Chap 16 Electric Potential, Energy, and Capacitance

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CREDITS

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    - College Physics, Serway
    - http://hyperphysics.phy-astr.gsu.edu
    - The McGraw-Hill Companies.
    - Physics with health science applications, Urone, John Wiley and Sons
    - www.prenhall.com/esm_wilson_physics
    - http://www.walter-fendt.de/ph11e
    - http://www.lon-capa.org/~mmp/
    - SERWAY COLLEGE PHYSICS 7E MEDIA LIBRARY

Objectives I

- Explain the concept of "field" and compare it to "action-at-a-distance" using forces.
- Explain and draw the electric field configuration due to various discrete and continuous charge distributions.
- Relate the theoretical interpretation of electric potential to everyday phenomena and use it to solve problems.
- Explain the meaning of electrostatic energy and apply it to solve problems involving capacitance.
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Outline I

- Electric Potential Energy and Electric Potential Difference
- Equipotential Surfaces and the Electric Field
- Capacitance
- Dielectrics
- Capacitors in Series and in Parallel
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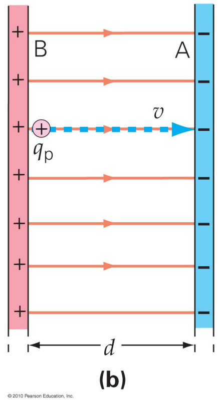
Potential differences

- Are defined in terms of positive charges, as is the electric field.



- we must account for the difference between positive and negative charges.
- Positive charges, when released, accelerate toward regions of lower electric potential.
- Negative charges, when released, accelerate toward regions of higher electric potential.
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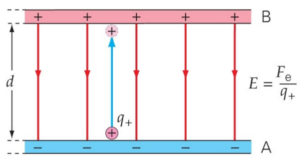
Electric Potential Energy and Electric Potential Difference

- It takes work to move a charge against an electric field.



$$\Delta U_e = U_A - U_B = q_+ \cdot Ed$$

- Electric field is a measure of the change in electric potential over a distance.
  - Just as with gravity, this work increases the potential energy of the charge.
- It is convenient to define a quantity that is the electric potential energy per unit charge.

$$\Delta V = \frac{\Delta U_e}{q_+} \rightarrow \quad \text{expressed in } Volts$$

- This is called the electric potential.
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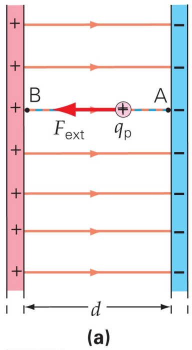
Electric Potential Energy and Electric Potential Difference

- The potential difference between parallel plates can be calculated relatively easily:



$$\Delta V = \frac{\Delta U_e}{q_+} = \frac{q_+ \cdot E \cdot d}{q_+} = E \cdot d$$

- For a pair of oppositely charged parallel plates, the positively charged plate is at a higher electric potential than the negatively charged one by an amount ΔV
- only changes in the electric potential can be defined.
- The choice of $V = 0$ is arbitrary.
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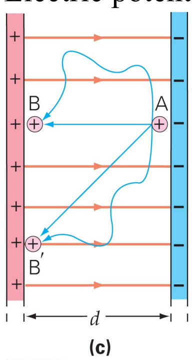
Electric potential difference of a point charge

- Electric potential difference of a point charge:



$$\Delta V = E \cdot d$$

$$E = \frac{F}{q}$$

$$F = kq_1 \frac{q_2}{d^2}$$

$$\Delta V = \frac{k \cdot q}{r_B} - \frac{k \cdot q}{r_A}$$

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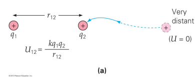
Electric potential energy of a system of two charges

- The electric potential energy of a system of two charges is the change in electric potential multiplied by the charge:

  $$\Delta\, U_e = q_2 \cdot\ \Delta\, V = q_2 V_1 - V_\infty$$

  $$\Delta\, U_e = q_2 \cdot \left(\frac{k \cdot q_1}{r_{12}} - 0 \right) = \frac{k \cdot q_1 \cdot q_2}{r_{12}}$$

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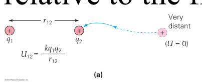
Potential energy due to a system of charges

- The additional potential energy due to a third charge is the sum of its potential energies relative to the first two.
  

- Further charges extend the sum.
  $U_{total} = U_{12} + U_{13} + U_{23} + \ldots$
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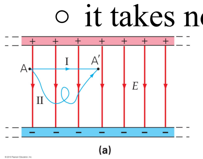
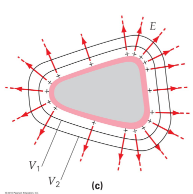
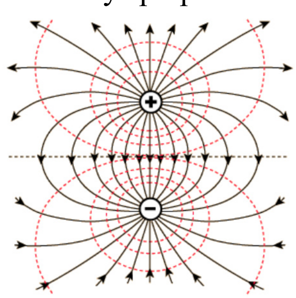
Equipotential Surfaces and the Electric Field

- An equipotential surface is one on which the electric potential does not vary;
  - it takes no work to move a charge along an equipotential surface.

- Equipotentials are always perpendicular to electric field lines.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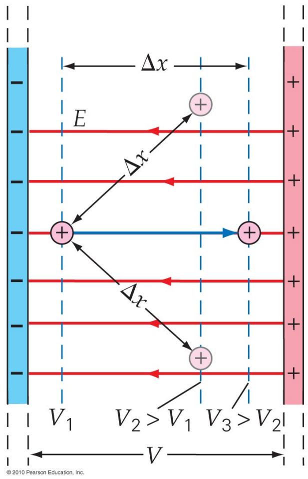
Equipotential Surfaces and the Electric Field



- The direction of the electric field E is that in which the electric potential decreases the most rapidly.
- Its magnitude is given by

$$E = \left(\frac{\Delta V}{\Delta x}\right)_{max}$$

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Common voltages

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TABLE 16.1 Common Electric Potential Differences (Voltages)

Source	*Approximate Voltage (ΔV)*
Across nerve membranes	100 mV
Small-appliance batteries	1.5 to 9.0 V
Automotive batteries	12 V
Household outlet (United States)	110 to 120 V
Houschold outlets (Europe)	220 to 240 V
Automotive ignitions (spark plug firing)	10 000 V
Laboratory generators	25 000 V
High-voltage electric power delivery lines	300 kV or more
Cloud-to-Earth surface during thunderstorm	100 MV or more

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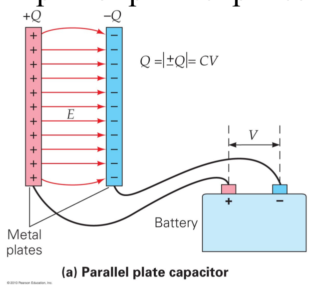
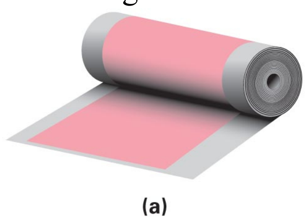
Capacitance

- A pair of parallel plates will store electric energy if charged oppositely;



(a) Parallel plate capacitor

- this arrangement is called a capacitor.


(a)

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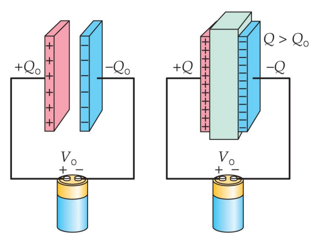
Capacitance of a capacitor

- The charge is related to the potential difference; the ratio is called the capacitance.

$Q = CV \rightarrow$

$C = \frac{Q}{V}$ expressed in Farrad.



(b)

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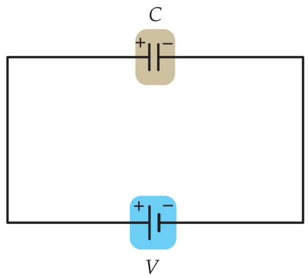
Capacitance of a parallel-plate capacitor

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

$$C = \frac{Q}{V} = \varepsilon_0 \cdot \frac{A}{d}$$

- 

(b) Schematic diagram
- ε_0 is the permitivity of free space:

$$\varepsilon_0 = \frac{1}{4\pi k} = 8.85 \cdot 10^{-12} \frac{C^2}{N \cdot m^2}$$

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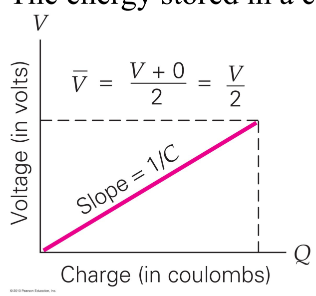
The energy stored in a capacitor

- The energy stored in a capacitor is the energy required to charge it:



$$U_C = \frac{1}{2}QV = \frac{Q^2}{2C} = \frac{1}{2}CV^2$$

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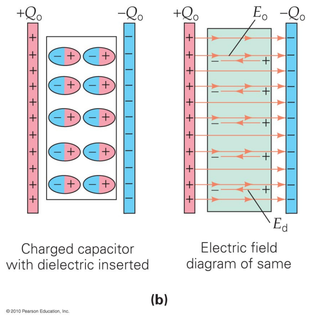
Dielectrics

- Dielectric: another word for insulator.



- A dielectric inside a capacitor increases the capacitor's energy storage by an amount characterized by the dielectric constant, k.

$$C = \frac{Q}{V} = \frac{Q_0}{\frac{V_0}{k}} \rightarrow$$

$$C = k\left(\frac{Q_0}{V_0}\right) \rightarrow$$

$$C = kC_0$$

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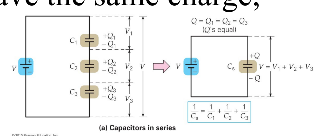
Capacitors in Series

- Capacitors in series all have the same charge;

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \ldots$$



- the total potential difference is the sum of the potentials across each capacitor.
  - this gives the inverse of the capacitance.
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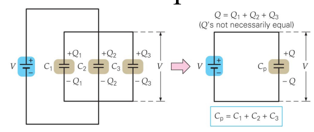
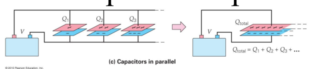
Capacitors connected in Parallel

- Capacitors in parallel all have the same potential difference;

  $C_p = C_1 + C_2 + C_3 + ...$ 

(b) Capacitors in parallel

- the total charge is the sum of the charge on each.
- We can picture capacitors in parallel as forming one capacitor with a larger area:

(c) Capacitors in parallel

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Summary I

- Electric potential difference between two points is the work done per unit charge in moving a charge between those two points.
- Equipotential surfaces are surfaces on which the electric potential is constant.
- Electric potential for a point charge:

  $$V = \frac{kq}{r}$$

- Electric potential energy for a pair of point charges:

  $$U_{12} = \frac{kq_1q_2}{r_{12}}$$

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Summary II

- Electric potential energy for an array of point charges:

  $U_{total} = U_{12} + U_{13} + U_{23} + ...$
- The electric field is in the direction of maximum change of the electron potential. Its Magnitude:

  $$E = \left(\frac{\Delta V}{\Delta x}\right)_{max}$$

- A capacitor consists of two metallic plates; capacitors store electric energy. Capacitance:

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

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Sample Problem

- $$K = \Delta U = q \Delta V = \left(1.60 \cdot 10^{-19} C\right) \cdot \left(10^{6} V\right)$$
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Classroom TASK

- $Q = CV \rightarrow$ doubling V ...
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Sample Problem

- $$d \rightarrow d_2 = 3d, \quad \text{then}$$
  $$C \rightarrow C_2 = \varepsilon_0 \cdot \frac{A}{d'}$$
  $$C_2 = \varepsilon_0 \cdot \frac{A}{3 \cdot d} = \frac{C}{3}$$
  $$Q = \frac{C}{V} \text{ since } V \text{ is constant } \rightarrow$$
  $$Q = \frac{Q_2}{3}$$
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Sample Problem

- $$W_{elec} = -U_t = -k\frac{q_1 \cdot q_2}{r} = \frac{k \cdot q^2}{r} \rightarrow$$
  $$q = \sqrt{\frac{W \cdot r}{k}}$$
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Sample Problem

- $$E = \frac{\Delta V}{\Delta x} \rightarrow \Delta x$$
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Sample Problem

- For a point charge q, the potential is
  $$V = k\frac{q}{r}, V = \frac{kq}{r} \rightarrow q$$
  q is positive because the potential is positive relative to infinity
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