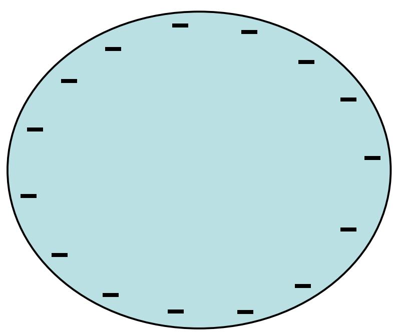
19.11:Conductors in Electrostatic Equilibrium

Like charges repel and can move freely along the surface.

In electrostatic equilibrium, charges are not moving

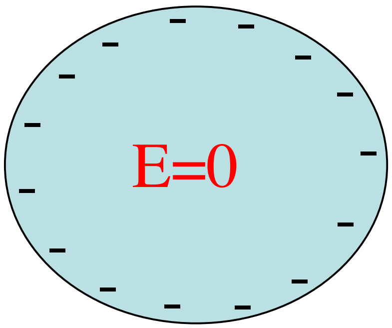
4 key properties:

1: Charge resides entirely on its surface (like charges move as far apart as possible)

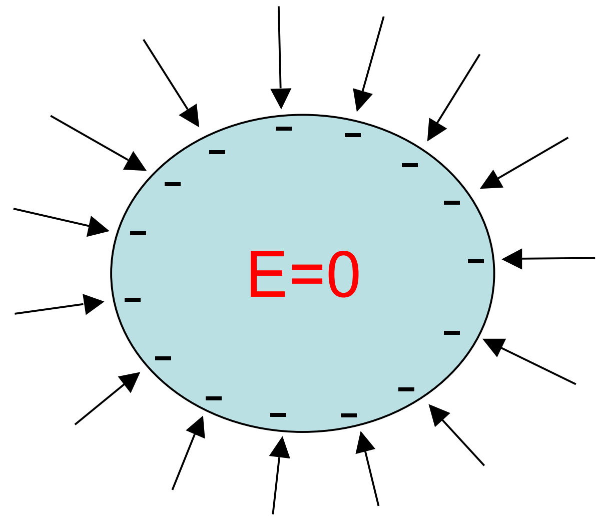


2: Inside a conductor, E-field is zero

(if there are charges, an E-field is established, and other charges would move, and conductor wouldn't be at equilibrium)

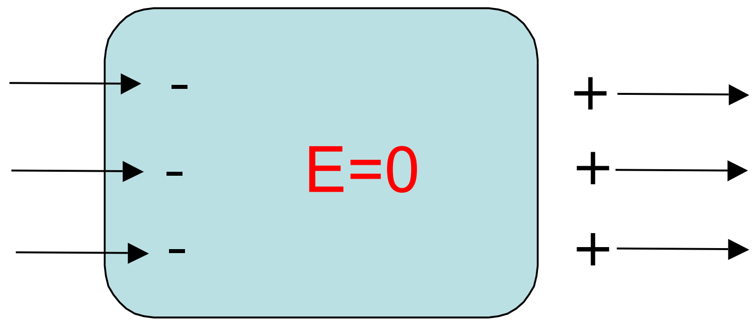


2: Inside a conductor, E-field is zero



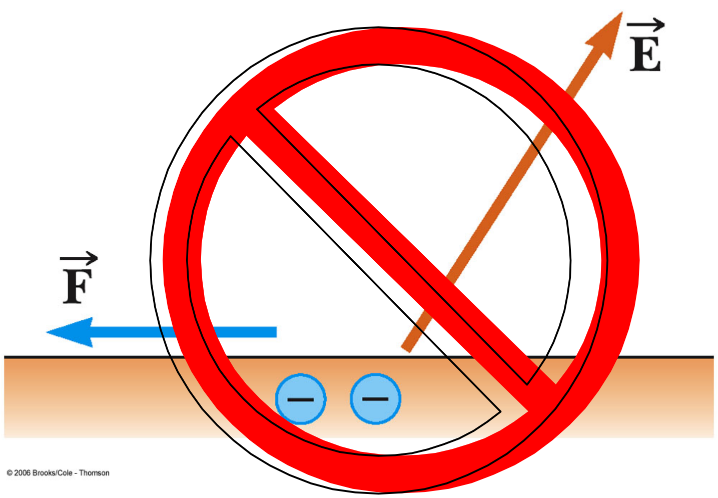
True for a conductor with excess charge

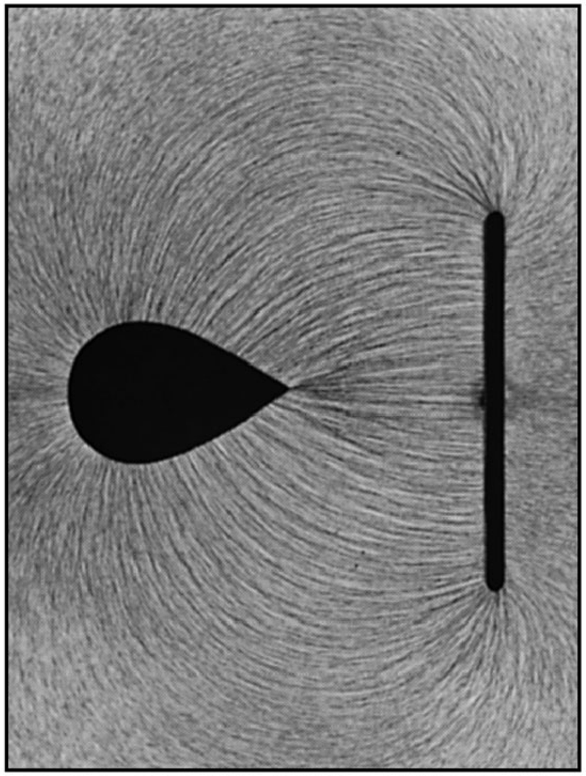
And for a conductor in an external E-field:



3: E-field just outside the conductor is perpendicular to its surface

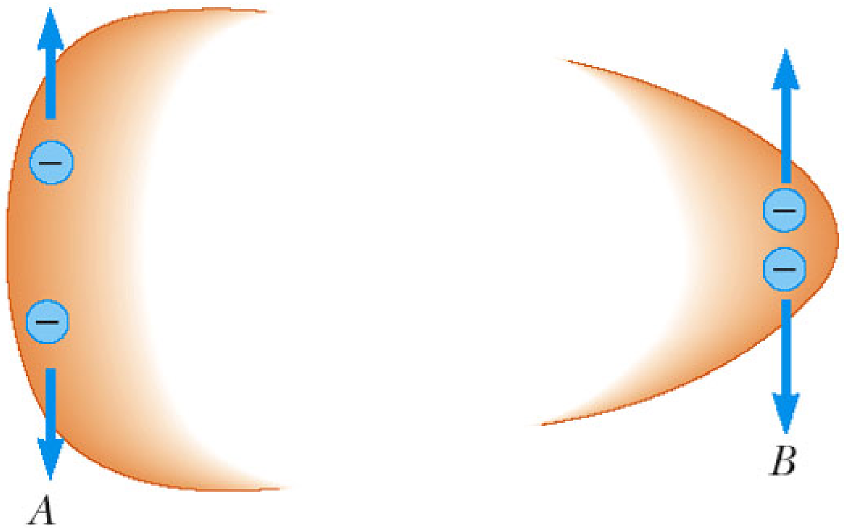
Any non-perpendicular component would cause charges to migrate, thereby disrupting equilibrium





4: Charges accumulate at sharp points (smallest radius of curvature)

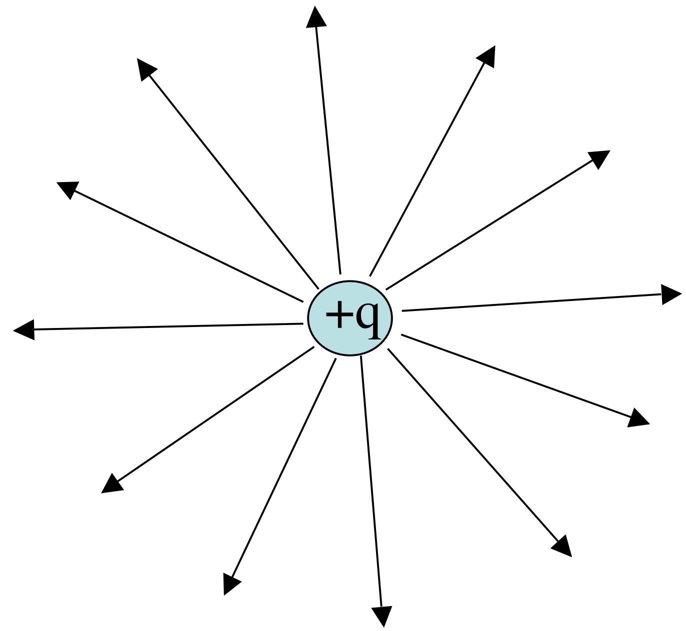
Here, repulsive forces are directed more away from surface, so more charges per unit area can accumulate



Conductors in Electrostatic Equilibrium

Suppose you had a point charge +q. You surround the charge with a conducting spherical shell.

What happens?

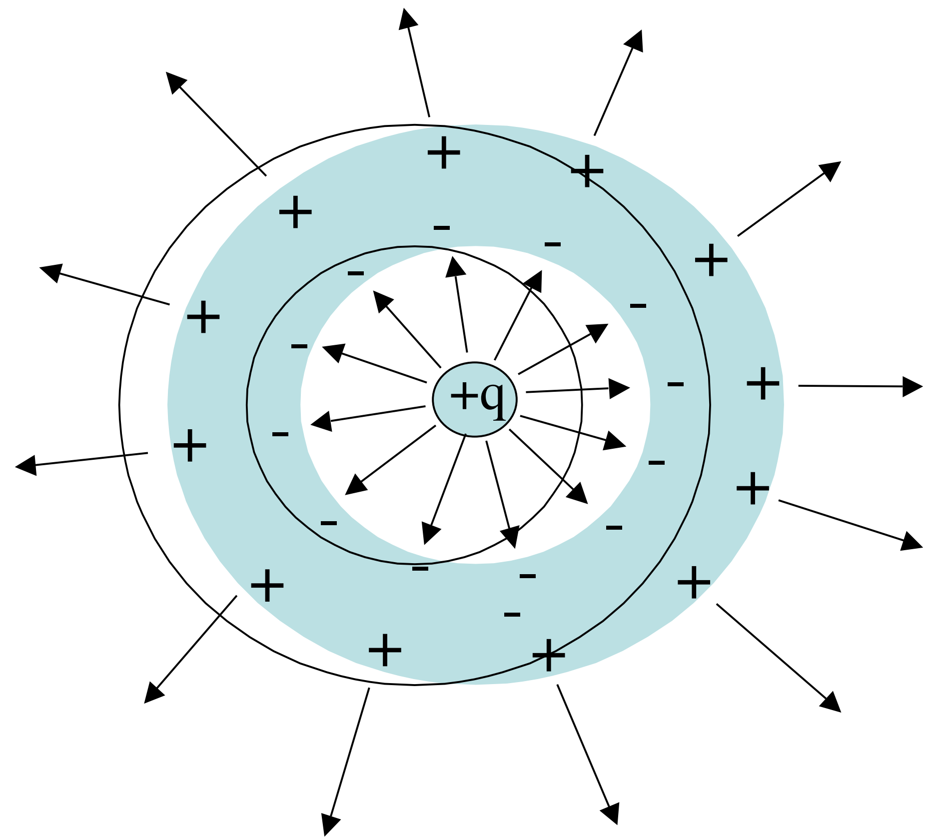


Conductors in Electrostatic Equilibrium

-'s accumulate on inner surface. +'s accumulate on outer surface

E-field within conductor is zero

From very far away, field lines look exactly as they did before

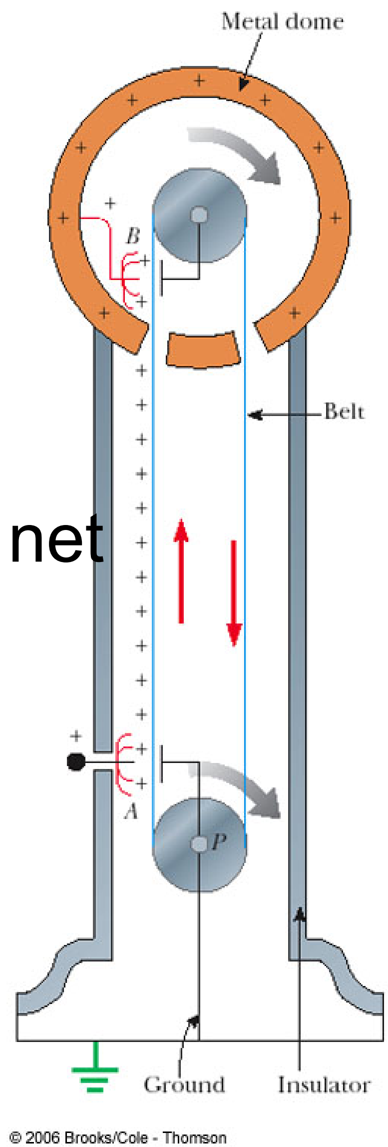


Van de graff Generators

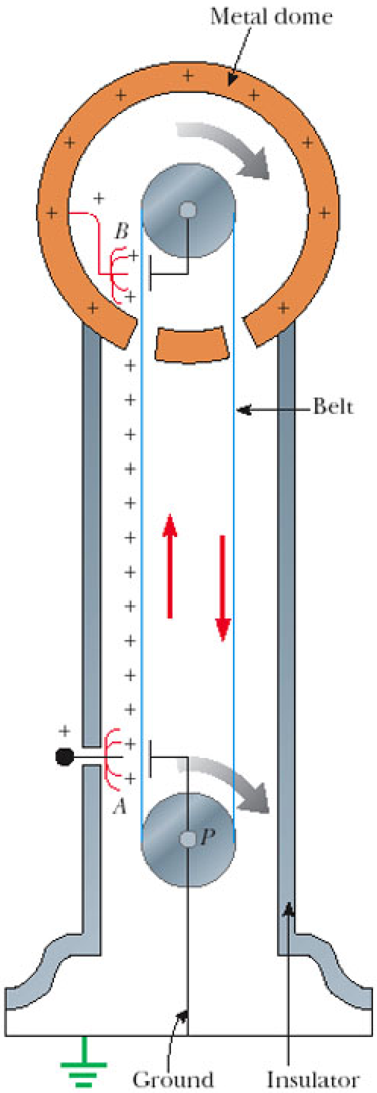
Positive charges transferred to conducting dome, accumulate, spread out

Left side of belt has net positive charge

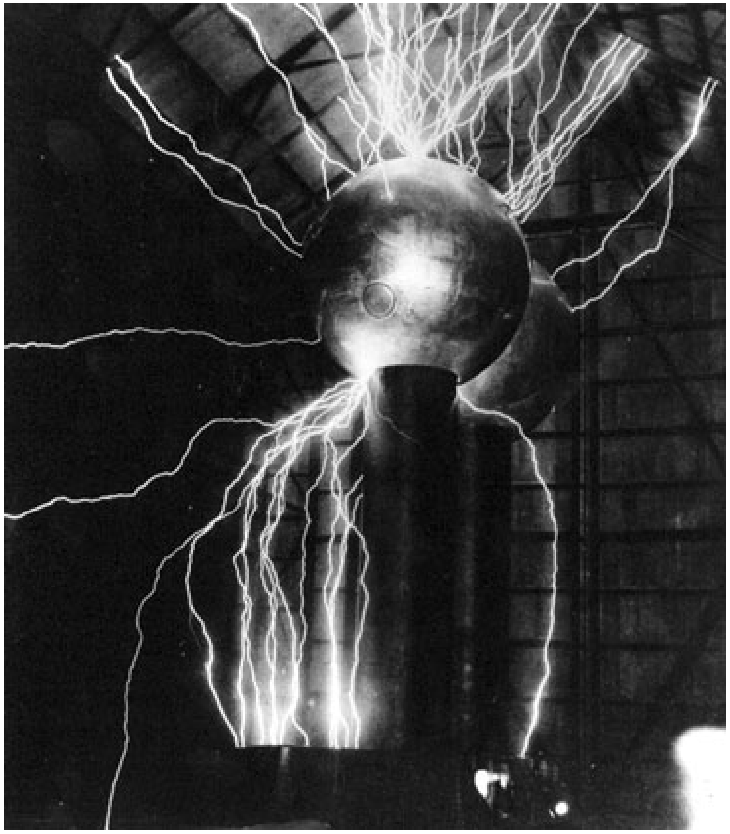
Positively-charged needles in contact w/ belt: pulls over e^{-}'s



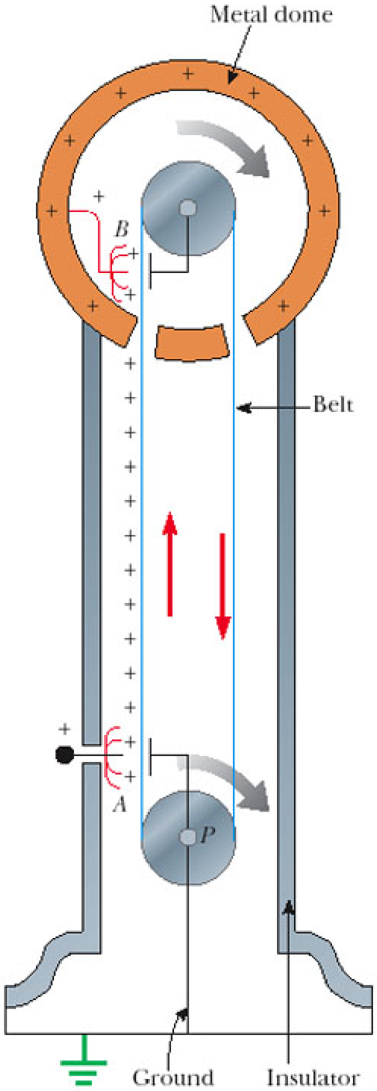
Positive charges transferred to conducting dome, accumulate, spread out



E-field eventually gets high enough to ionize air & increase its conductivity-- get mini-lightning bolts



Boston Museum of Science / M.I.T.



VdG generator at Boston Museum of Science
(largest air-insulating VdG in the world):
lightning travels along outside of operator's conducting cage:
http://www.youtube.com/watch?v=PT_MJotkMd8
(fast forward to ~1:10)

Another example of a Faraday cage:
(Tesla coil, not VdG generator, used to generate the lightning):
http://www.youtube.com/watch?v=Zi4kXgDBFhw

More Boston Museum of Science VdG demonstrations
http://www.youtube.com/watch?v=TTPBDkbiTSY
http://www.youtube.com/watch?v=rzbEPcD-DKM

Ch 20: Electric Energy, Potential & Capacitance

Electrical potential energy corresponding to Coulomb force (e.g., assoc. with distributions of charges)

Electric Potential = P.E. per unit charge

Introduction to Circuit Elements: Capacitors: devices for storing electrical energy

20.1 & 20.2:

Potential Energy U

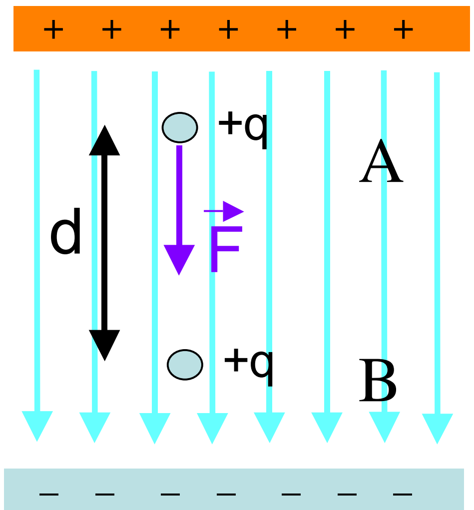
Potential Energy Difference ΔU

Potential V

Potential Difference ΔV

General Case and the simple case of a uniform E-field

Potential Energy of a system of charges



Potential Energy U (scalar):

ΔU = – Work done by the Electric field

= + work done by us / external agent

Recall that $\vec{\mathbf{F}} = q_o \vec{\mathbf{E}}$

Work done by field = $\vec{\mathbf{F}}_e \cdot d\vec{\mathbf{s}} = q_o \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$

When moving from A to B:

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

When $\vec{ds} \parallel \vec{E}$: $\Delta U = U_B - U_A = -W = -Fd = -qEd$

(units = J)

For a positive charge:

Work done by the E-field (to move a positive charge “downhill/downstream” closer to the negative plate) REDUCES the P.E. of the field-charge system

+W done by field = $-\Delta U$

If we supply work to move a positive charge “uphill/upstream” AGAINST an E-field (which points from + to -), the charge-field system gains P.E.

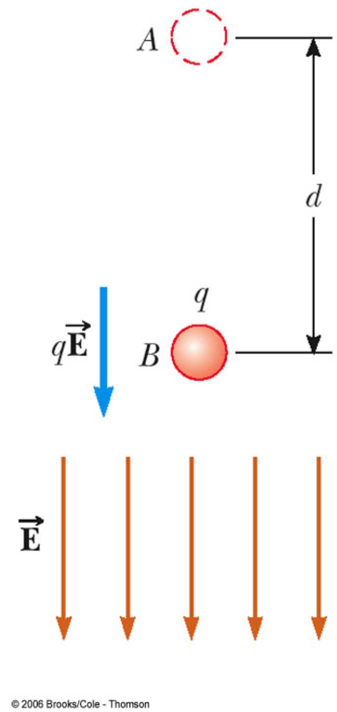
+W done by us = -work done by field = $+\Delta U$

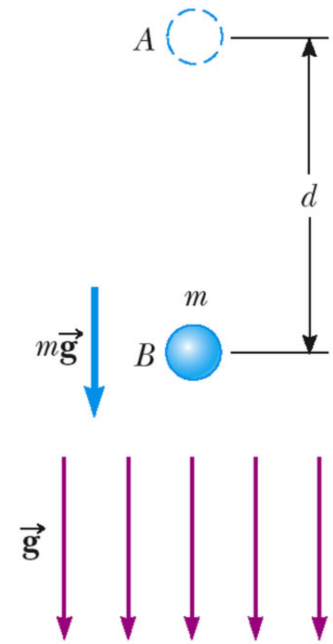
If the field moves a negative charge against an E-field (opposite to $\vec{E}$), the charge-field system loses potential energy (for an electron, that’s “downhill”)

Comparing Electric and Gravitational fields

Higher U→

Lower U→





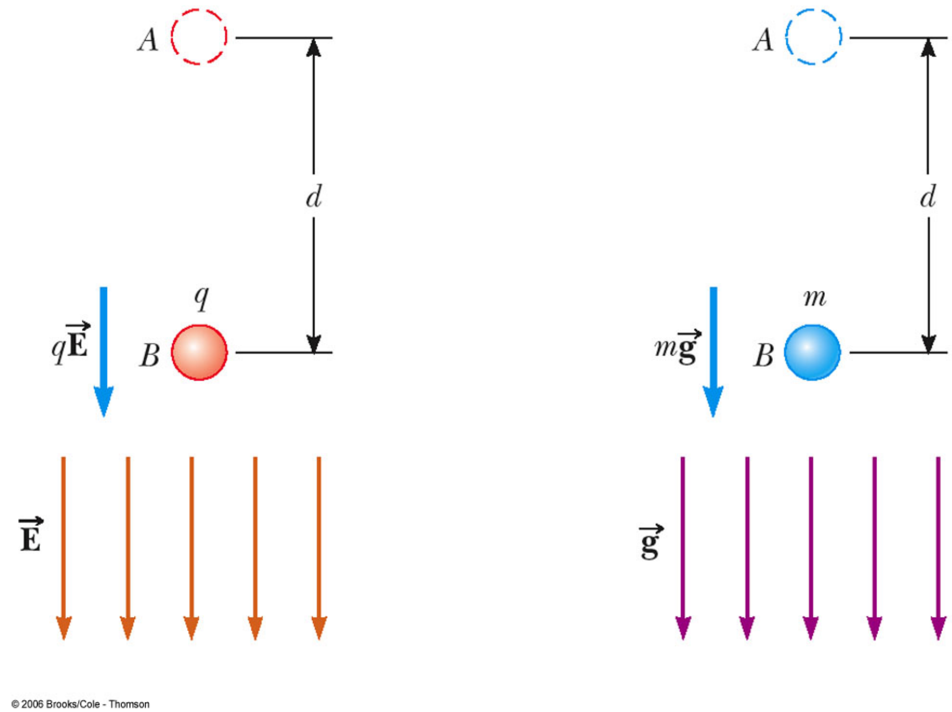
$\Delta U = -qEd$

$\Delta U = -mgd$

Comparing Electric and Gravitational fields

Higher U➜

Lower U➜



If released from rest (K=0) at point A, K when it reaches point B will be $-\Delta U$

$\Delta U = -qEd$

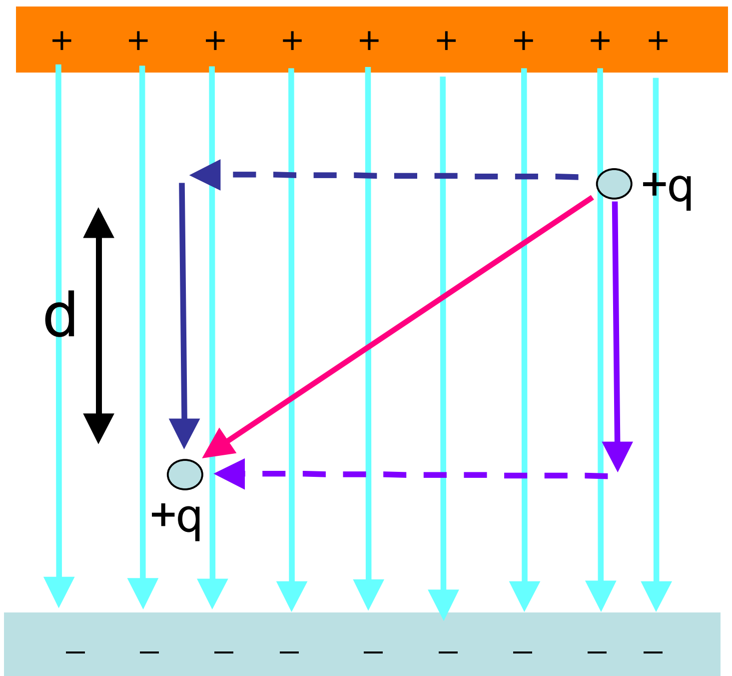
$\Delta U = -mgd$

$\Delta K + \Delta U = 0$

eV

- 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
  - $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$

Electric Force $q\vec{E}$ is conservative



$\Delta U = -qEd =$ independent of path chosen (depends only on end points)

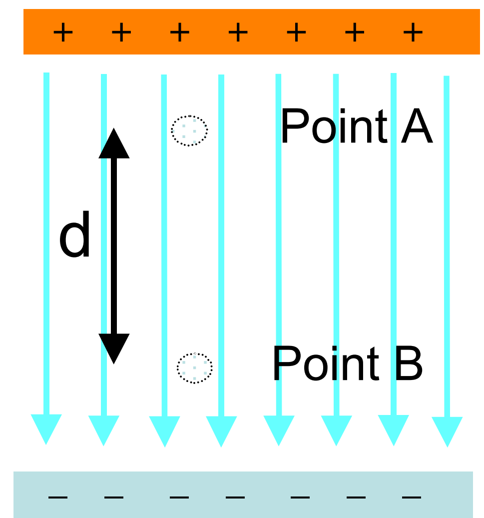
Electric Potential Difference, ΔV

$\Delta V = V_B - V_A = \Delta U / q$

Units: Joule/Coulomb = VOLT

Scalar quantity

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

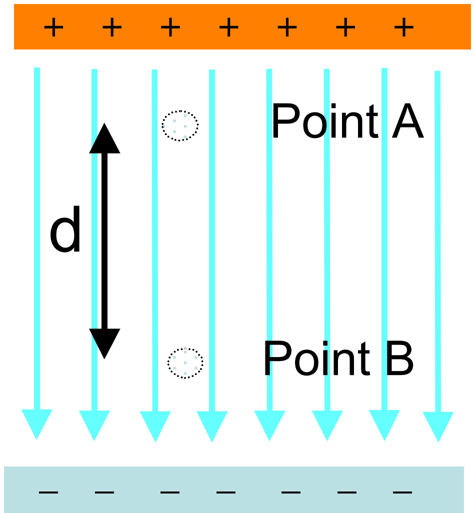


Electric Potential Difference, ΔV

$\Delta V = V_B - V_A = \Delta U / q$

Units: Joule/Coulomb = VOLT

Scalar quantity



Relation between ΔV and E:

For a uniform E-field: $\Delta V = -Ed$

E has units of V/m = N/C

(V / m = J / Cm = Nm / Cm = N / C)

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

V (absolute)

V usually taken to be 0 at some point, such as r=infinity

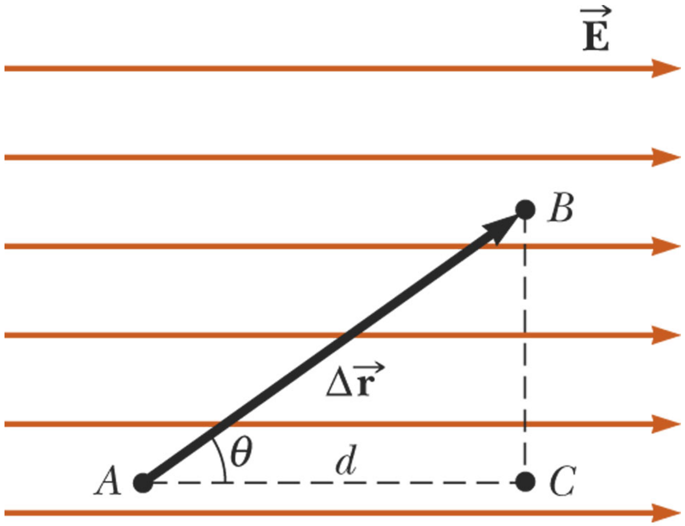
V at any point = (work required by us to bring in a test particle from infinity to that point) / (charge of test particle)

$$V = -\int_{\infty}^{P} \vec{E} \cdot d\vec{s}$$

$$U = \left(-\int_{\infty}^{P} \vec{E} \cdot d\vec{s}\right) q_0$$

Assuming the source charge is positive, we're moving against the E-field vectors (towards higher potential) as we move towards point P. $\vec{ds}$ and $\vec{E}$ are opposing, and their dot product is negative. So U ends up being a positive value.

More general case: When moving a charge along a path not parallel to field lines



Now consider the more general case of a charged particle moving between two points in a uniform electric field as in Figure 20.2. If $\Delta\vec{\mathbf{r}}$ represents the placement vector between points A and B, Equation 20.3 gives

$$\Delta V = -\int_A^B \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\vec{\mathbf{E}} \cdot \int_A^B d\vec{\mathbf{s}} = -\vec{\mathbf{E}} \cdot \Delta\vec{\mathbf{r}} \quad [20$$

where again we are able to remove $\vec{\mathbf{E}}$ from the integral because the electric field uniform. Furthermore, the change in electric potential energy of the charge–field system is

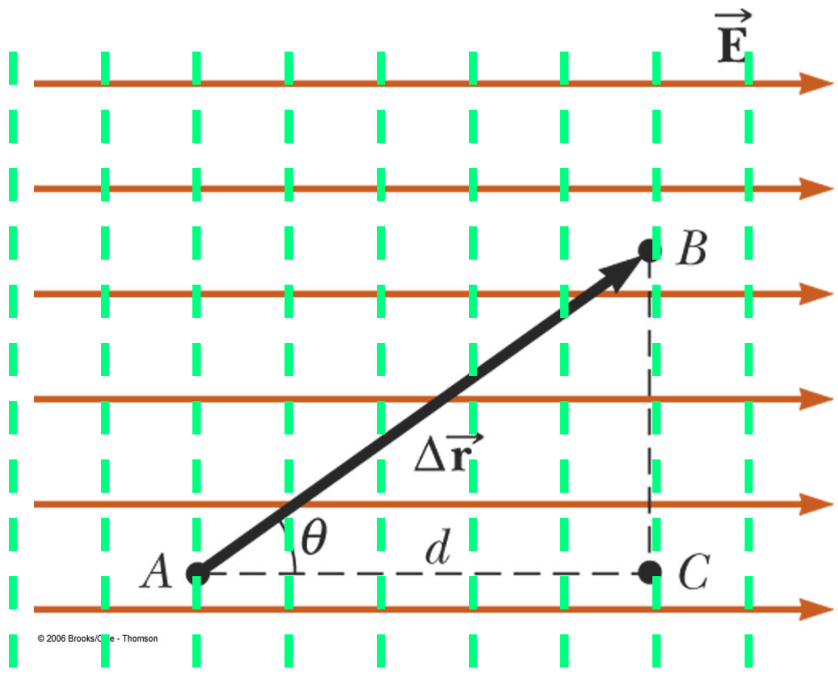
$$\Delta U = q_0 \Delta V = -q_0 \vec{\mathbf{E}} \cdot \Delta\vec{\mathbf{r}} \quad [20$$

Finally, our results show that all points in a plane *perpendicular* to a uniform electric field are at the same potential as can be seen in Figure 20.2, where the potential difference $V_B - V_A = -\vec{\mathbf{E}} \cdot \Delta\vec{\mathbf{r}} = -E\Delta r\cos\theta = -Ed = V_C - V_A$. Therefore, $V_B = V_C$. The name **equipotential surface** is given to any surface consisting

Points B and C are at identical potential

Equipotential surfaces: continuous distribution of points have the same electric potential

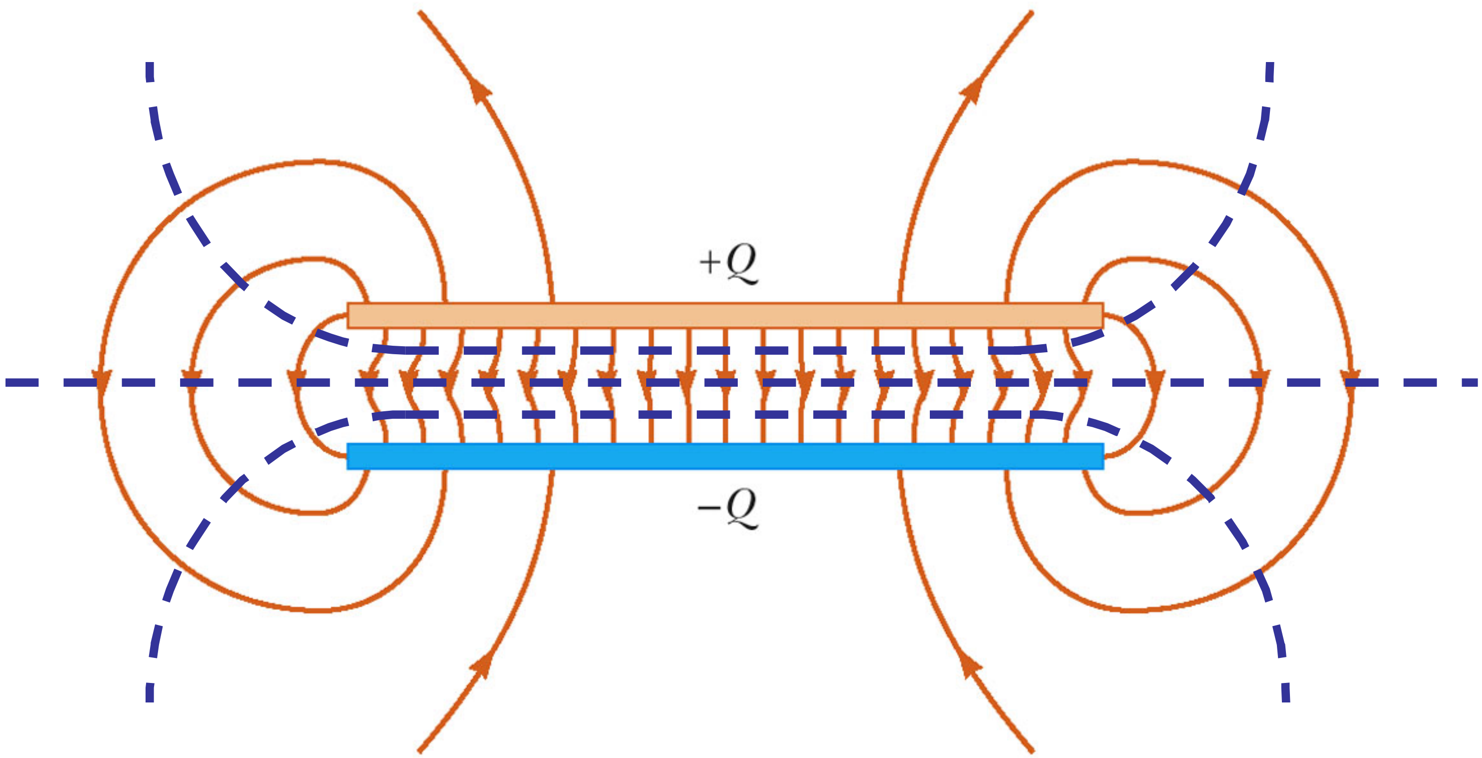
Equipotential surfaces are ⊥ to the E-field lines



Points B and C are at identical potential

2 Oppositely-Charged Planes

Equipotential surfaces are parallel to the planes and ⊥ to the E-field lines



Potential vs. Potential Energy

POTENTIAL: Property of space due to charges; depends only on location

Positive charges will accelerate towards regions of low potential.

POTENTIAL ENERGY: due to the interaction between the charge and the electric field