Chapter 25

Electric Potential

Electrical Potential Energy

- When a test charge is placed in an electric field, it experiences a force
  - $\mathbf{F} = q_o\mathbf{E}$
- The force is conservative
- $d\mathbf{s}$ is an infinitesimal displacement vector that is oriented tangent to a path through space

Electric Potential Energy, cont

- The work done by the electric field is $\mathbf{F}\cdot d\mathbf{s} = q_o\mathbf{E}\cdot d\mathbf{s}$
- As this work is done by the field, the potential energy of the charge-field system is changed by $\Delta U = -q_o\mathbf{E}\cdot d\mathbf{s}$
- For a finite displacement of the charge from A to B,

$$\Delta U = U_B - U_A = -q_o \int_A^B \mathbf{E} \cdot d\mathbf{s}$$

Electric Potential Energy, final

- Because $q_o\mathbf{E}$ is conservative, the line integral does not depend on the path taken by the charge
- This is the change in potential energy of the system

Electric Potential

- The potential energy per unit charge, U/q_o, is the **electric potential**
  - The potential is independent of the value of q_o
  - The potential has a value at every point in an electric field
- The electric potential is $V = \frac{U}{q_o}$

Electric Potential, cont.

- The potential is a scalar quantity
  - Since energy is a scalar
- As a charged particle moves in an electric field, it will experience a change in potential

$$\Delta V = \frac{\Delta U}{q_o} = -\int_A^B \mathbf{E} \cdot d\mathbf{s}$$

Electric Potential, final

- The *difference* in potential is the meaningful quantity
- We often take the value of the potential to be zero at some convenient point in the field
- Electric potential is a scalar characteristic of an electric field, independent of any charges that may be placed in the field

Work and Electric Potential

- Assume a charge moves in an electric field without any change in its kinetic energy
- The work performed on the charge is

$$W = \Delta V = q\,\Delta V$$

Units

- 1 V = 1 J/C
  - V is a volt
  - It takes one joule of work to move a 1-coulomb charge through a potential difference of 1 volt
- In addition, 1 N/C = 1 V/m
  - This indicates we can interpret the electric field as a measure of the rate of change with position of the electric potential

Electron-Volts

- Another unit of energy that is commonly used in atomic and nuclear physics is the electron-volt
- One ***electron-volt*** is defined as the energy a charge-field system gains or loses when a charge of magnitude *e* (an electron or a proton) is moved through a potential difference of 1 volt
  - 1 eV = 1.60×10^{-19} J

Potential Difference in a Uniform Field

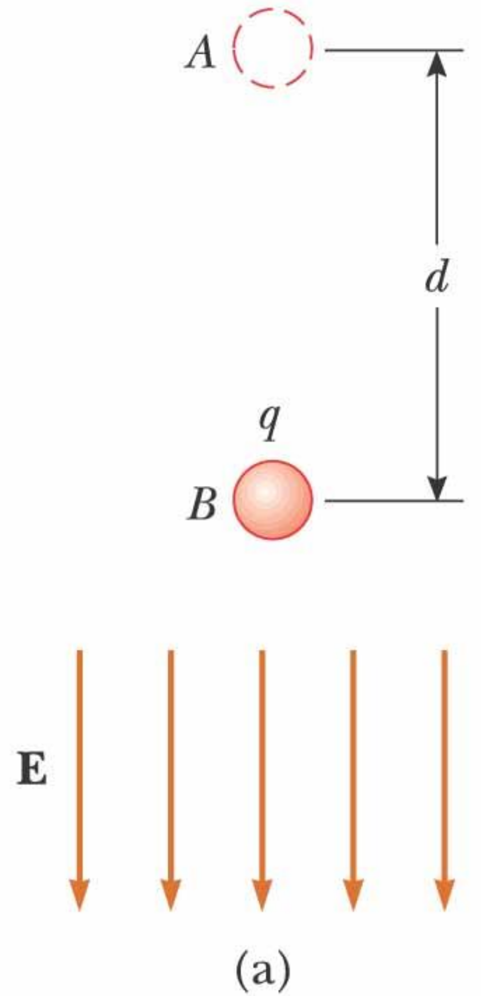
- The equations for electric potential can be simplified if the electric field is uniform:

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

- The negative sign indicates that the electric potential at point *B* is lower than at point *A*

Energy and the Direction of Electric Field

- When the electric field is directed downward, point *B* is at a lower potential than point *A*
- When a positive test charge moves from *A* to *B*, the charge-field system loses potential energy



More About Directions

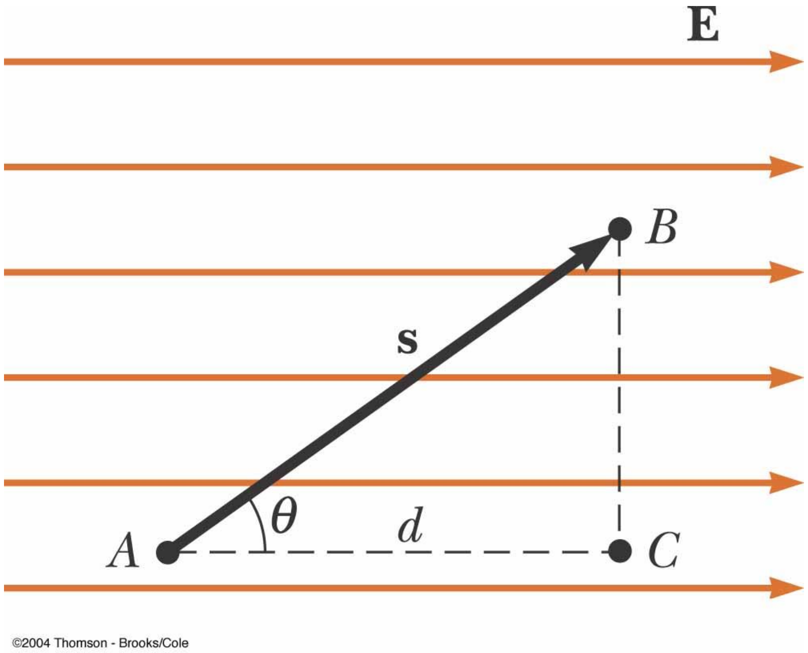
- A system consisting of a positive charge and an electric field **loses** electric potential energy when the charge moves in the direction of the field
  - An electric field does work on a positive charge when the charge moves in the direction of the electric field
- The charged particle gains kinetic energy equal to the potential energy lost by the charge-field system
  - Another example of Conservation of Energy

Directions, cont.

- If q_o is negative, then ΔU is positive
- A system consisting of a negative charge and an electric field *gains* potential energy when the charge moves in the direction of the field
  - In order for a negative charge to move in the direction of the field, an external agent must do positive work on the charge

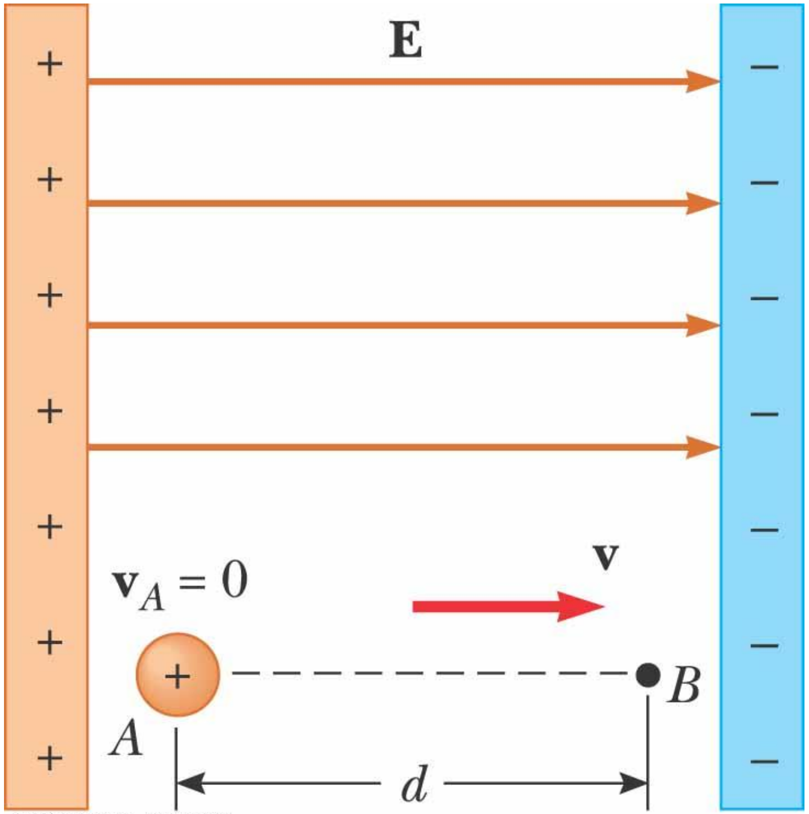
Equipotentials

- Point *B* is at a lower potential than point *A*
- Points *A* and *C* are at the same potential
- The name **equipotential surface** is given to any surface consisting of a continuous distribution of points having the same electric potential



Charged Particle in a Uniform Field, Example

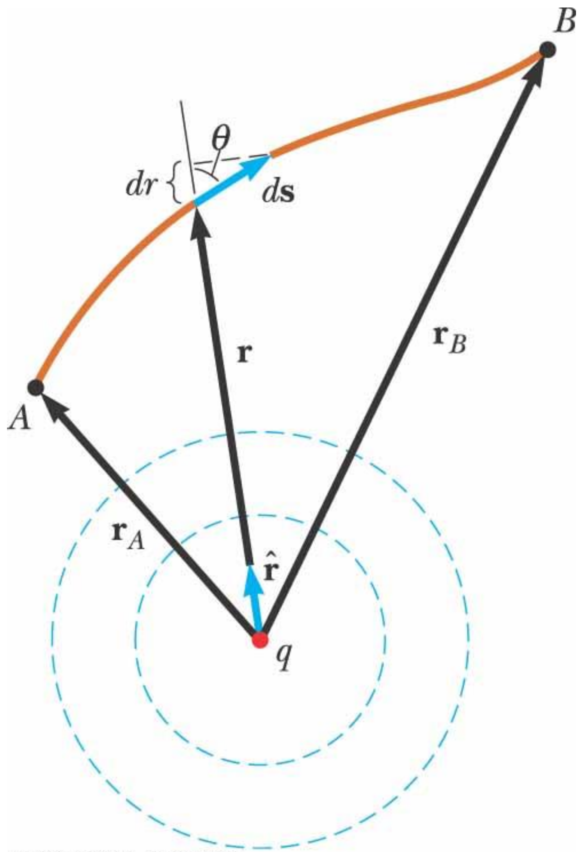
- A positive charge is released from rest and moves in the direction of the electric field
- The change in potential is negative
- The change in potential energy is negative
- The force and acceleration are in the direction of the field



Potential and Point Charges

- A positive point charge produces a field directed radially outward
- The potential difference between points *A* and *B* will be

$$V_B - V_A = k_e q \left[\frac{1}{r_B} - \frac{1}{r_A} \right]$$



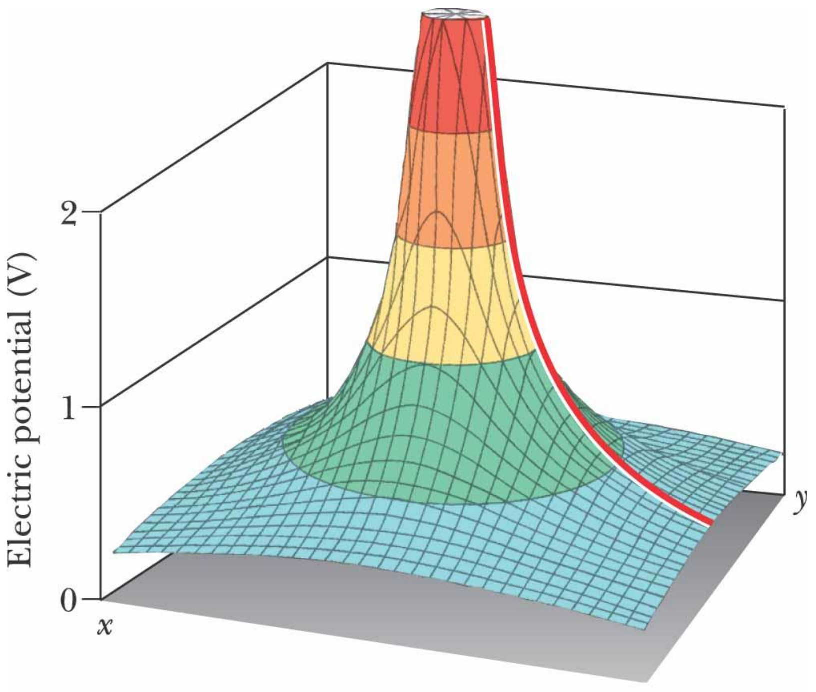
Potential and Point Charges, cont.

- The electric potential is independent of the path between points *A* and *B*
- It is customary to choose a reference potential of $V = 0$ at $r_A = \infty$
- Then the potential at some point *r* is

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

Electric Potential of a Point Charge

- The electric potential in the plane around a single point charge is shown
- The red line shows the 1/*r* nature of the potential



Electric Potential with Multiple Charges

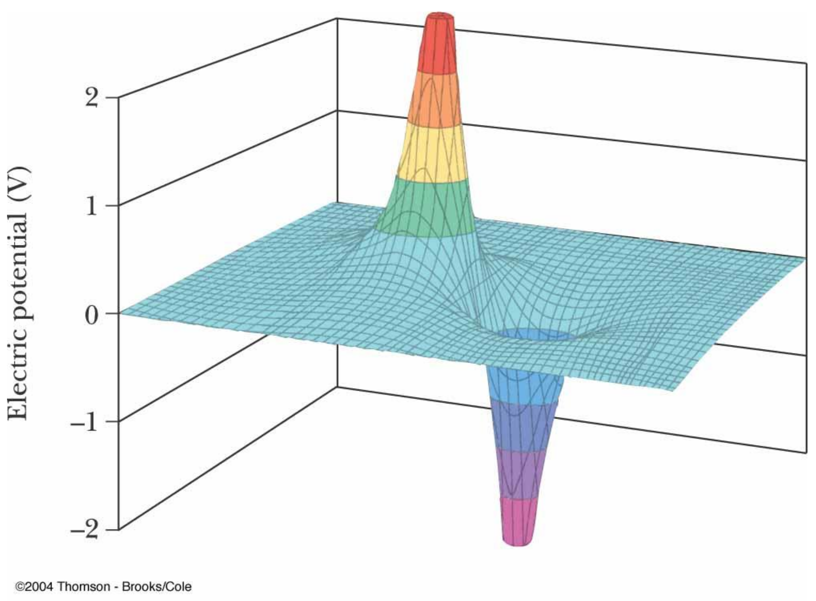
- The electric potential due to several point charges is the sum of the potentials due to each individual charge
  - This is another example of the superposition principle
  - The sum is the algebraic sum

$$V = k_e \sum_i \frac{q_i}{r_i}$$

  - $V = 0$ at $r = \infty$

Electric Potential of a Dipole

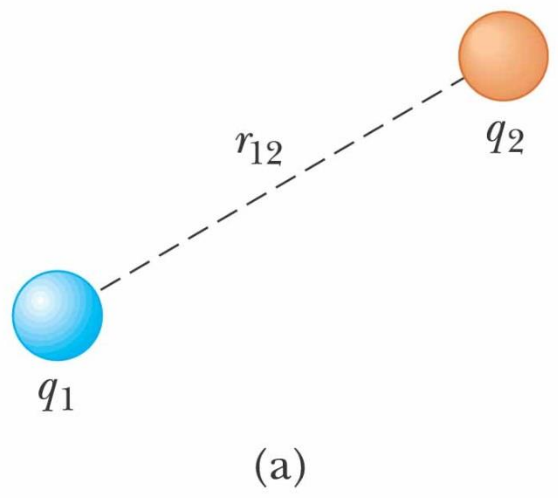
- The graph shows the potential (y-axis) of an electric dipole
- The steep slope between the charges represents the strong electric field in this region



Potential Energy of Multiple Charges

- Consider two charged particles
- The potential energy of the system is

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



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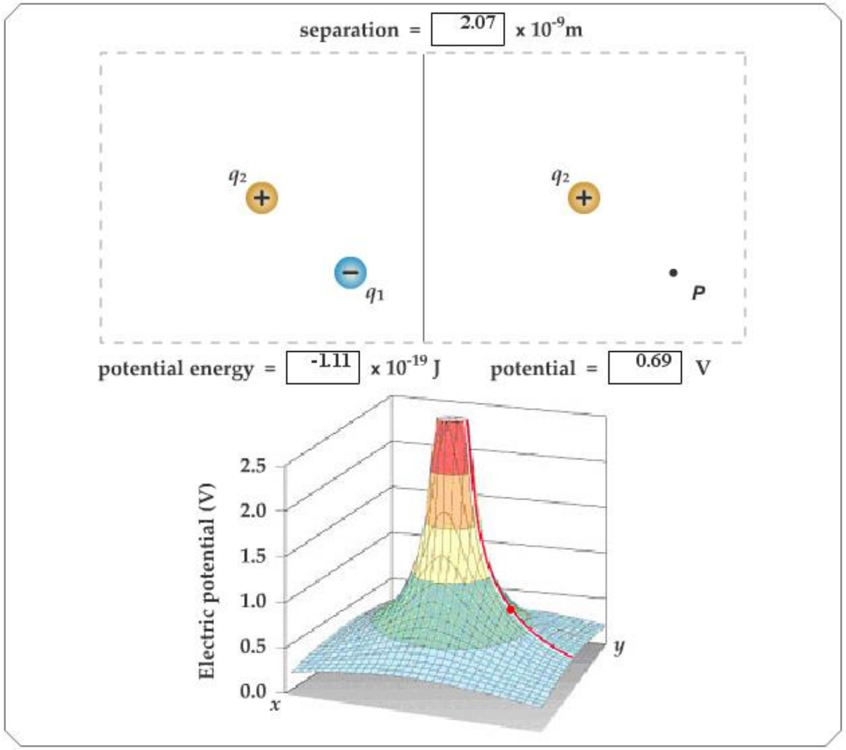

PLAY ANIMATION

(SLIDESHOW MODE ONLY)

More About *U* of Multiple Charges

- If the two charges are the same sign, U is positive and work must be done to bring the charges together
- If the two charges have opposite signs, U is negative and work is done to keep the charges apart

U with Multiple Charges, final

- If there are more than two charges, then find *U* for each pair of charges and add them
- For three charges:

$$U = k_e\left(\frac{q_1q_2}{r_{12}} + \frac{q_1q_3}{r_{13}} + \frac{q_2q_3}{r_{23}}\right)$$

  - The result is independent of the order of the charges