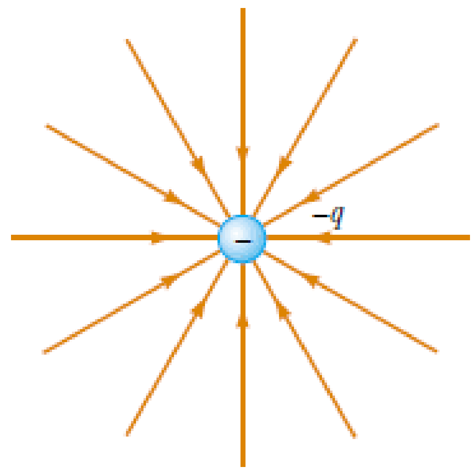
Electric Field Lines

- The number of lines per unit area through a surface perpendicular to the lines is proportional to the magnitude of the electric field in that region
- The field lines are close together where the electric field is strong and far apart where the field is weak

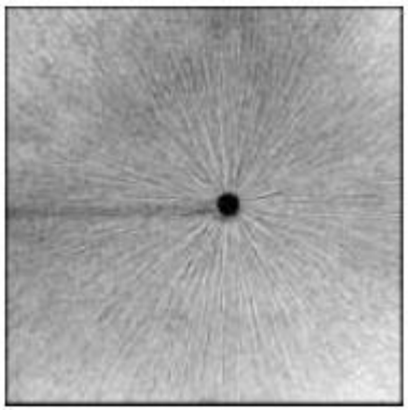
Electric Field Lines



(a)



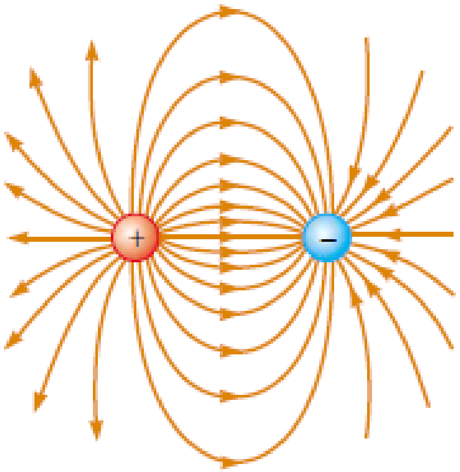
(b)


(c)

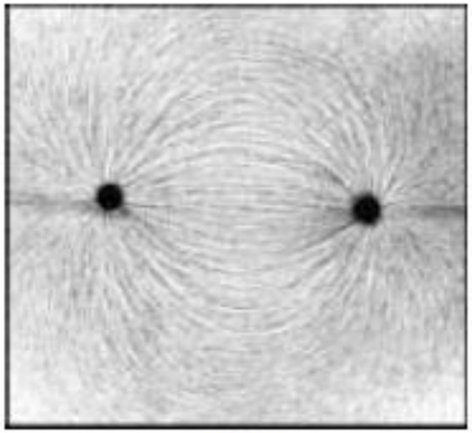
Rules for Drawing Electric Field Lines

- The lines must begin on a positive charge and terminate on a negative charge.
- In the case of an excess of one type of charge, some lines will begin or end infinitely far away.
- The number of lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge.
- No two field lines can cross.

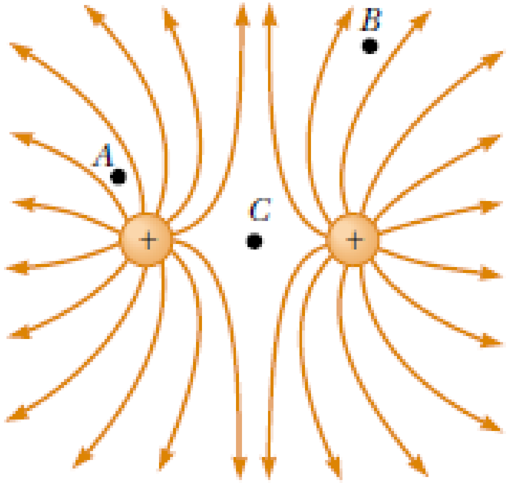
Electric Field Lines



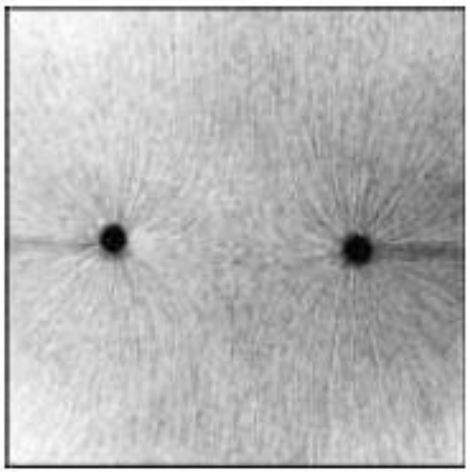
(a)


(b)

Electric Field Lines

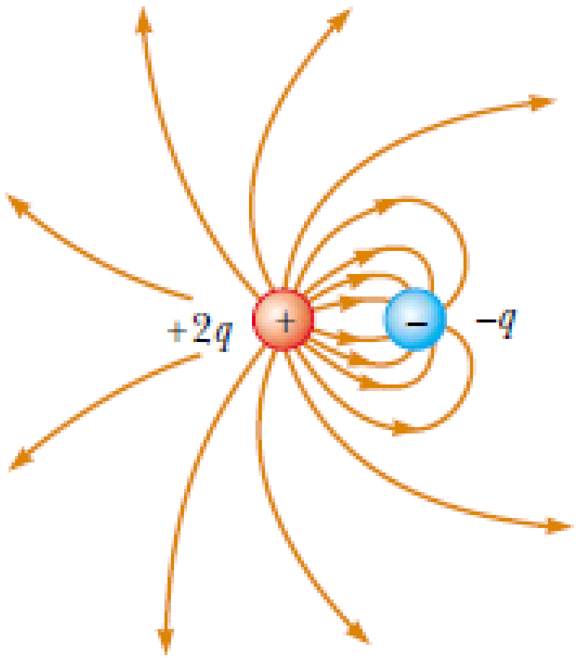


(a)



(b)

Electric Field Lines

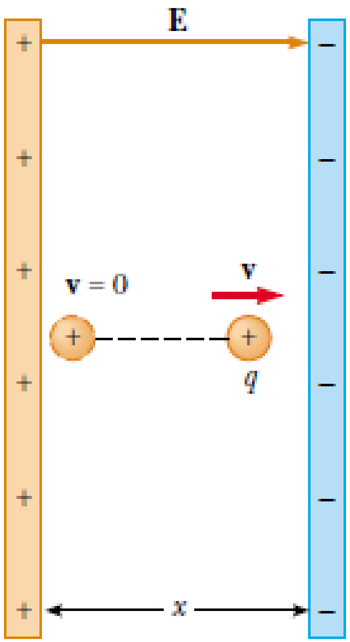


Motion of Charged Particles in a Uniform Electric Field

- When a particle of charge *q* and mass *m* is placed in an electric field E, the electric force exerted on the charge causes the particle to accelerate with magnitude of a, where

$$\vec{F} = q\vec{E} = m\vec{a}$$

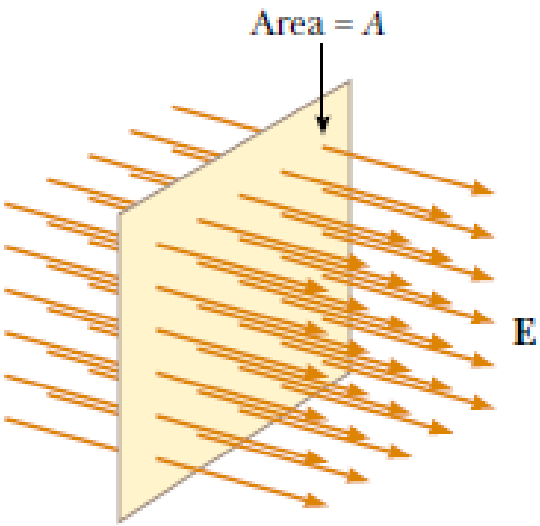
Example #3



- A positive point charge *q* of mass *m* is released from rest in a uniform electric field E directed along the *x* axis, as shown in the figure, Describe its motion

Gauss's Law

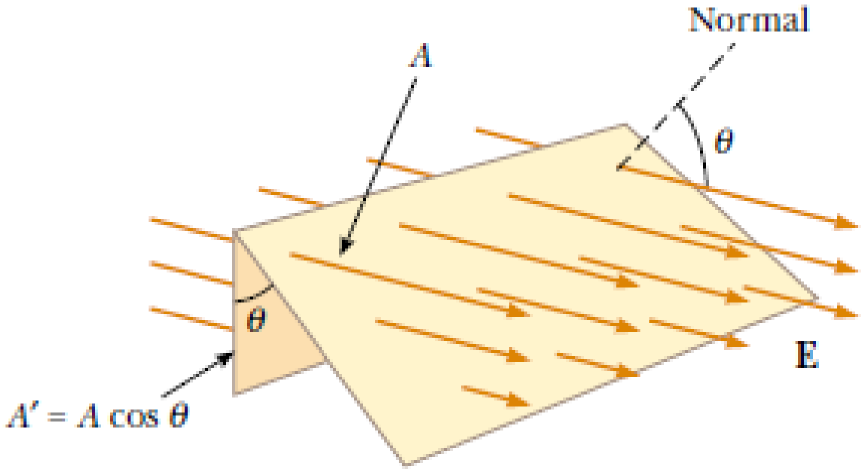
- Electric Flux (Φ_E)
  - The number of electric field lines penetrating some surface



$$\Phi_E = EA$$

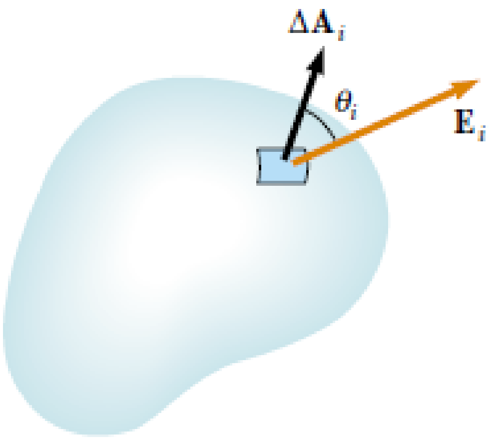
N.m²/C

Electric Flux



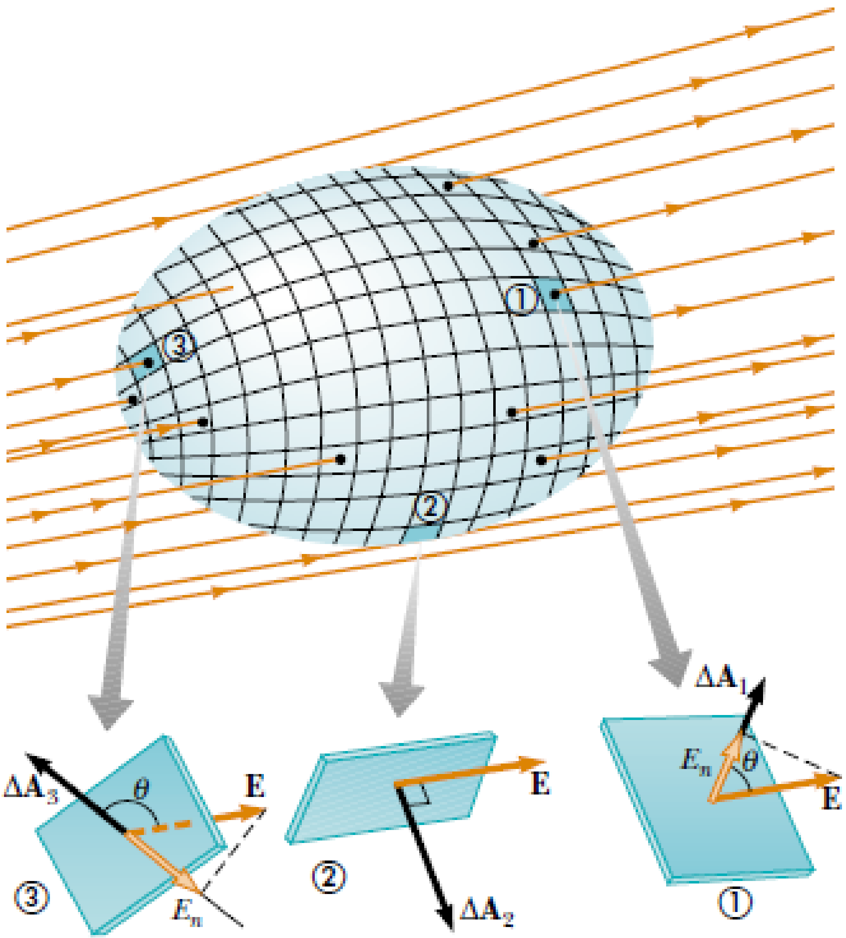
$$\Phi_E = EA' = EA\cos\theta$$

Electric Flux



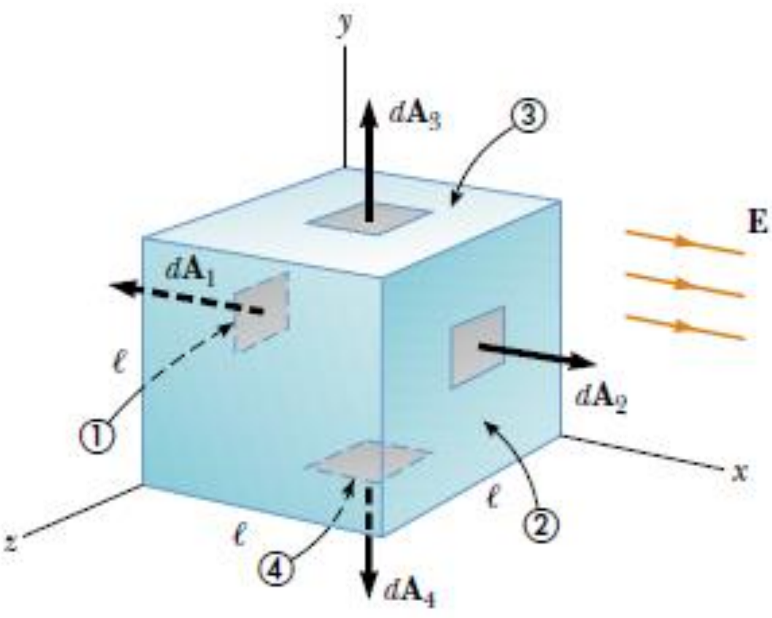
$$\Phi_E = \lim_{\Delta A_i \to 0} \sum_i \vec{E}_i \cdot \Delta\vec{A}_i = \int_{Surface} \vec{E} \cdot d\vec{A}$$

Electric Flux



$$\Phi_E = \oint \vec{E} \cdot d\vec{A}$$

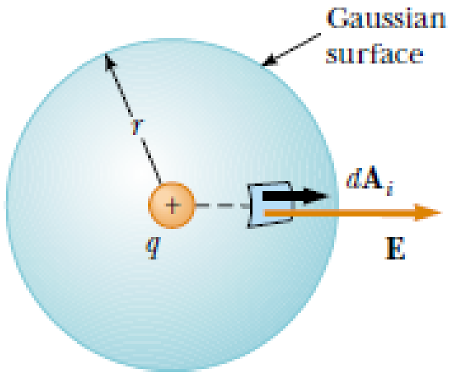
Example #4



- Consider a uniform electric field *E* oriented in the *x* direction. Find the net electric flux through the surface of a cube of edge length *l*, oriented as shown in the figure.

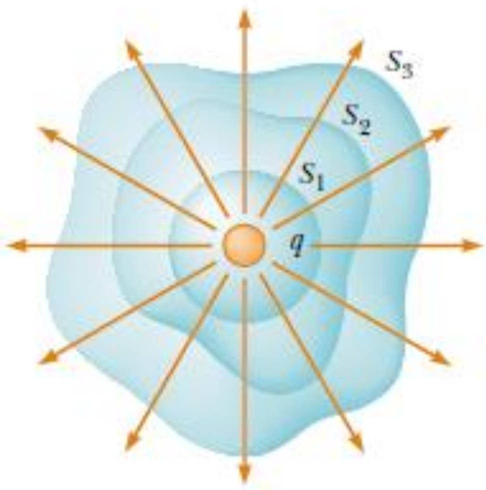
Gauss's Law

- a general relationship between the net electric flux through a closed surface (often called a *gaussian surface*) and the charge enclosed by the surface



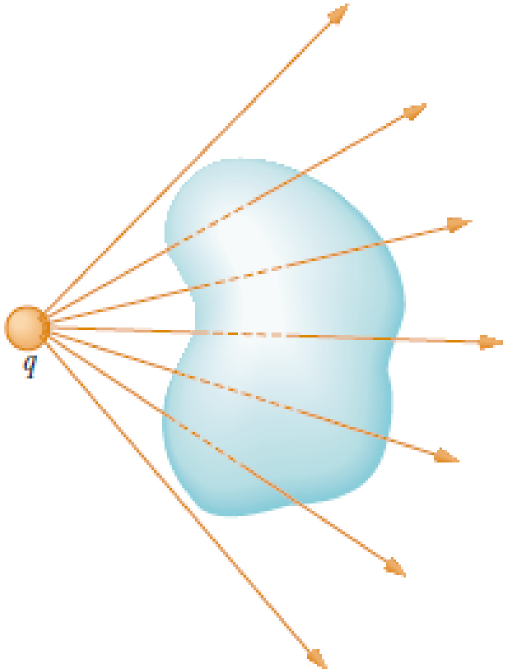
$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = E\oint dA = \frac{q}{\varepsilon_0}$$

Gauss's Law



- The net flux through any closed surface surrounding a point charge q is given by q/ε_0 and is independent of the shape of that surface

Gauss's Law



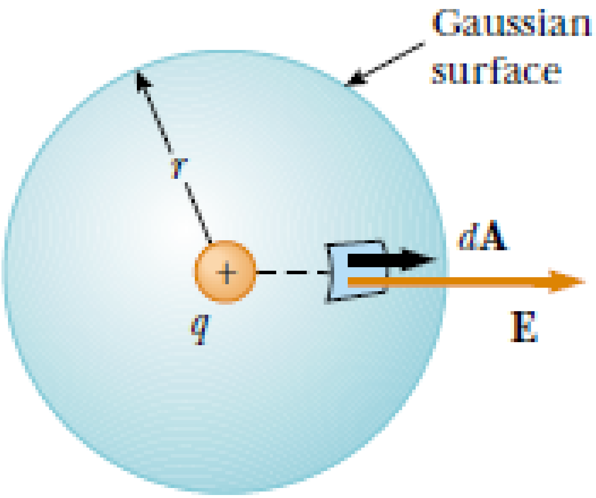
- The net electric flux through a closed surface that surrounds no charge is zero
- The electric field due to many charges is the vector sum of the electric fields produced by the individual charges

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = \oint (\vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots).d\vec{A}$$

Gauss's Law

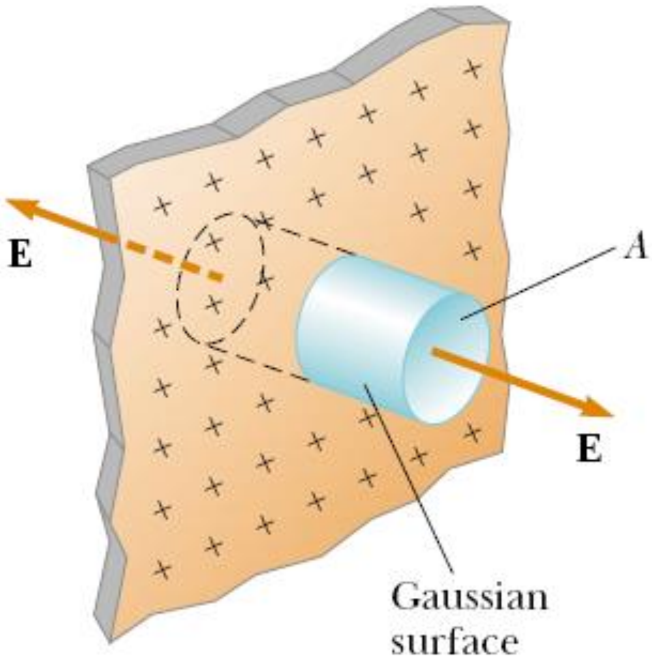
$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\varepsilon_0}$$

Example #5



- Starting with Gauss's law, calculate the electric field due to an isolated point charge *q*

Quiz #6



- Find the electric field due to an infinite plane of positive charge with uniform surface charge density σ

Electric Potential

- Electric Potential
- Potential Difference
- Potential Differences in a Uniform Electric Field

Electric Potential

- The potential energy per unit charge U/q_0 is independent of the value of q_0 and has a value at every point in an electric field

$$V = \frac{U}{q_0}$$

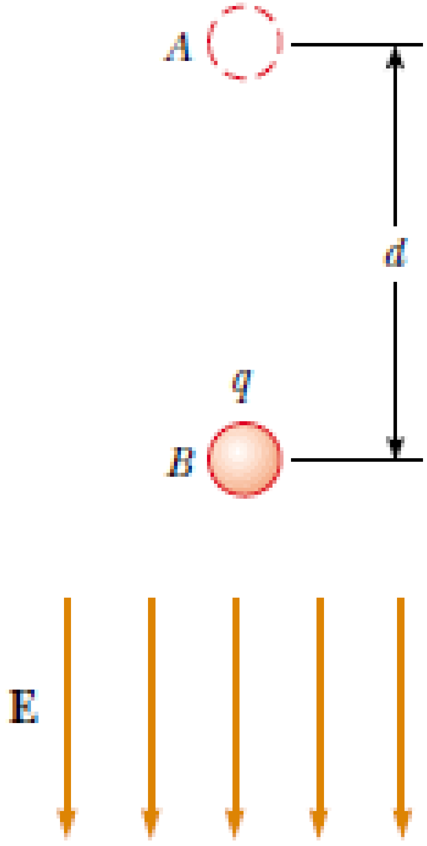
V

Potential Difference

- The change in potential energy of the system when a test charge is moved between the points divided by the test charge q_0

$$\Delta V = V_B - V_A = \frac{\Delta U}{q_0} = -\int_A^B \vec{E} \cdot d\vec{s}$$

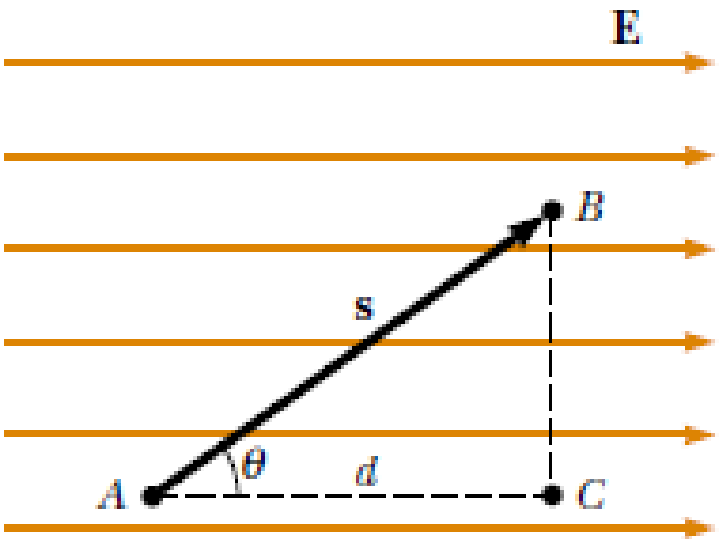
Potential Differences in a Uniform Electric Field



$$\Delta V = V_B - V_A = -\int_A^B \vec{E} \cdot d\vec{s} = -E\int_A^B ds = -Ed$$

$$V_B < V_A$$

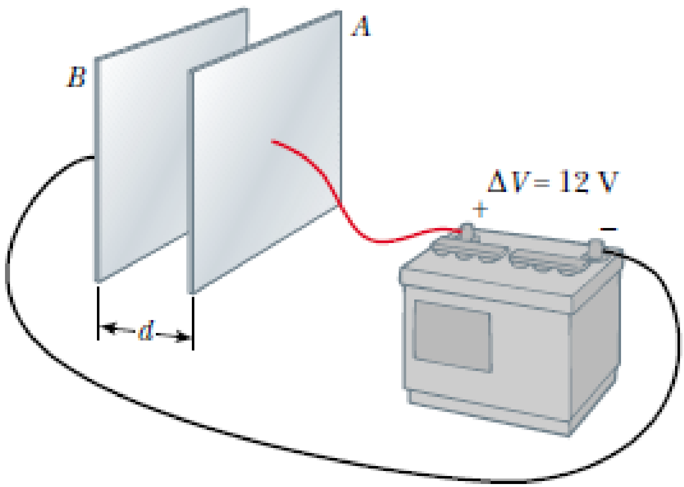
Example #6



$$V_B - V_A = ?$$

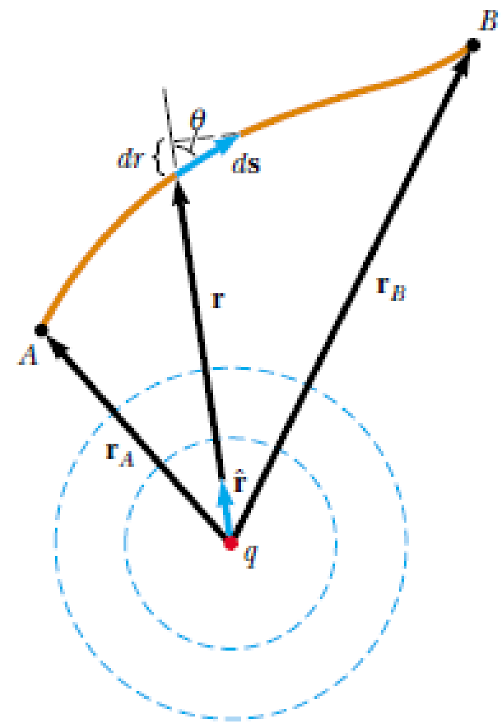
$$V_C - V_A = ?$$

Example #7



- A battery produces a specified potential difference ΔV between conductors attached to the battery terminals. A 12-V battery is connected between two parallel plates, as shown in the figure. The separation between the plates is d = 0.30 cm, and we assume the electric field between the plates to be uniform.

Electric Potential and Potential Energy due to Point Charges



$$\Delta V = V_B - V_A = -k_e q \int_A^B \frac{dr}{r^2} = \frac{k_e q}{r}\bigg|_{r=r_A}^{r=r_B} = k_e q\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$

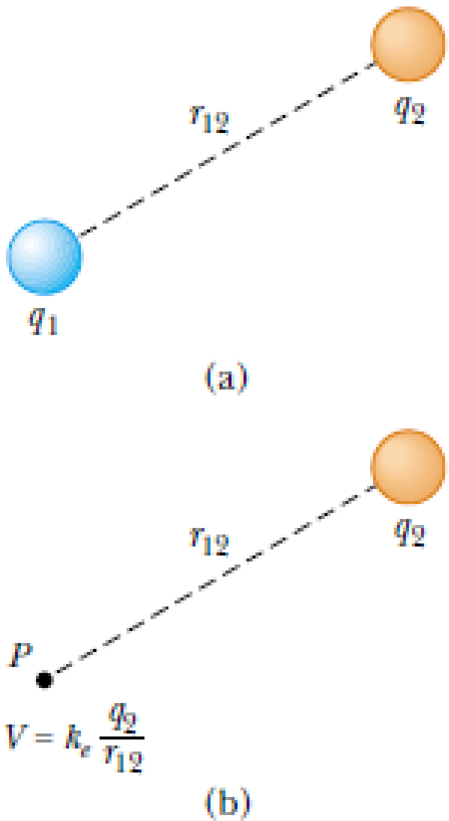
Electric Potential due to Point Charges

- The electric potential created by a point charge at any distance r from the charge is

$$V = \frac{k_e q}{r}$$

At $r_A = \infty \rightarrow V_A = 0$

Potential Energy due to Point Charges



- If two point charges are separated by a distance r_{12}, the potential energy of the pair of charges is given by

$$U = \frac{k_e q_1 q_2}{r_{12}}$$

Capacitor

- A device that store electric charge
  - a combination of two conductors carrying charges of equal magnitude and opposite sign

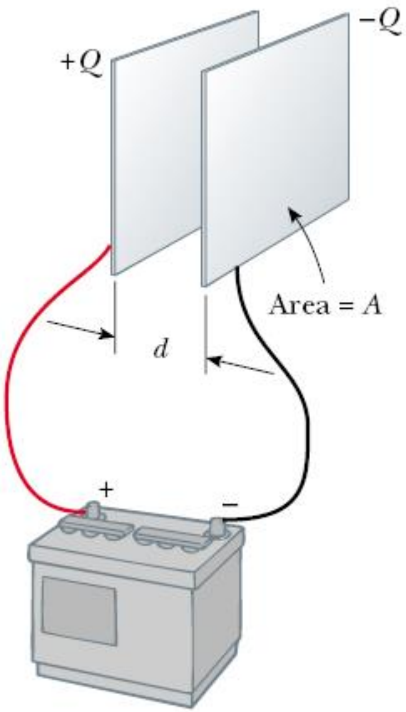
Capacitance (C)

- The ratio of the magnitude of the charge (Q) on either conductor to the magnitude of the potential difference (ΔV) between the conductors
  - *always a positive quantity*

$$C = \frac{Q}{\Delta V}$$

Farad, F

Parallel-Plate Capacitors



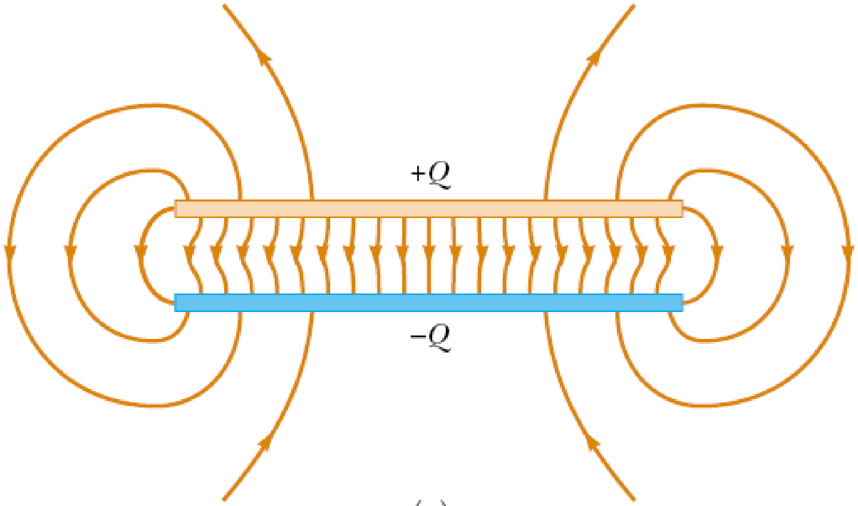
- The capacitance of a parallel-plate capacitor is proportional to the area of its plates and inversely proportional to the plate separation

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}$$

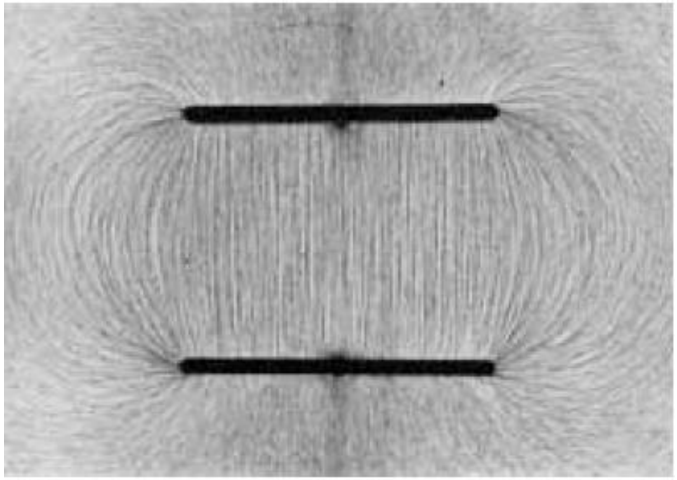
$$\Delta V = Ed = \frac{Qd}{\varepsilon_0 A}$$

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

Electric Field Pattern of a Parallel-Plate Capacitor

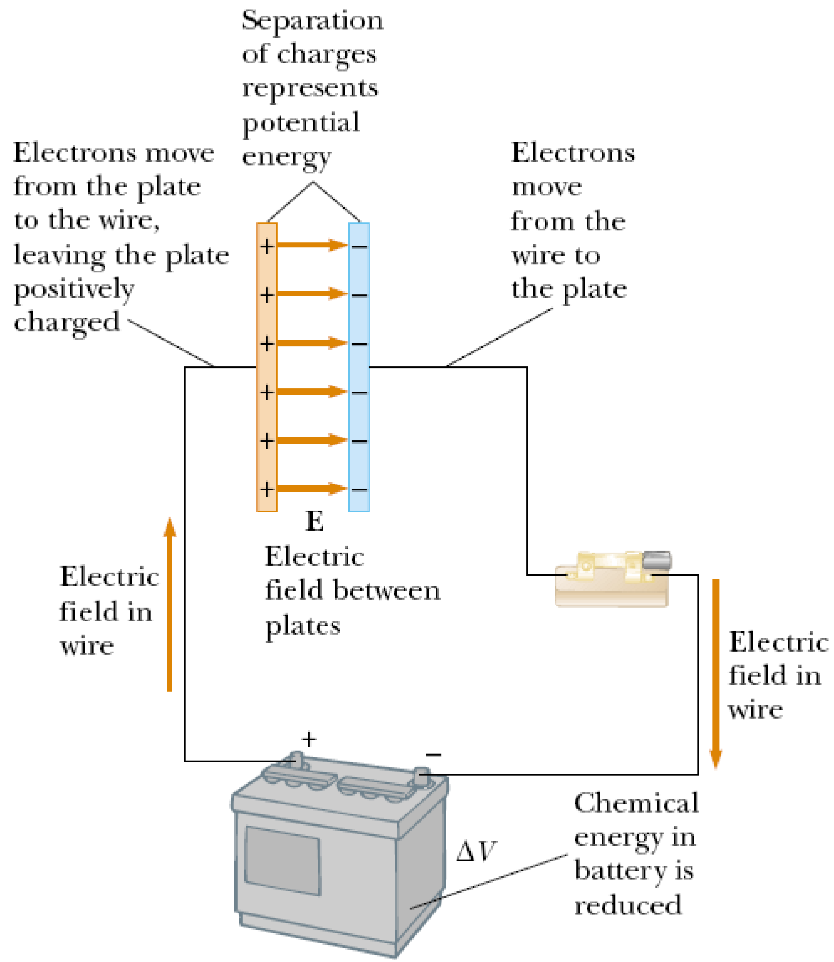


(a)



(b)

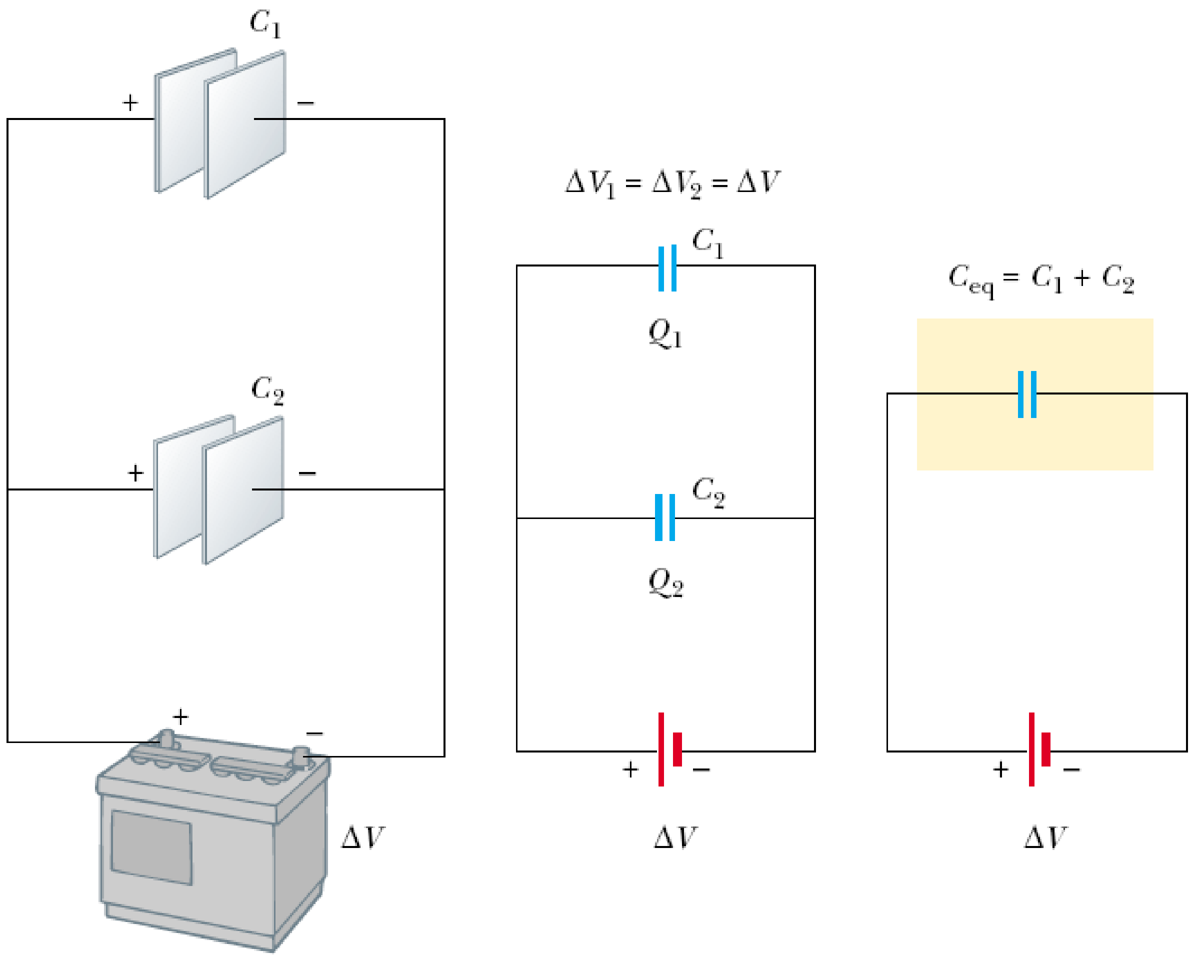
A Circuit with a Capacitor



Combinations of Capacitors

- The individual potential differences across capacitors connected in parallel are the same and are equal to the potential difference applied across the combination
- The total charge on capacitors connected in parallel is the sum of the charges on the individual capacitors
- The equivalent capacitance of a parallel combination of capacitors is the algebraic sum of the individual capacitances and is greater than any of the individual capacitances

Parallel Combination

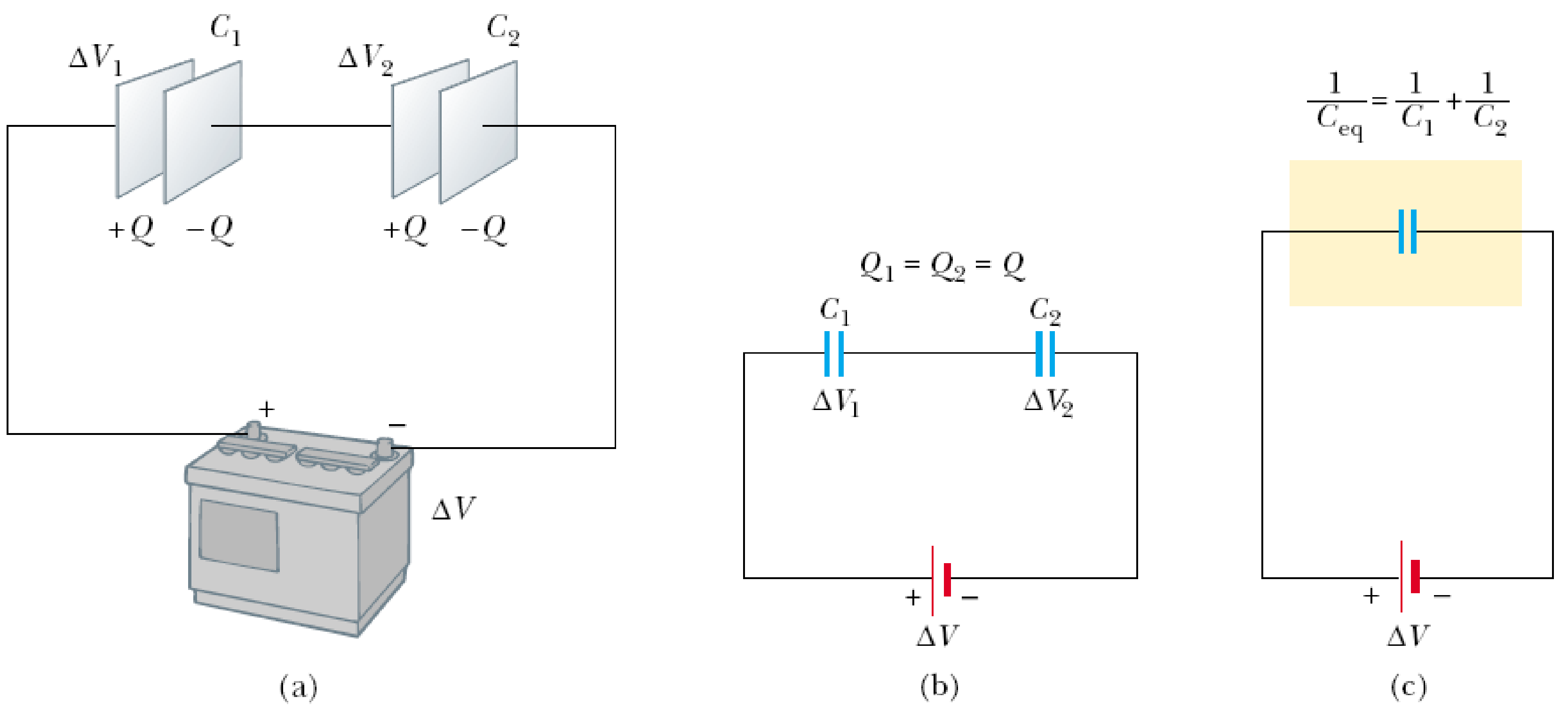


(a) (b) (c)

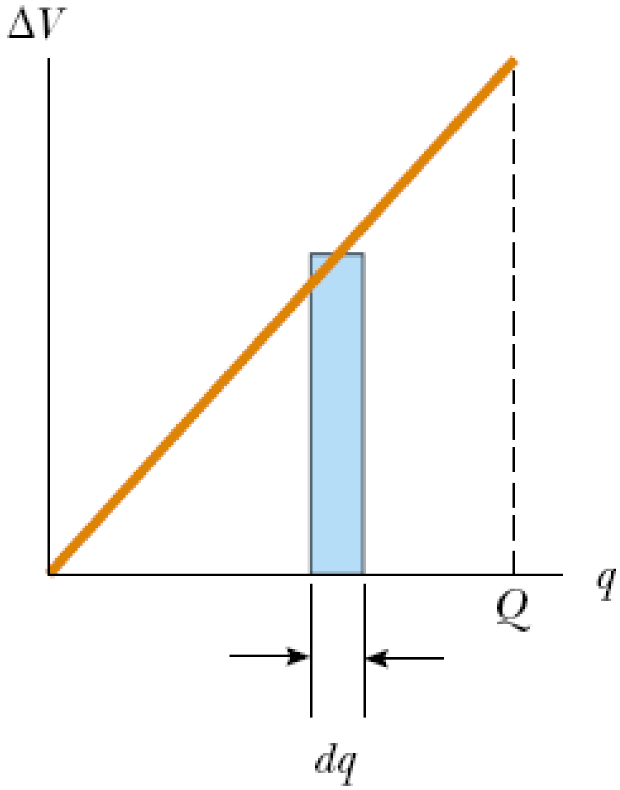
Combinations of Capacitors

- The charges on capacitors connected in series are the same
- The total potential difference across any number of capacitors connected in series is the sum of the potential differences across the individual capacitors
- The inverse of the equivalent capacitance is the algebraic sum of the inverses of the individual capacitances and the equivalent capacitance of a series combination is always less than any individual capacitance in the combination

Series Combination



Energy Stored in a Charged Capacitor

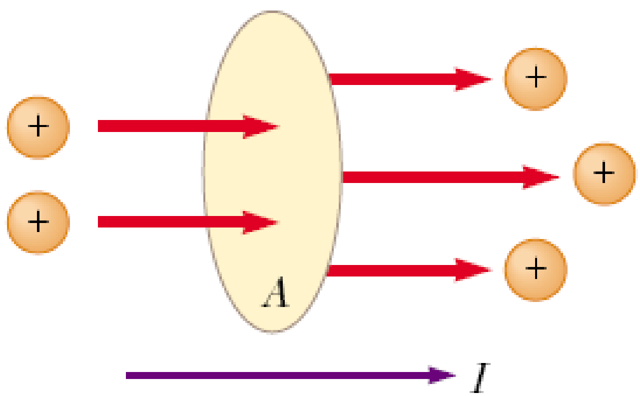


$$U = \frac{Q^2}{2C} = \frac{1}{2} Q \Delta V = \frac{1}{2} C (\Delta V)^2$$

กระแสไฟฟ้า

Electric Current

- กระแสไฟฟ้า (***I***)
  - The rate at which charge flows through a perpendicular surface



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

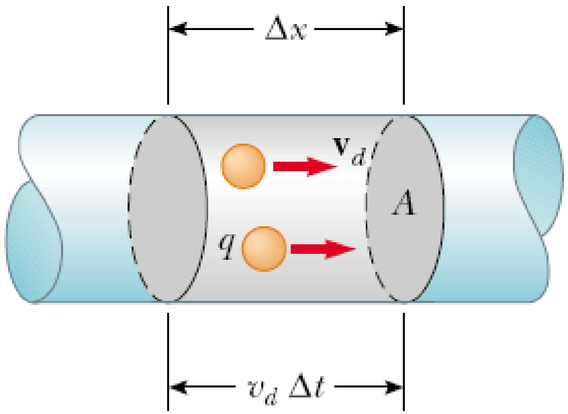
C/s or Ampere, A

The current has the same direction as the flow of positive charge.

Current

- Direct Current (DC)
  - The constant current in magnitude and direction
- Alternating Current (AC)
  - The current changing in magnitude and direction all the time

Current



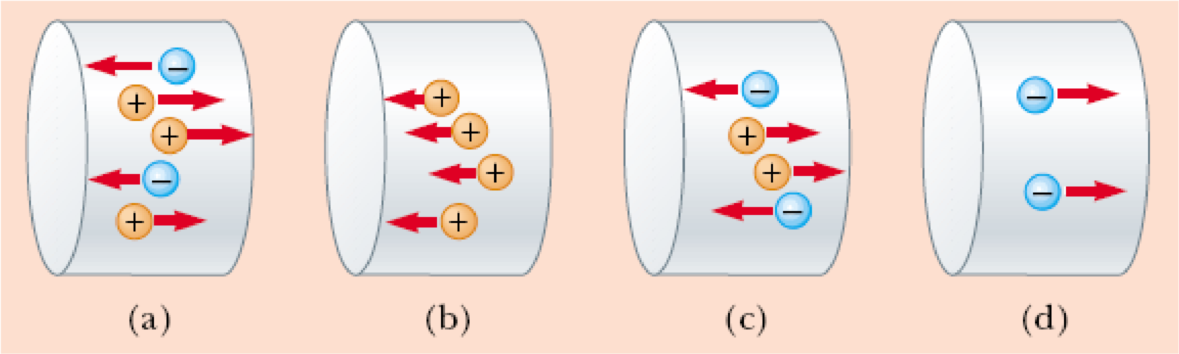
$$\Delta Q = (nAv_d \Delta t)q$$

$$I_{av} = \frac{\Delta Q}{\Delta t} = \frac{(nAv_d \Delta t)q}{\Delta t} = nqv_d A$$

v_d : drift speed of charge q

n : number of mobile charge carriers per unit volume

Quiz



- Consider positive and negative charges moving horizontally through the four regions shown in the figure. Rank the current in these four regions, from lowest to highest.

current density

- The current density (*J*)
  - the current per unit area

$$J = \frac{I}{A} = nqv_d$$

⇨

$$\vec{J} = nq\vec{v}_d$$

current density

- A current density J and an electric field E are established in a conductor whenever a potential difference is maintained across the conductor

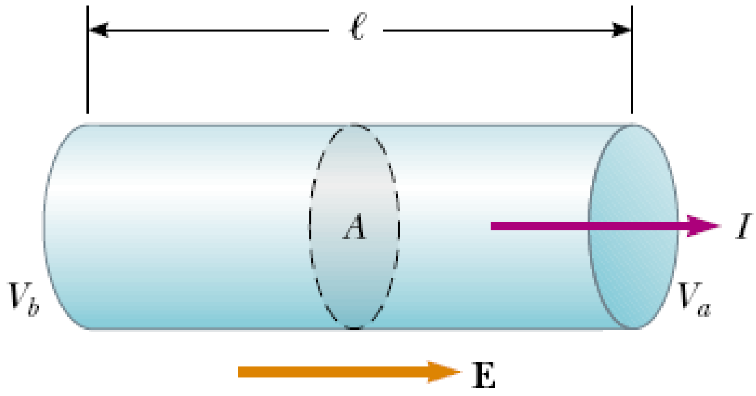
$$\vec{J} = \sigma \vec{E}$$

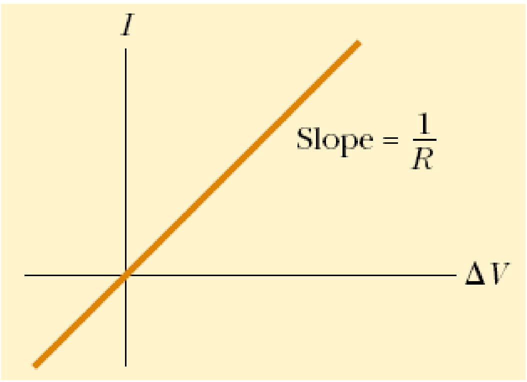
Ohm's law

σ : conductivity

Georg Simon Ohm
German physicist (1789–1854)

Resistance





$$\Delta V = V_b - V_a = El = \left(\frac{J}{\sigma}\right) l = \left(\frac{I}{A\sigma}\right) l = I\left(\rho \frac{l}{A}\right) = IR$$

$\rho = 1/\sigma$: Resistivity

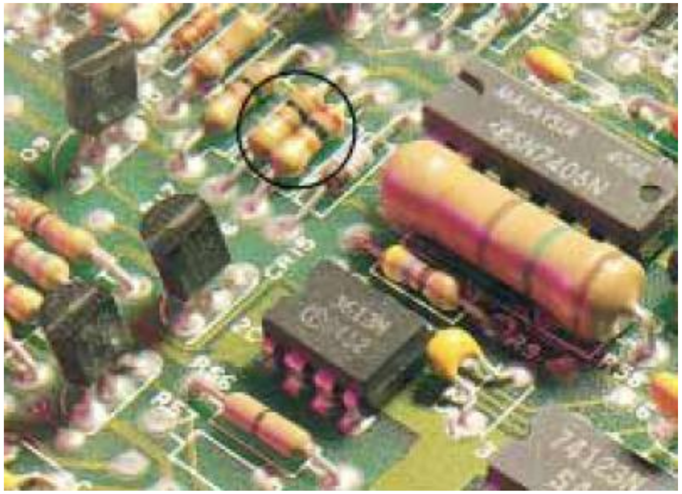
$R = \rho \dfrac{l}{A}$ Resistance (Ω.m)

Resistivity

Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] ($\Omega \cdot m$)	Temperature Coefficient[b] $\alpha[(°C)^{-1}]$
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome[c]	1.50×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}
Silicon	640	-75×10^{-3}
Glass	10^{10} to 10^{14}	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

Resistors



Resistance

Color Coding for Resistors

Color	Number	Multiplier	Tolerance
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5%
Silver		10^{-2}	10%
Colorless			20%

Resistance and Temperature

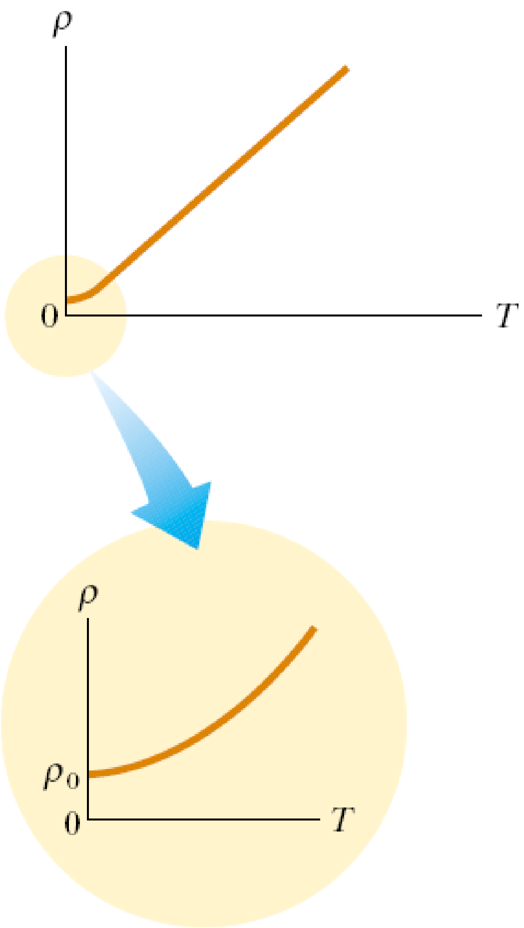
Conductor

$$\rho = \rho_0 \left[1 + \alpha (T - T_0) \right]$$

$$R = R_0 \left[1 + \alpha (T - T_0) \right]$$

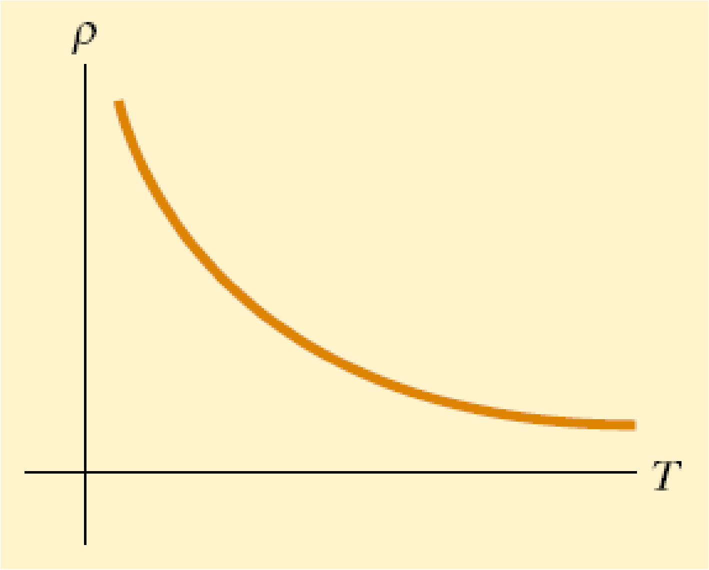
$$\alpha = \frac{\Delta \rho}{\rho_0 \Delta T}$$

temperature coefficient of resistivity

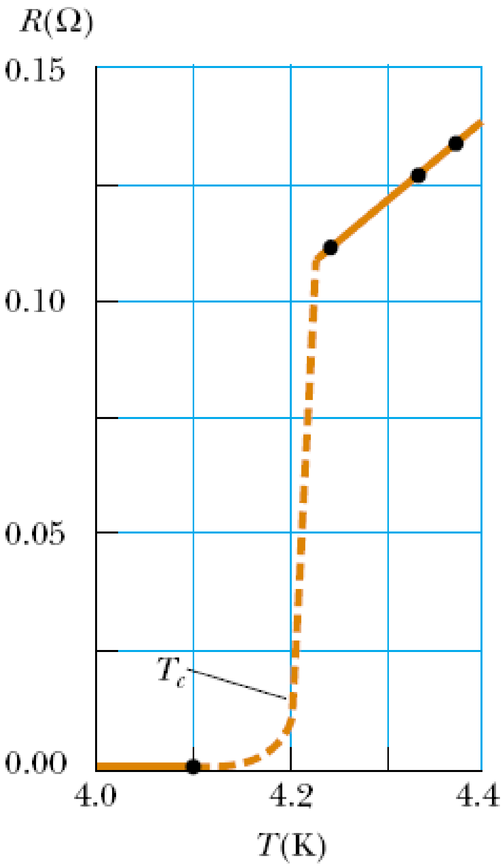


Resistance and Temperature

Semiconductor



superconductor



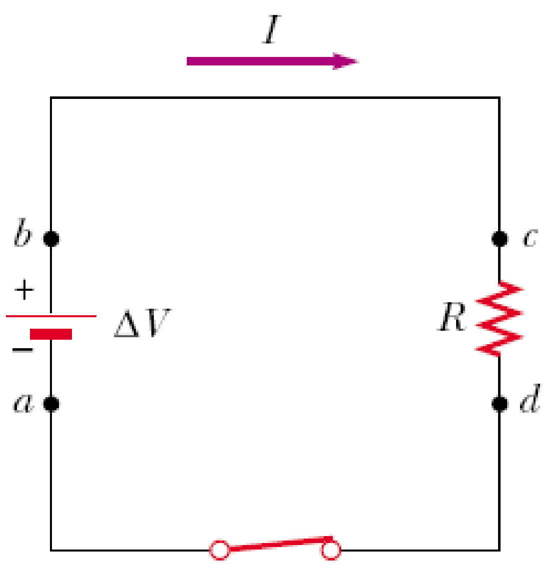
- a class of metals and compounds whose resistance decreases to zero when they are below a certain temperature T_c, known as the critical temperature

superconductor

- A small permanent magnet levitated above a disk of the superconductor $Ba_2Cu_3O_7$, which is at 77 K.

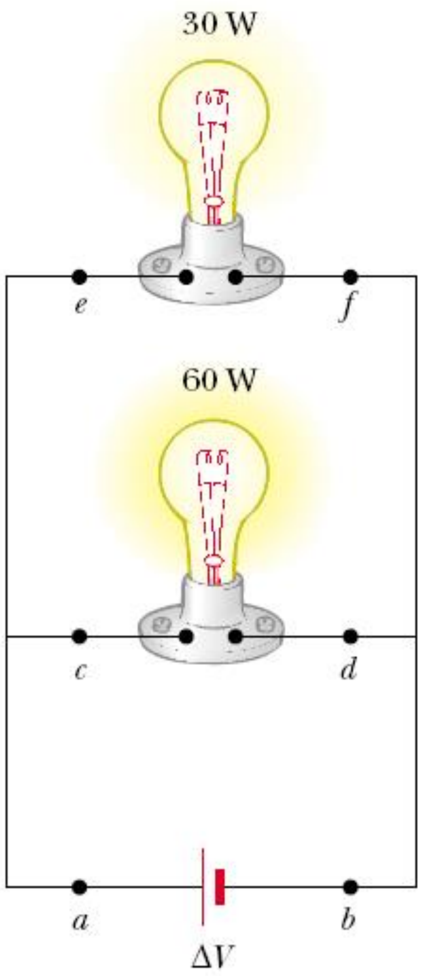
Electrical Power (*P*)

- The rate at which energy is delivered to a resistor



$$P = I\Delta V = \frac{(\Delta V)^2}{R} = I^2 R$$

Example #7



- For the two lightbulbs shown in figure, rank the current values at points *a* through *f*, from greatest to least

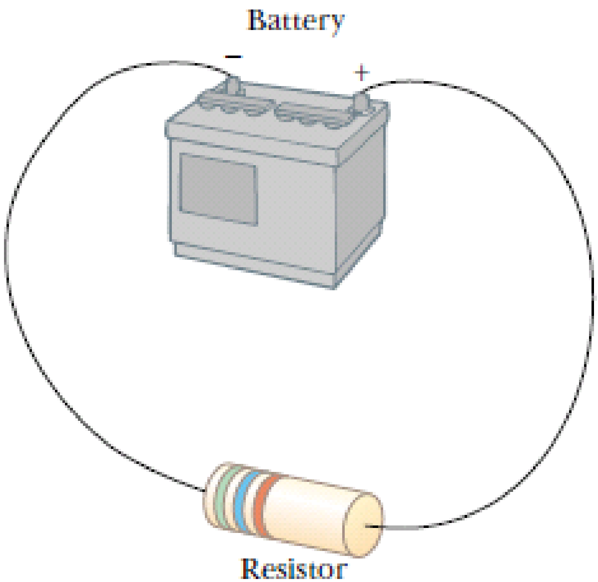
Direct Current Circuits

- Electromotive Force
- Resistors in Series and Parallel
- Kirchhoff’s Rules
- RC Circuits
- Electrical Meters

Electromotive Force

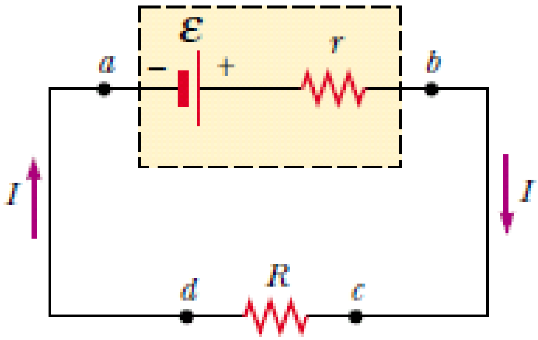
- Describing not a force but rather a potential difference in volts
- A battery is called either a source of electromotive force, or more commonly, a *source of emf*

Electromotive Force

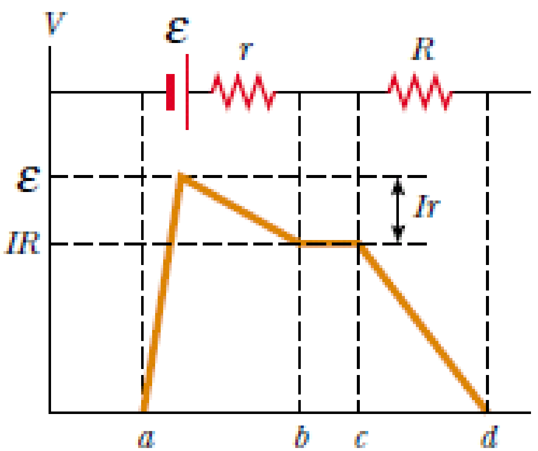


- The emf of a battery is the maximum possible voltage that the battery can provide between its terminals

Circuit Diagram



(a)



$$\Delta V = V_a - V_b = \varepsilon - Ir$$

r = internal resistance

$$IR = \varepsilon - Ir \Rightarrow I = \frac{\varepsilon}{R + r}$$

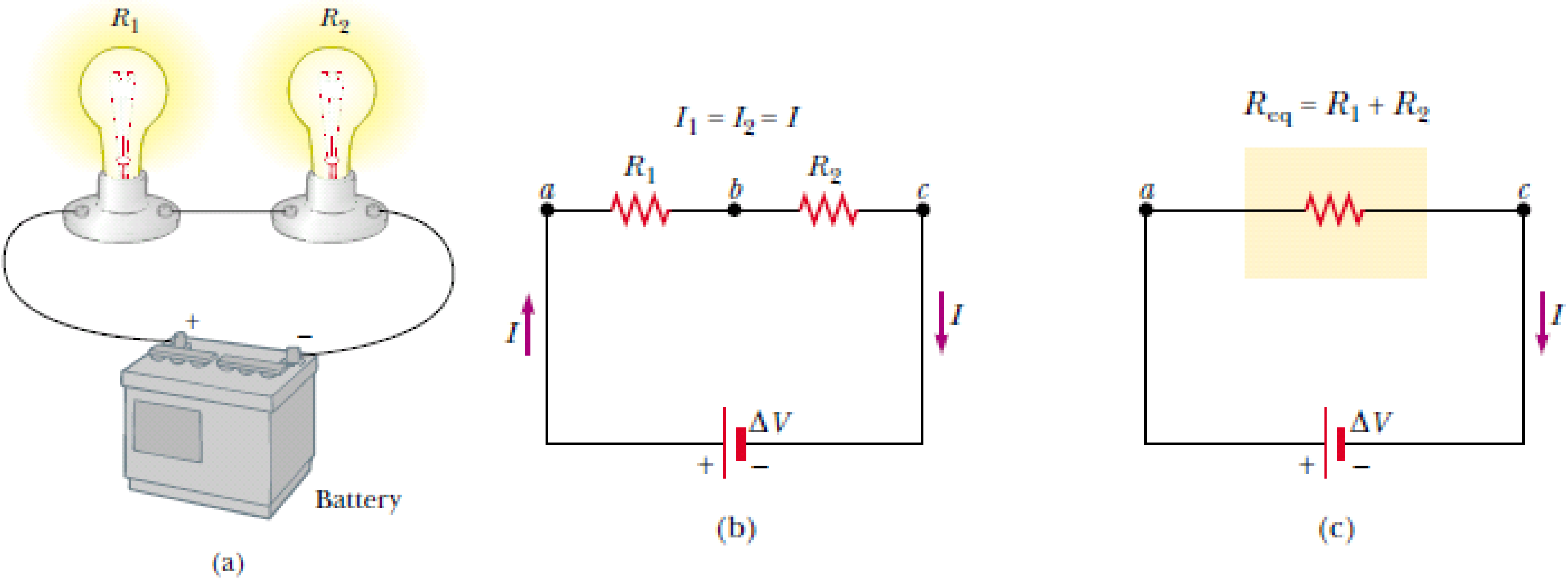
R = load resistance

$$Power = I\varepsilon = I^2 R + I^2 r$$

Example #8

- A battery has an emf of 12.0 V and an internal resistance of 0.05 Ω. Its terminals are connected to a load resistance of 3.00 Ω.

Resistors in Series

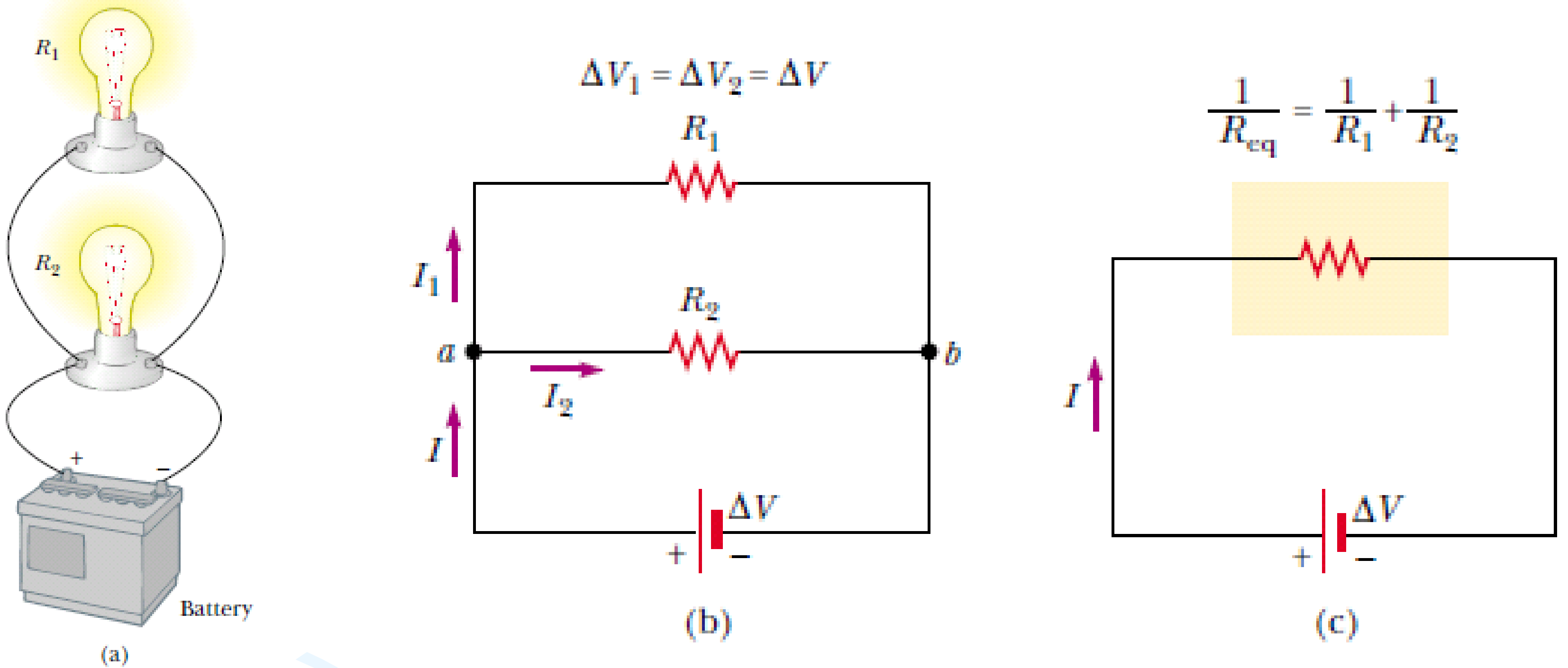


$$\Delta V = IR_1 + IR_2 = I(R_1 + R_2) = IR_{eq}$$

$$\Rightarrow$$

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

Resistors in Parallel

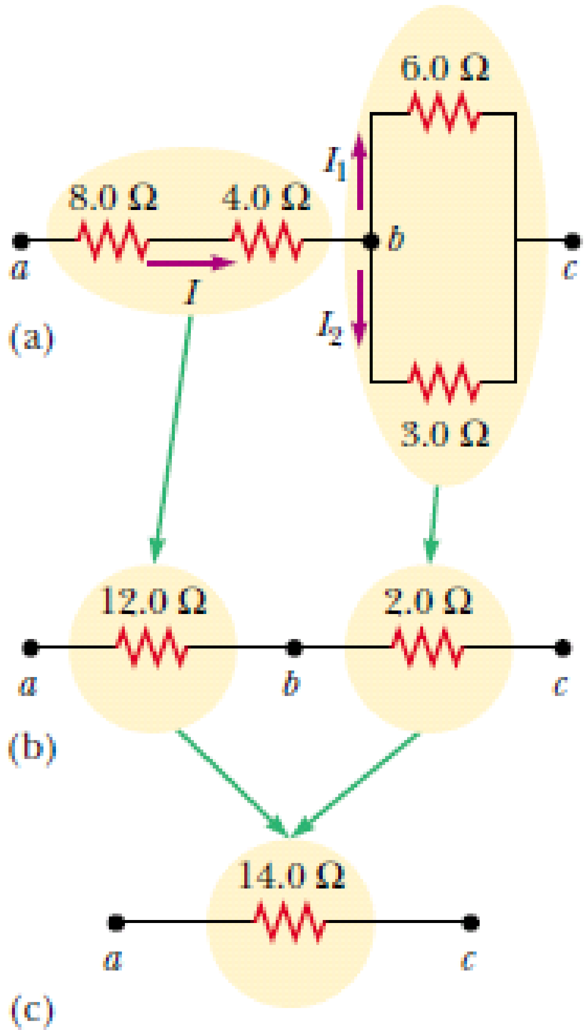


$$I = I_1 + I_2 = \left(\frac{\Delta V}{R_1}\right) + \left(\frac{\Delta V}{R_2}\right) = \left(\frac{\Delta V}{R_{eq}}\right)$$

$$\Rightarrow$$

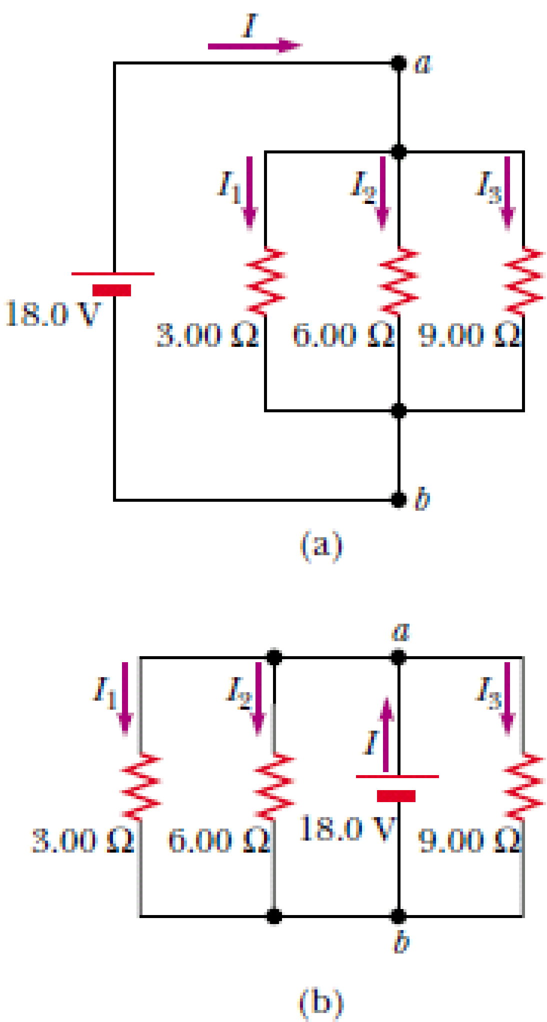
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Example



- Four resistors are connected as shown in the figure,
  - Find the equivalent resistance between points *a* and *c*
  - What is the current in each resistor if a potential difference of 42 V is maintained between *a* and *c*

Example

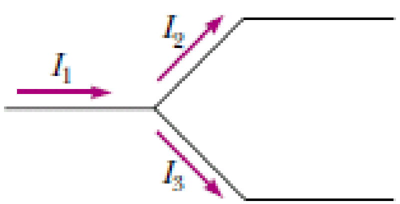


- Three resistors are connected in parallel as shown in the figure 28.11 Ω. A potential difference of 18.0 V is maintained between points *a* and *b*
  - Find the current in each resistor
  - Calculate the power delivered to each resistor and the total power delivered to the combination of resistors
  - Calculate the equivalent resistance of the circuit

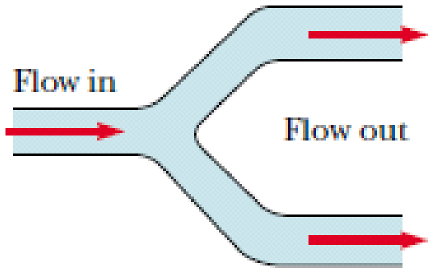
กฎของเคอร์ชอฟฟ์
Kirchhoff's Rules

- กฎที่รอยต่อ (Junction rule)
  - ผลรวมของกระแสที่ไหลเข้าไปในรอยต่อหรือจุดร่วมใดๆในวงจรไฟฟ้ามีค่าเท่ากับผลรวมของกระแสที่ไหลออกจากรอยต่อหรือจุดร่วมนั้น

$$\sum I_{in} = \sum I_{out}$$



(a)

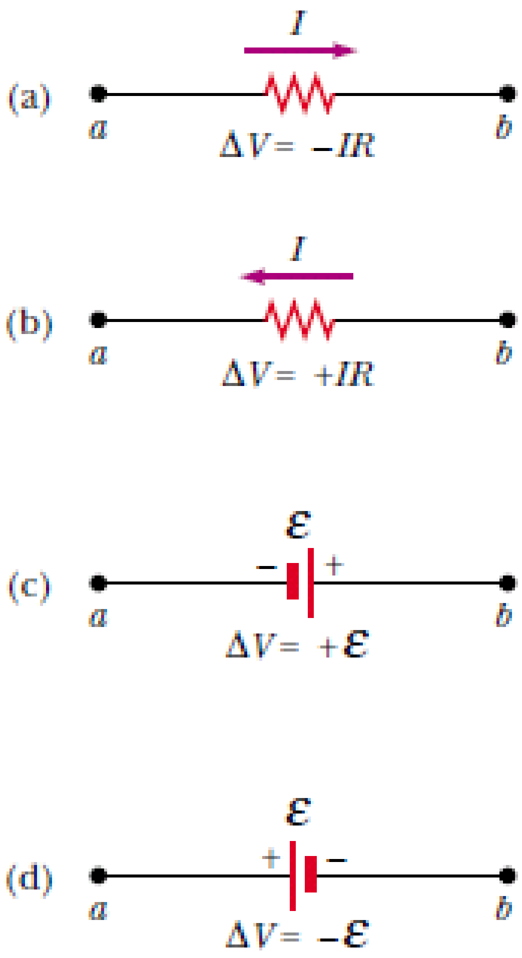


(b)

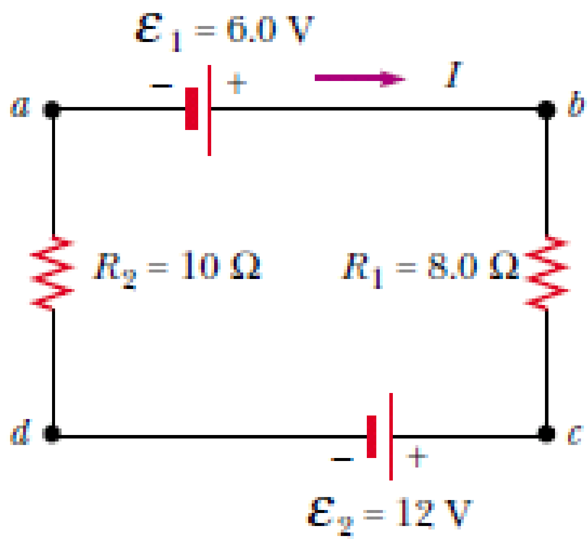
กฎของเคอร์ชอฟฟ์
Kirchhoff’s Rules

- กฎภายในลูป (Loop rule)
  - ผลรวมของความต่างศักย์ที่คร่อมอุปกรณ์ทั้งหมดในลูปปิดใดๆจะมีค่าเท่ากับศูนย์

$$\sum_{CosedLoop} \Delta V = 0$$



ตัวอย่าง



- วงจรที่มี 1 ลูป ดังรูป ประกอบด้วยตัวต้านทาน 2 ตัว และแบตเตอรี่ 2 ตัว (ไม่คำนึงถึงความต้านทานภายใน) จงหา
  - กระแสที่ไหลในวงจร
  - กำลังที่เกิดขึ้นกับตัวต้านทานแต่ละตัว
  - กำลังที่ส่งออกไปจากแบตเตอรี่ 12 V

วิธีทำ

$$\sum \Delta V = 0$$

$$\mathcal{E}_1 - IR_1 - \mathcal{E}_2 - IR_2 = 0$$

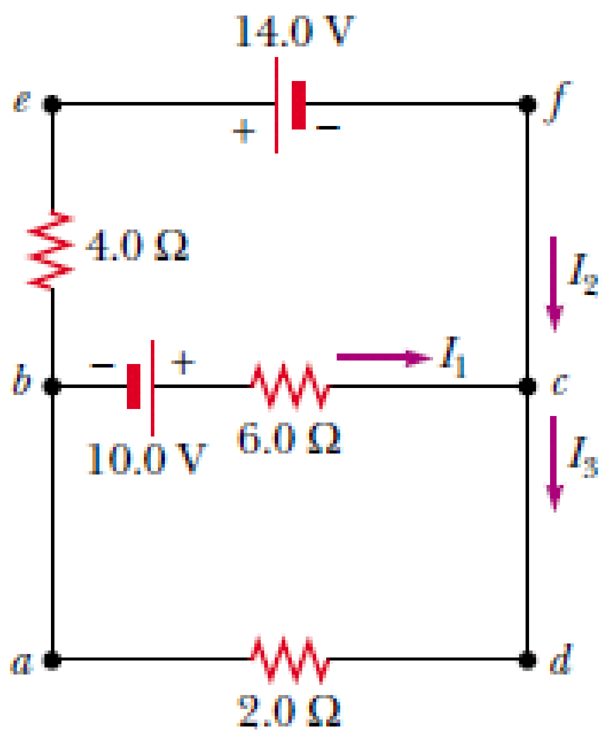
$$I = \frac{\mathcal{E}_1 - \mathcal{E}_2}{R_1 + R_2} = \frac{6.0\ \text{V} - 12\ \text{V}}{8.0\ \Omega + 10\ \Omega} = \boxed{-0.33\ \text{A}}$$

$$\mathcal{P}_1 = I^2 R_1 = (0.33\ \text{A})^2 (8.0\ \Omega) = \boxed{0.87\ \text{W}}$$

$$\mathcal{P}_2 = I^2 R_2 = (0.33\ \text{A})^2 (10\ \Omega) = \boxed{1.1\ \text{W}}$$

The 12-V battery delivers power $I\mathcal{E}_2 = 4.0\ \text{W}$.

ตัวอย่าง



- จากวงจรในรูป จงหาค่ากระแส I_1, I_2, และ I_3

วิธีทำ

$$I_1 + I_2 = I_3$$

abcda $\quad 10.0\text{ V} - (6.0\ \Omega)I_1 - (2.0\ \Omega)I_3 = 0$

$$10.0\text{ V} - (6.0\ \Omega)I_1 - (2.0\ \Omega)\ (I_1 + I_2) = 0$$

befcb $\quad -14.0\text{ V} + (6.0\ \Omega)I_1 - 10.0\text{ V} - (4.0\ \Omega)\ I_2 = 0$

$$-12.0\text{ V} = -(3.0\ \Omega)I_1 + (2.0\ \Omega)I_2$$

$$I_1 = \boxed{2.0\text{ A}}$$

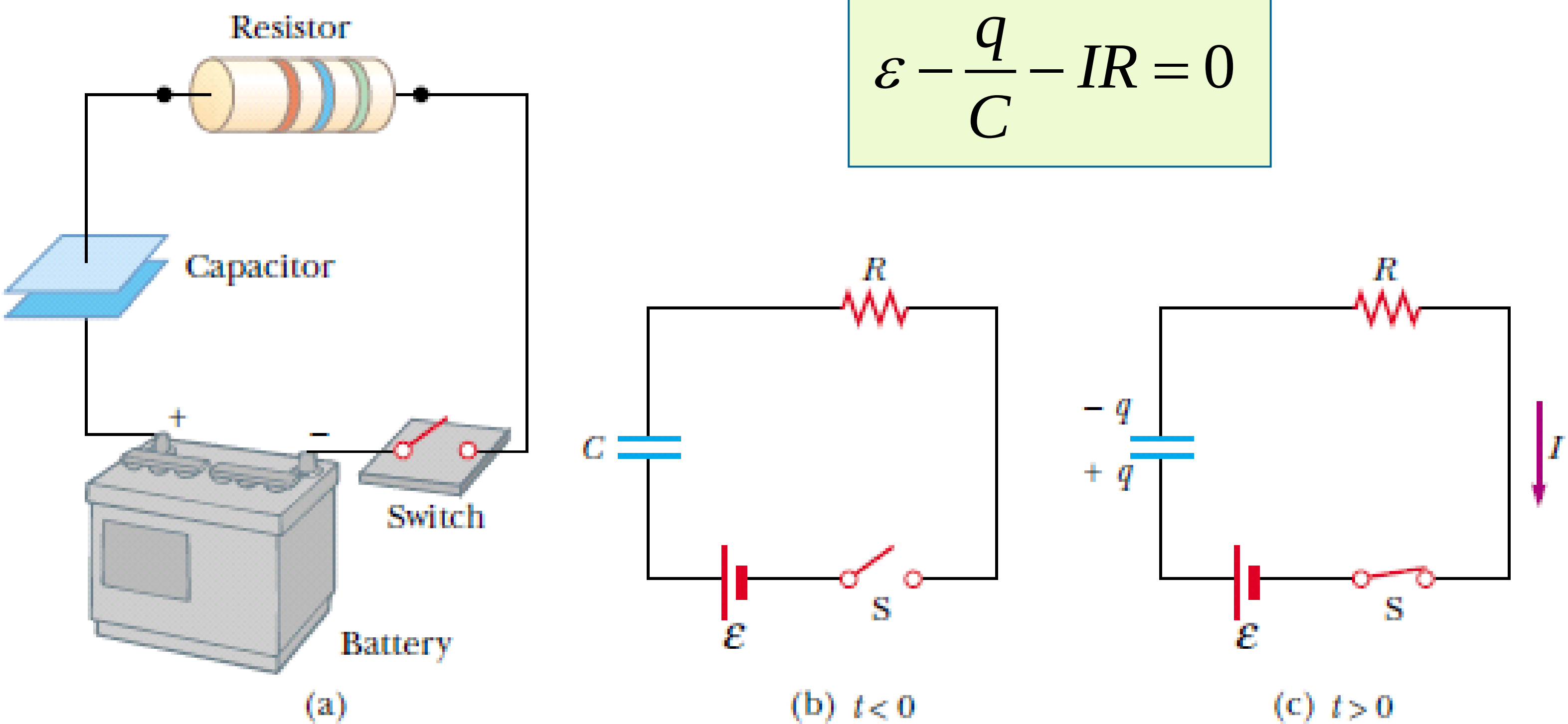
$$I_2 = \boxed{-3.0\text{ A}}$$

$$I_3 = I_1 + I_2 = \boxed{-1.0\text{ A}}$$

วงจร RC

- การอัดประจุในตัวเก็บประจุ

$$\varepsilon - \frac{q}{C} - IR = 0$$



วงจร RC

- การอัดประจุในตัวเก็บประจุ

$$I = I_0 e^{-\frac{t}{RC}}$$

$$\tau = RC$$

ค่าคงที่เวลา (time constant)

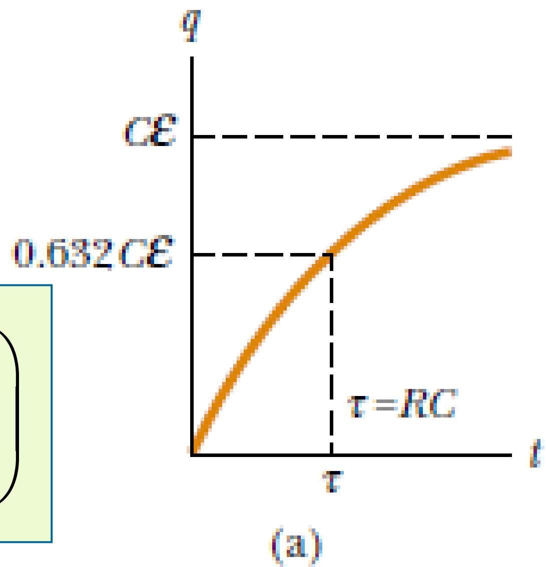
$$I_0 = \frac{\varepsilon}{R}$$

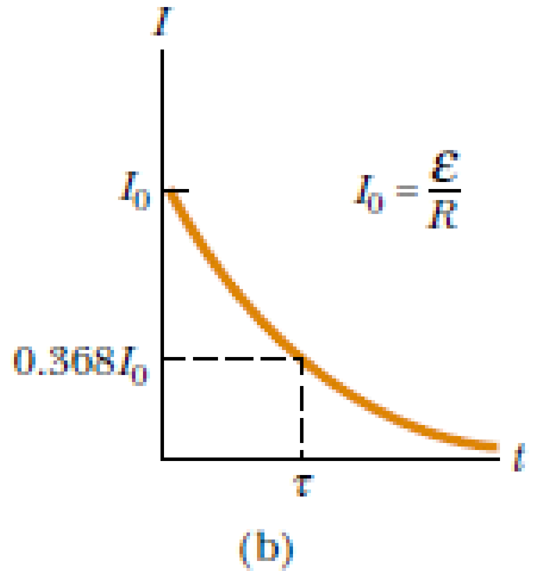
กระแสที่เวลา $t = 0$

$$Q = C\varepsilon$$

ค่าประจุมากสุด

$$q(t) = Q\left(1 - e^{-\frac{t}{RC}}\right)$$





RC Circuits

- การคายประจุในตัวเก็บประจุ

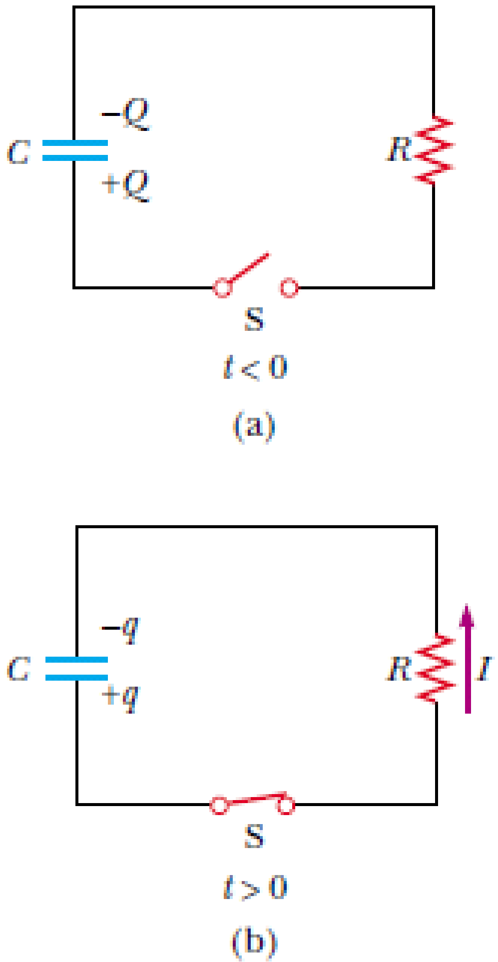
$$-\frac{q}{C} - IR = 0$$

$$q(t=0) = Q$$

ประจุที่เวลา $t = 0$

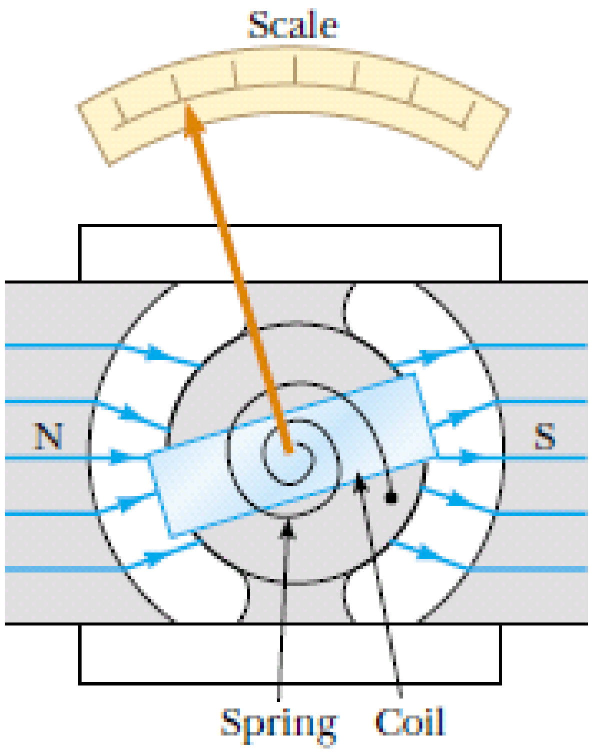
$$q(t) = Qe^{-\frac{t}{RC}}$$

$$I(t) = \frac{dq(t)}{dt} = -\frac{Q}{RC}e^{-\frac{t}{RC}} = -I_0 e^{-\frac{t}{RC}}$$



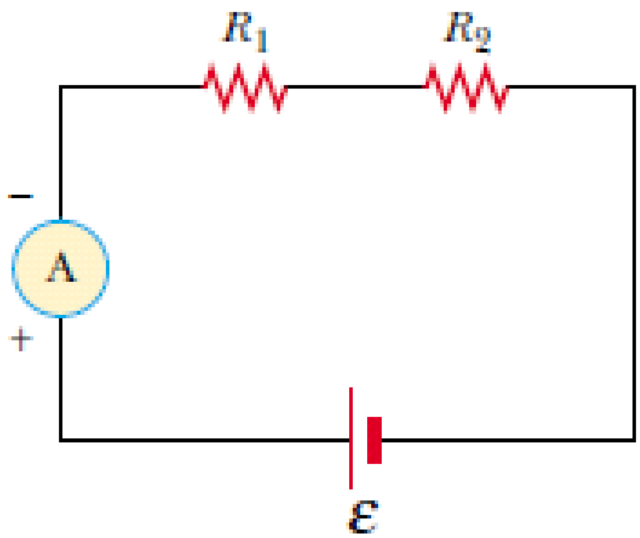
มิเตอร์ไฟฟ้า
(Electrical Meters)

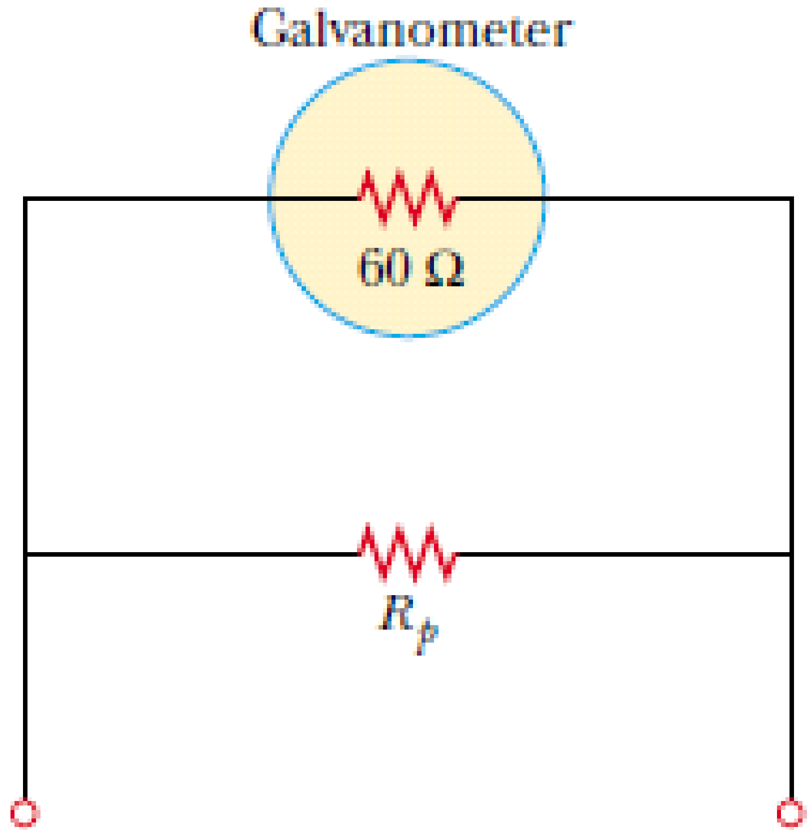
- กัลป์วานอมิเตอร์ (Galvanometer)
  - ส่วนอุปกรณ์หลักในมิเตอร์แบบอนาลอกที่ใช้วัดกระแสและความต่างศักย์



มิเตอร์ไฟฟ้า
(Electrical Meters)

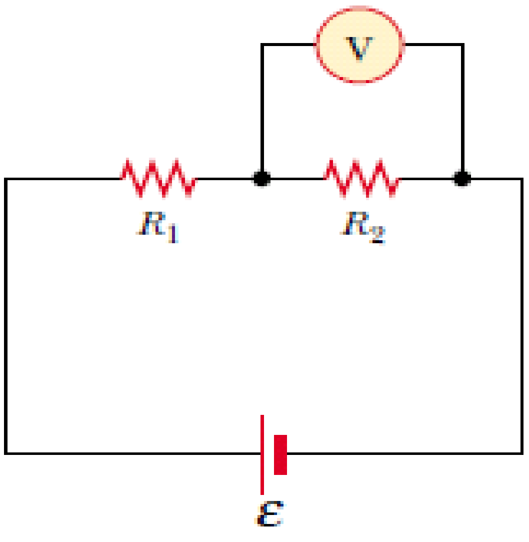
- **แอมมิเตอร์ (Ammeter)**
  - อุปกรณ์ที่ใช้วัดกระแสไฟฟ้า

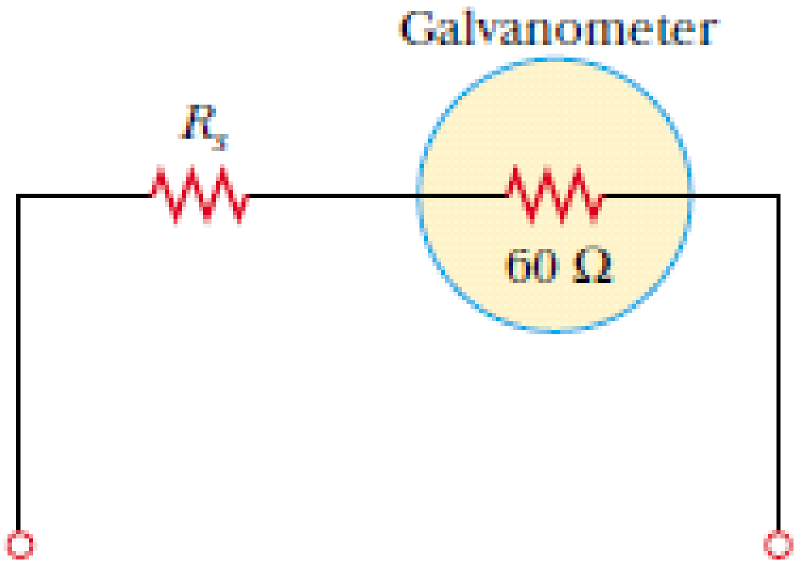




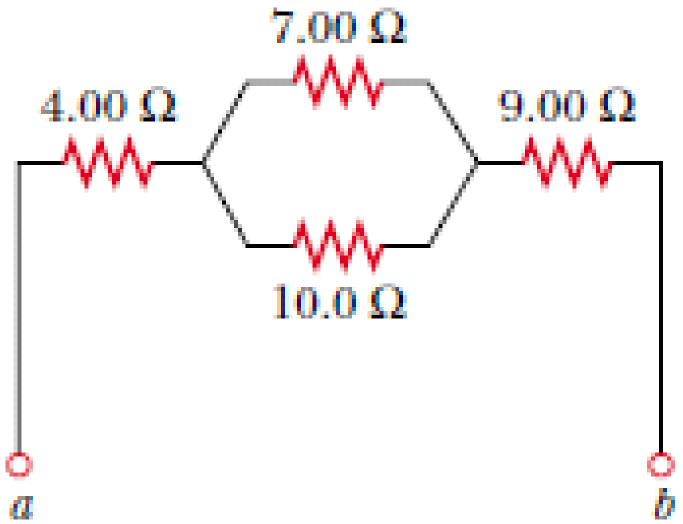
มิเตอร์ไฟฟ้า
(Electrical Meters)

- โวลต์มิเตอร์ (Voltmeter)
  - อุปกรณ์ที่ใช้วัดความต่างศักย์ไฟฟ้า





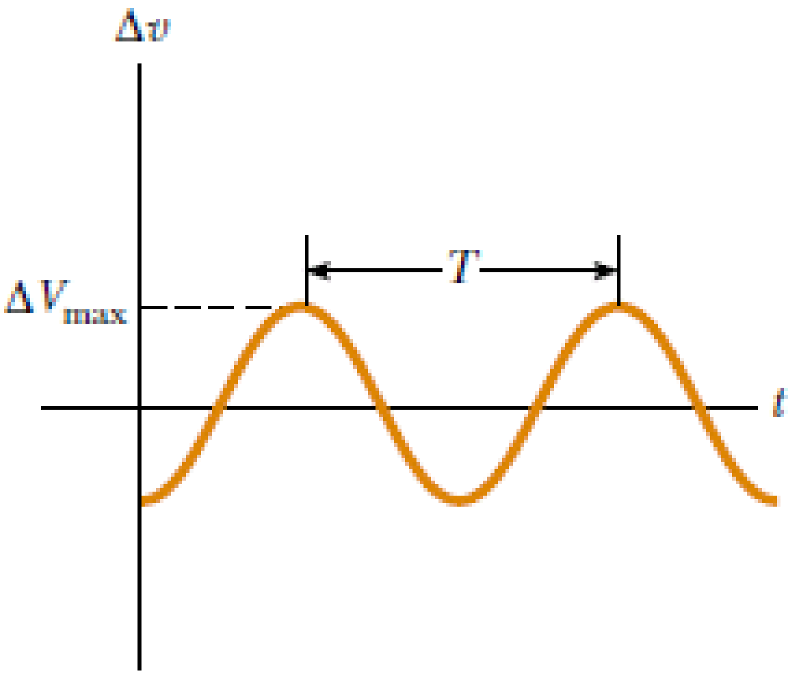
Quiz



- จากวงจรในรูป จงหาค่าความต้านทานรวมระหว่างจุด a และ จุด b
- ถ้าความต่างศักย์ระหว่างจุด a และ จุด b เท่ากับ 34.0 v จงหาค่ากระแสที่ไหลในตัวต้านทานแต่ละตัว

วงจรไฟฟ้ากระแสสลับ
Alternating Current Circuits

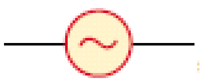
แหล่งจ่ายไฟฟ้า AC



$$\Delta v = \Delta V_{\max} \sin \omega t$$

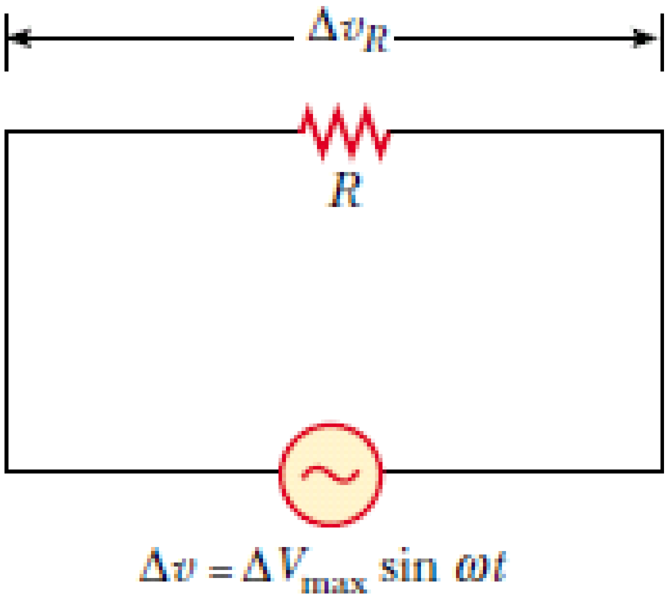
$$\omega = 2\pi f = \frac{2\pi}{T}$$

ω : ความถี่เชิงมุมของความต่างศักย์ AC



ΔV_{max} : ค่าความต่างศักย์สูงสุดของแหล่งจ่ายไฟฟ้าAC

ตัวต้านทานในวงจรไฟฟ้า AC



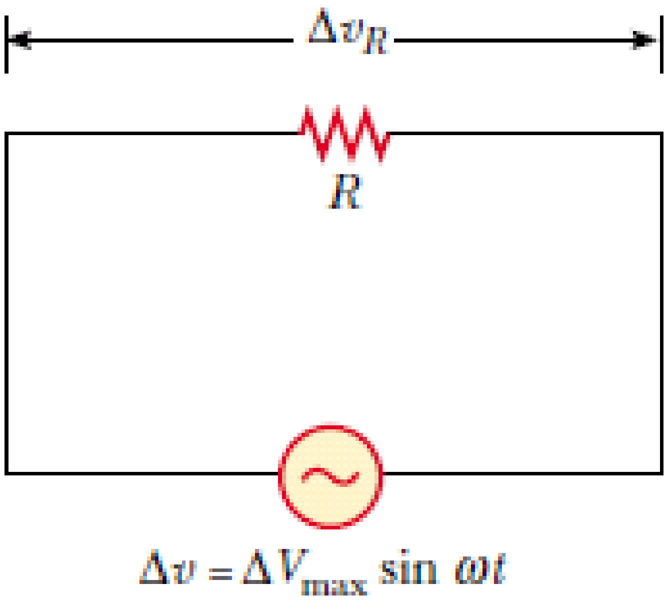
$$\Delta v = \Delta v_R = \Delta V_{max} \sin \omega t$$

$$i_R = \frac{\Delta v_R}{R} = \frac{\Delta V_{max}}{R} \sin \omega t = I_{max} \sin \omega t$$

i_R : กระแสไฟฟ้าที่ไหลผ่านตัวต้านทานขณะเวลา t ใดๆ

Δv_R : ความต่างศักย์ไฟฟ้าที่ตกคร่อมตัวต้านทานขณะเวลา t ใดๆ

ตัวต้านทานในวงจรไฟฟ้า AC

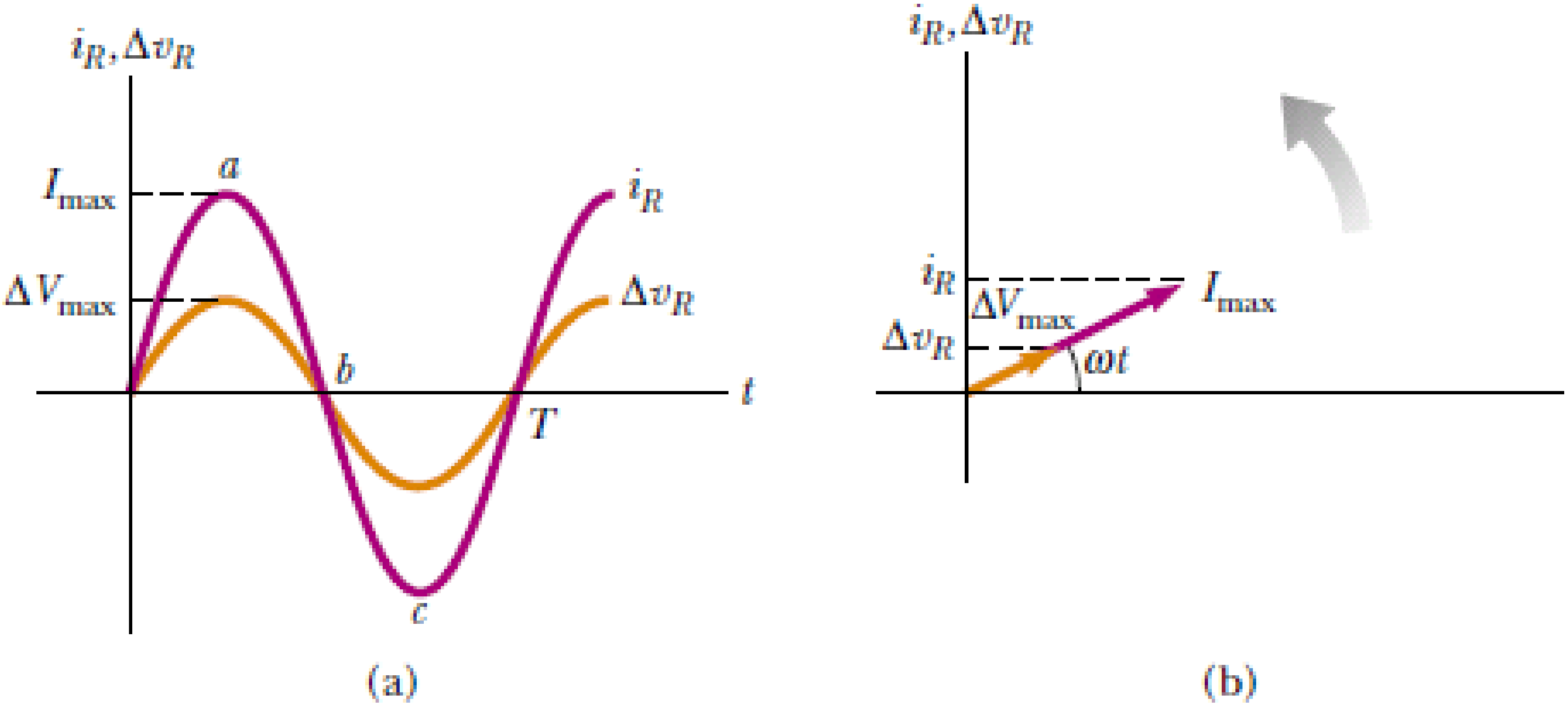


$$I_{max} = \frac{\Delta V_{max}}{R}$$

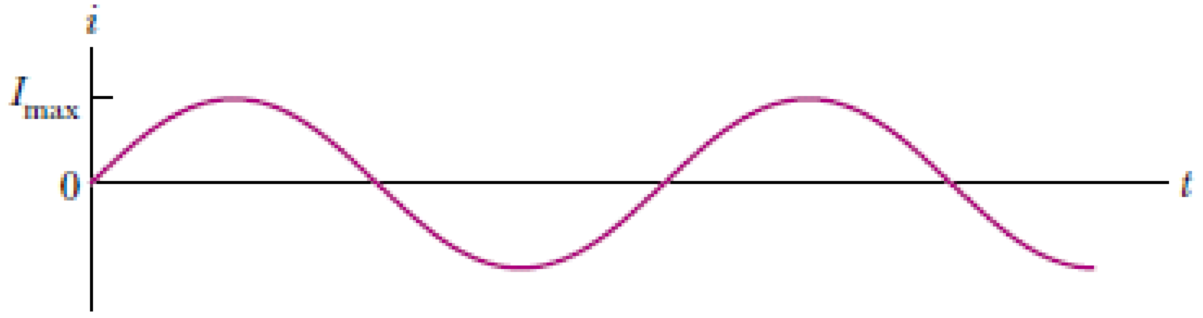
I_{max} : กระแสไฟฟ้าสูงสุด

$$\Delta v_R = I_{max} R \sin \omega t$$

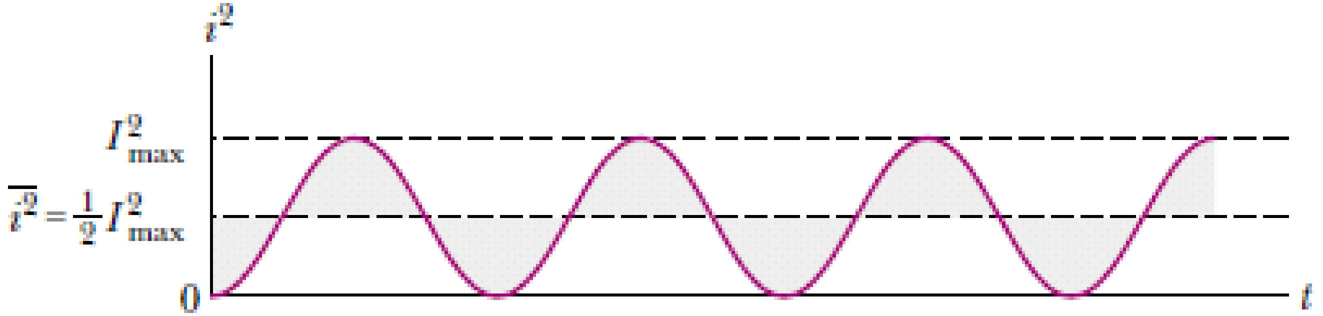
ตัวต้านทานในวงจรไฟฟ้า AC



ตัวต้านทานในวงจรไฟฟ้า AC



(a)



(b)

ตัวต้านทานในวงจรไฟฟ้า AC

$$I_{rms} = \frac{I_{max}}{\sqrt{2}} = 0.707 I_{max}$$

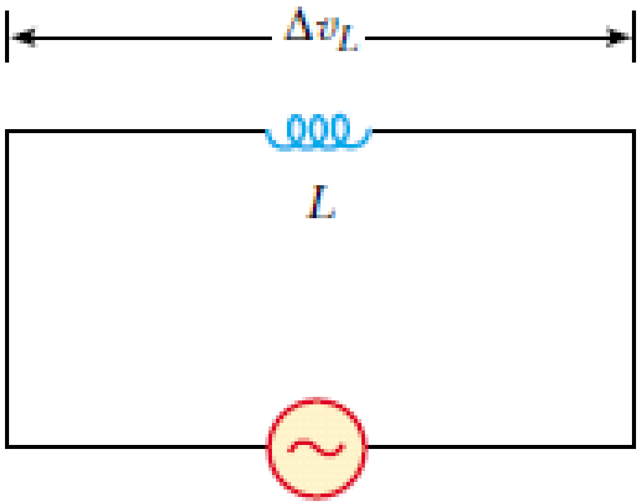
$$V_{rms} = \frac{V_{max}}{\sqrt{2}} = 0.707 V_{max}$$

rms : รากที่สองของกำลังสองเฉลี่ย (root mean square)

$$P_{av} = I_{rms}^2 R$$

P_{av} : กำลังไฟฟ้าเฉลี่ยที่ตัวต้านทาน

ตัวเหนี่ยวนำในวงจรไฟฟ้า AC



L : ความเหนี่ยวนำ หน่วย H

$$\Delta v + \Delta v_L = 0 = \Delta v - L\frac{di}{dt}$$

$$\Delta v = L\frac{di}{dt} = \Delta V_{max} \sin \omega t$$

Δv_L : ความต่างศักย์ไฟฟ้าที่ตกคร่อมตัวเหนี่ยวนำ

ตัวเหนี่ยวนำในวงจรไฟฟ้า AC

$$di = \frac{\Delta V_{max}}{L} \sin \omega t dt$$

$$i_L = \frac{\Delta V_{max}}{L} \int_0^t \sin \omega t = -\frac{\Delta V_{max}}{\omega L} \cos \omega t = \frac{\Delta V_{max}}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right)$$

i_L : กระแสไฟฟ้าที่ไหลผ่านตัวเหนี่ยวนำขณะเวลา t ใดๆ

$$I_{max} = \frac{\Delta V_{max}}{\omega L}$$

ตัวเหนี่ยวนำในวงจรไฟฟ้า AC

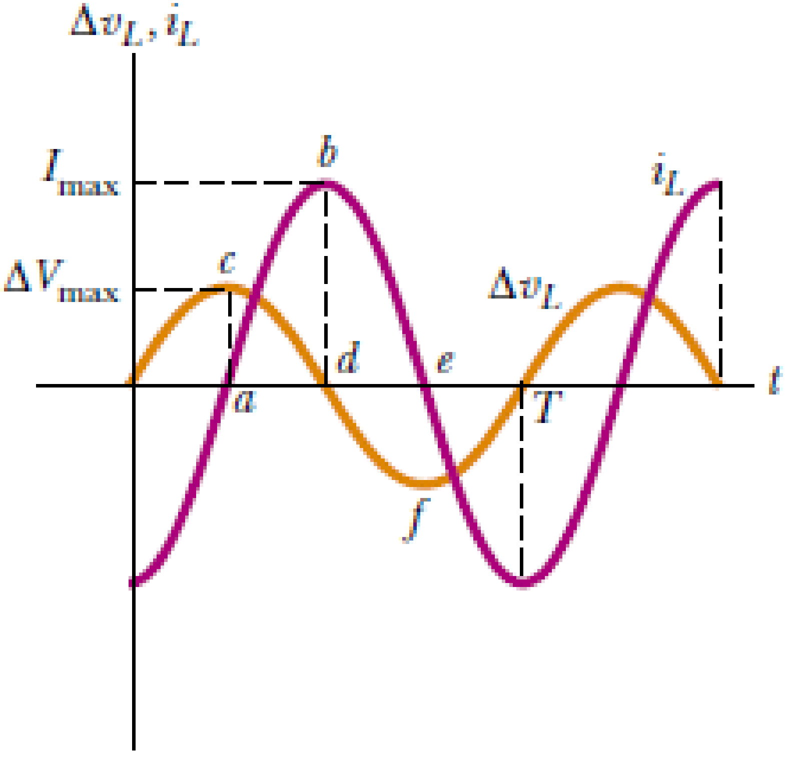
$$X_L = \omega L$$

ความต้านทานเชิงเหนี่ยวนำ
(Inductive reactance)

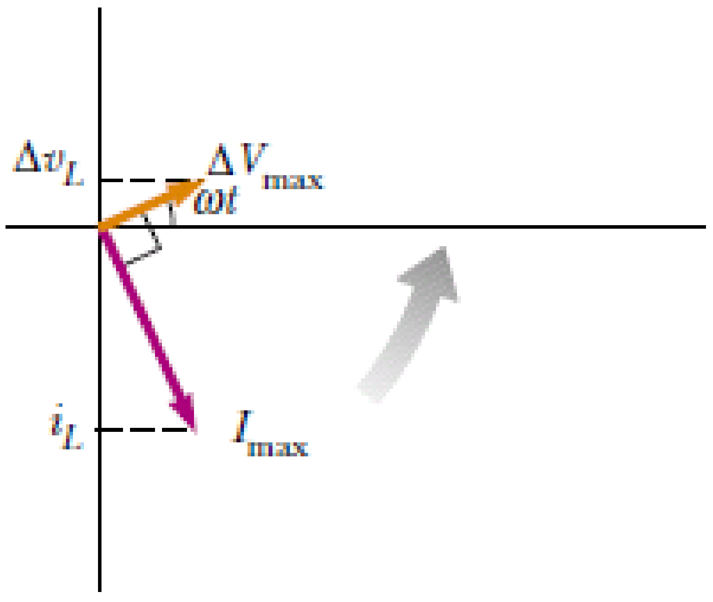
$$I_{\max} = \frac{\Delta V_{\max}}{X_L}$$

$$\Delta v_L = -L\frac{di}{dt} = -\Delta V_{\max}\sin\omega t = -I_{\max}X_L\sin\omega t$$

ตัวเหนี่ยวนำในวงจรไฟฟ้า AC

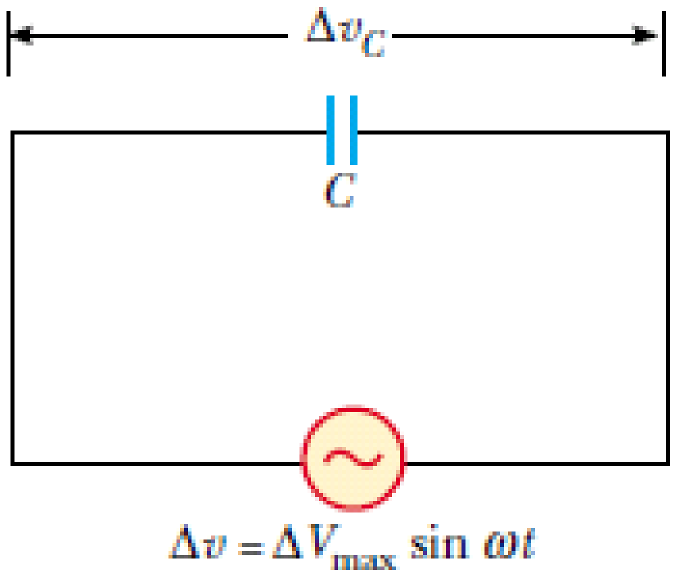


(a)



(b)

ตัวเก็บประจุในวงจรไฟฟ้า AC



$$\Delta v + \Delta v_C = 0 = \Delta v - \frac{q}{C}$$

$$\Delta v = \Delta V_{\max} \sin \omega t$$

$$q = C\Delta V_{\max} \sin \omega t$$

C : ความจุในตัวเก็บประจุ

Δv_C : ความต่างศักย์ไฟฟ้าที่ตกคร่อมตัวเก็บประจุขณะเวลา t ใดๆ

ตัวเก็บประจุในวงจรไฟฟ้า AC

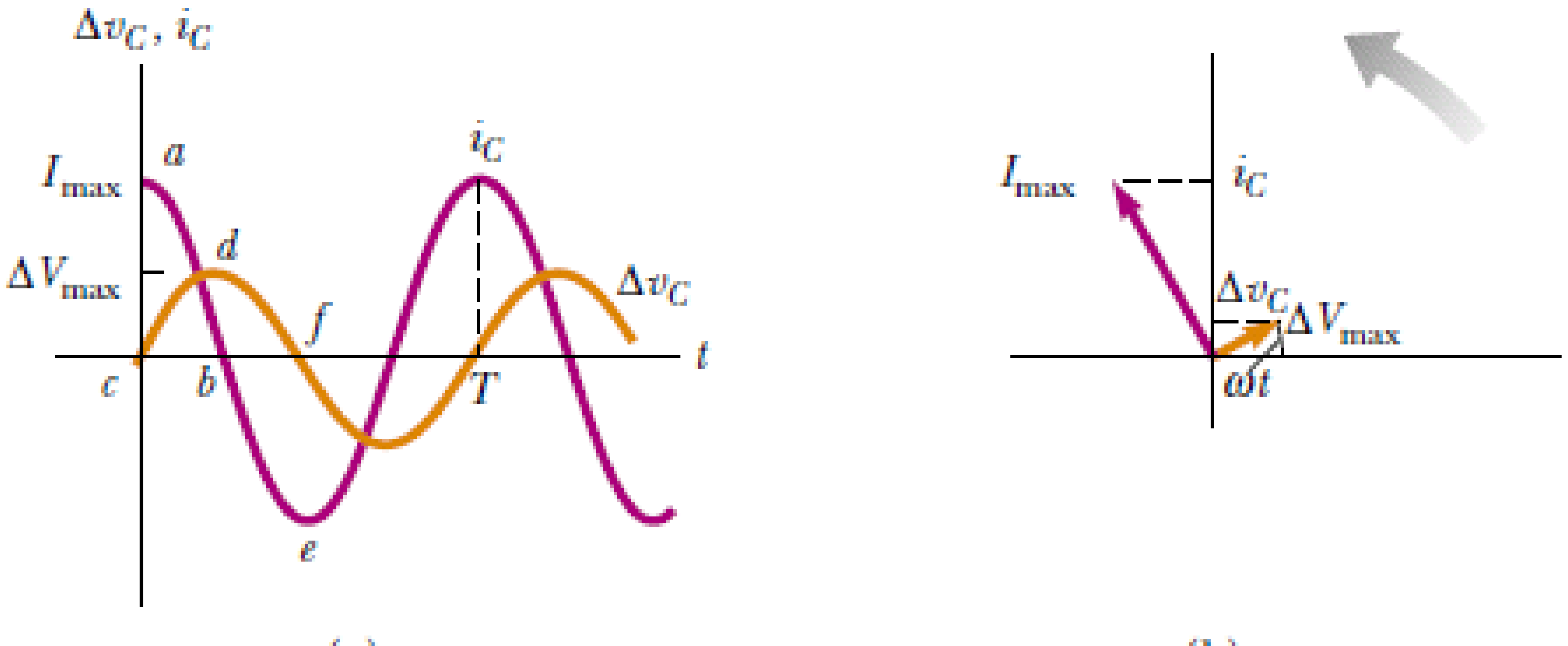
$$i_C = \frac{dq}{dt} = \omega C V_{\max} \cos \omega t = \omega C V_{\max} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I_{\max} = \omega C \Delta V_{\max} = \frac{\Delta V_{\max}}{\frac{1}{\omega C}} = \frac{\Delta V_{\max}}{X_C}$$

$$X_C = \frac{1}{\omega C}$$

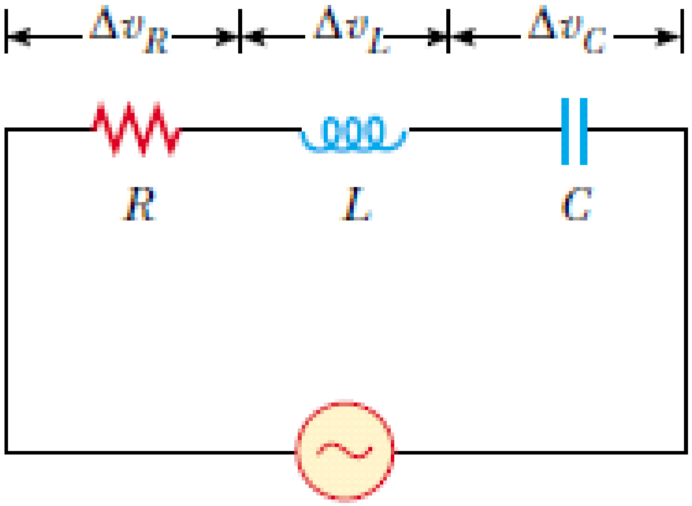
ความต้านทานเชิงความจุ
(capacitive reactance)

ตัวเก็บประจุในวงจรไฟฟ้า AC

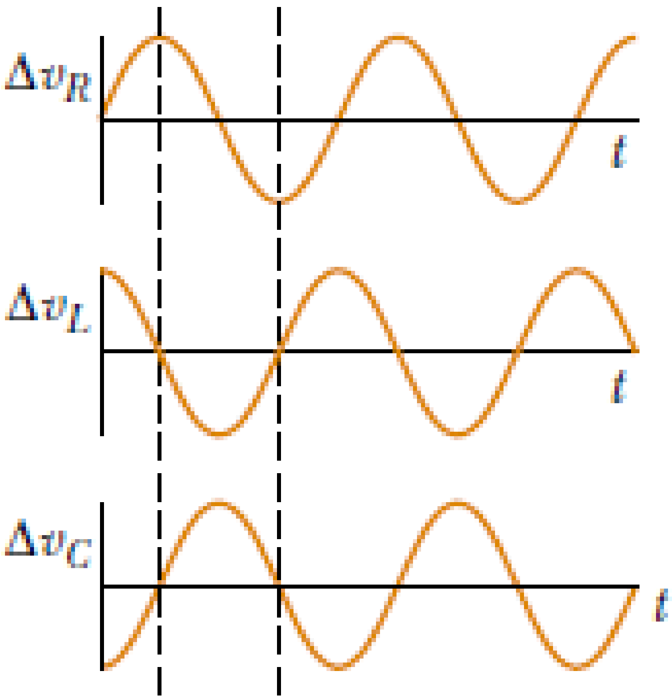


(a) (b)

วงจรอนุกรม RLC



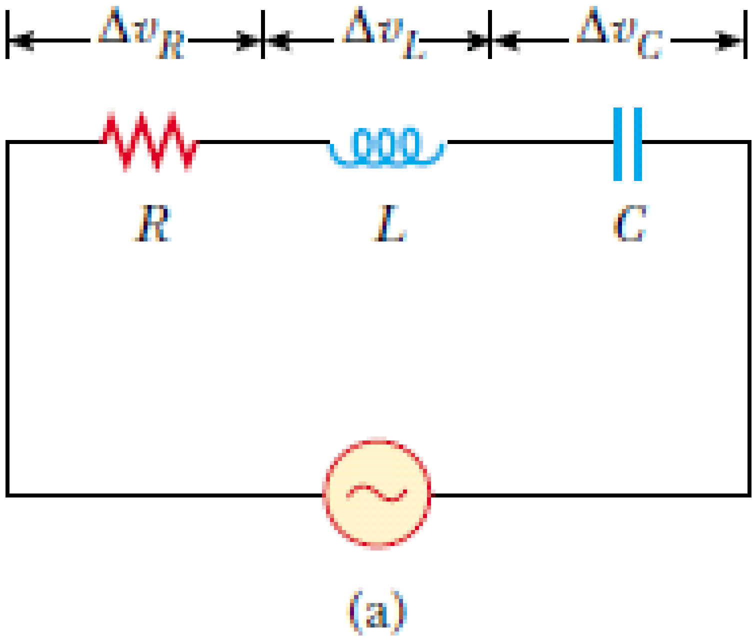
(a)



(b)

$$i = I_{\max} \sin \omega t$$

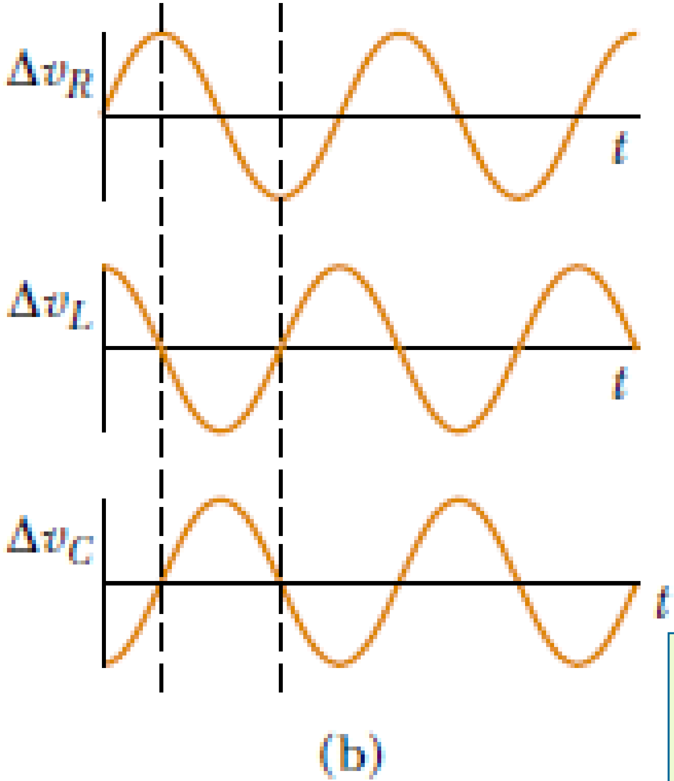
วงจรอนุกรม RLC



$$\Delta v = \Delta V_{\max} \sin \omega t$$

$$i = I_{\max} \sin \omega t$$

วงจรอนุกรม RLC

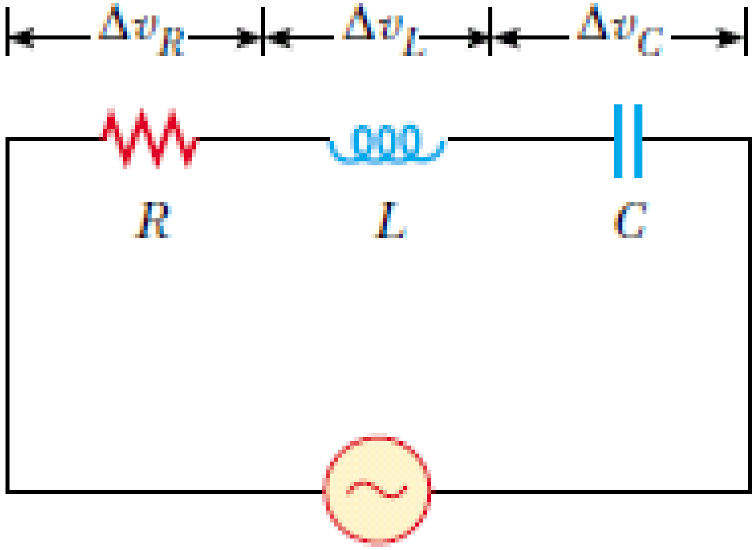


$$\Delta v_R = I_{\max} R \sin \omega t = \Delta V_R \sin \omega t$$

$$\Delta v_L = I_{\max} X_L \sin\left(\omega t + \frac{\pi}{2}\right) = \Delta V_L \cos \omega t$$

$$\Delta v_C = I_{\max} X_C \sin\left(\omega t - \frac{\pi}{2}\right) = -V_C \cos \omega t$$

วงจรอนุกรม RLC

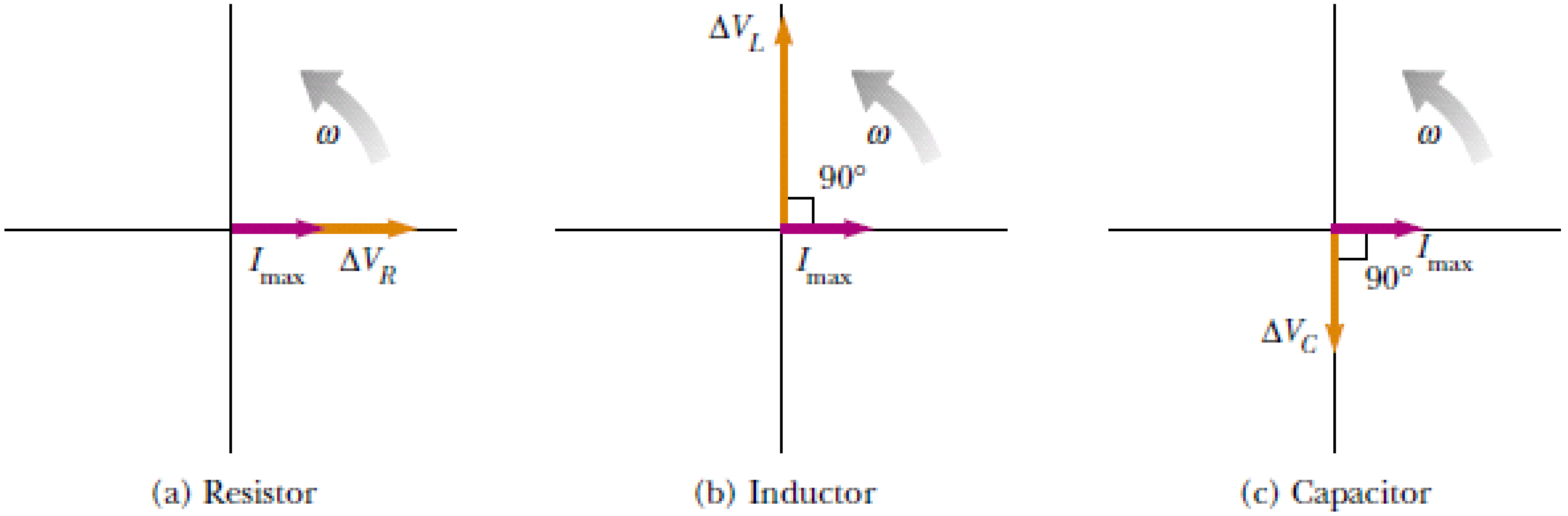


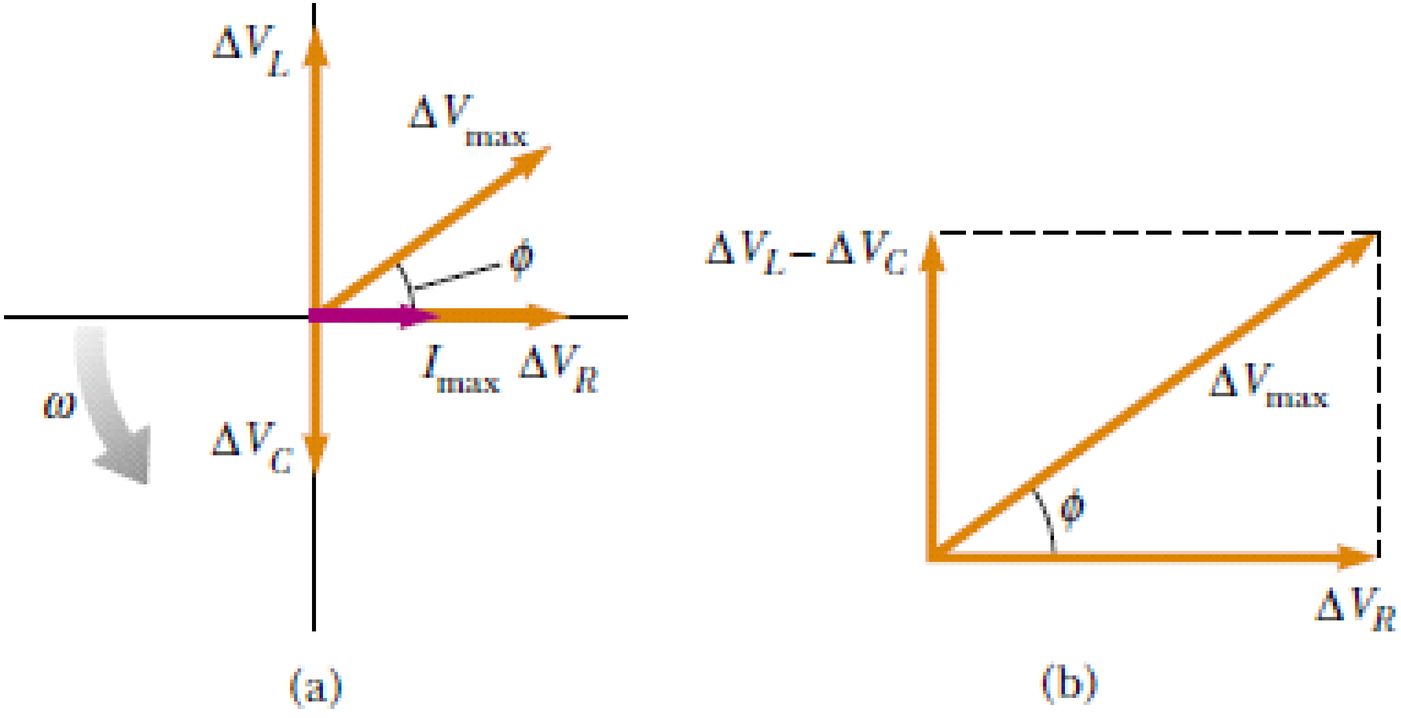
(a)

$$\Delta v = \Delta v_R + \Delta v_L + \Delta v_C$$

วงจรอนุกรม RLC

$$\Delta v = \Delta v_R + \Delta v_L + \Delta v_C$$





ΔV_L
ΔV_max
φ
I_max
ΔV_R
ω
ΔV_C
(a)
ΔV_L – ΔV_C
ΔV_max
φ
ΔV_R
(b)

วงจรอนุกรม RLC

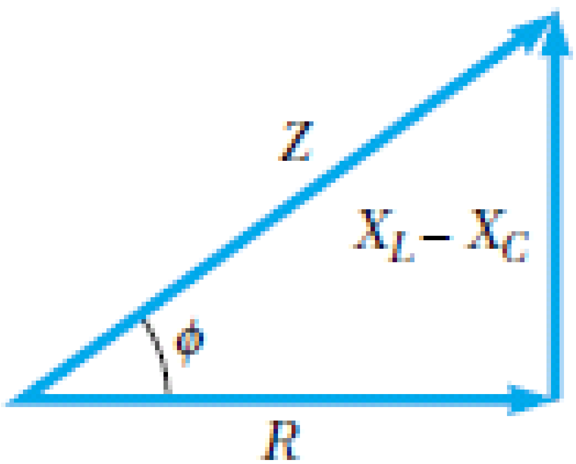
$$\Delta V_{\max} = \sqrt{\left(\Delta V_R\right)^2 + \left(\Delta V_L - \Delta V_C\right)^2} = \sqrt{\left(I_{\max} R\right)^2 + \left(I_{\max} X_L - I_{\max} X_C\right)^2}$$

$$I_{\max} = \frac{\Delta V_{\max}}{\sqrt{R^2 + \left(X_L - X_C\right)^2}}$$

$$Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}$$

ความต้านทานเชิงซ้อน (impedance)

วงจรอนุกรม RLC

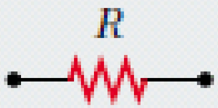
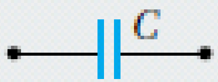
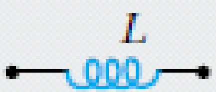
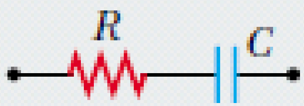
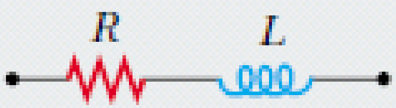
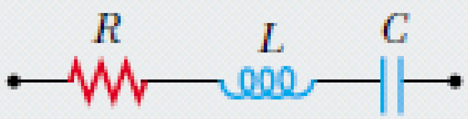


$$\Delta V_{max} = I_{max} Z$$

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

วงจรอนุกรม RLC

Impedance Values and Phase Angles for Various Circuit-Element Combinations[a]

Circuit Elements	Impedance Z	Phase Angle ϕ
	R	$0°$
	X_C	$-90°$
	X_L	$+90°$
	$\sqrt{R^2 + X_C^2}$	Negative, between $-90°$ and $0°$
	$\sqrt{R^2 + X_L^2}$	Positive, between $0°$ and $90°$
	$\sqrt{R^2 + (X_L - X_C)^2}$	Negative if $X_C > X_L$ Positive if $X_C < X_L$

กำลังไฟฟ้าในวงจร AC

$$P = i\Delta v = I_{\max}\sin(\omega t - \phi)V_{\max}\sin\omega t$$

$$P_{av} = \frac{1}{2}I_{\max}V_{\max}\cos\phi \Rightarrow P_{av} = I_{rms}V_{rms}\cos\phi$$

$\phi = 0$: P_{av} ในตัวต้านทานไฟฟ้า

$\phi = \pi/2$: P_{av} ในตัวเก็บประจุและตัวเหนี่ยวนำ