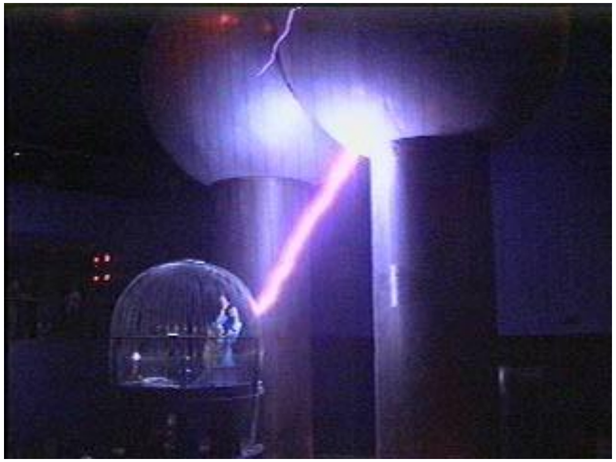
Electric Potential

Energy

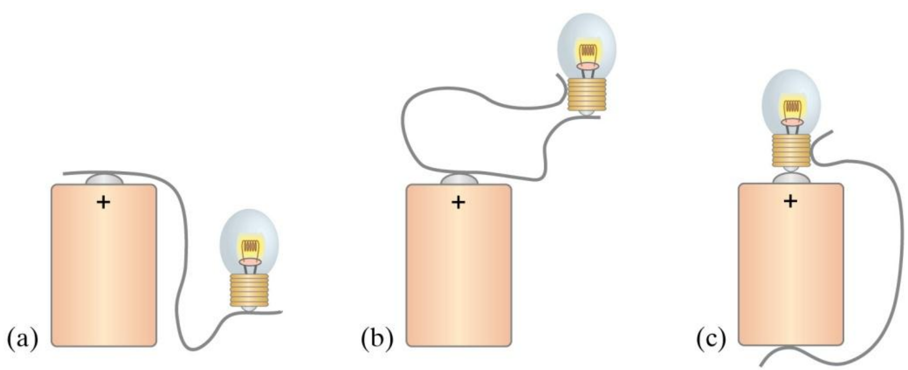
and



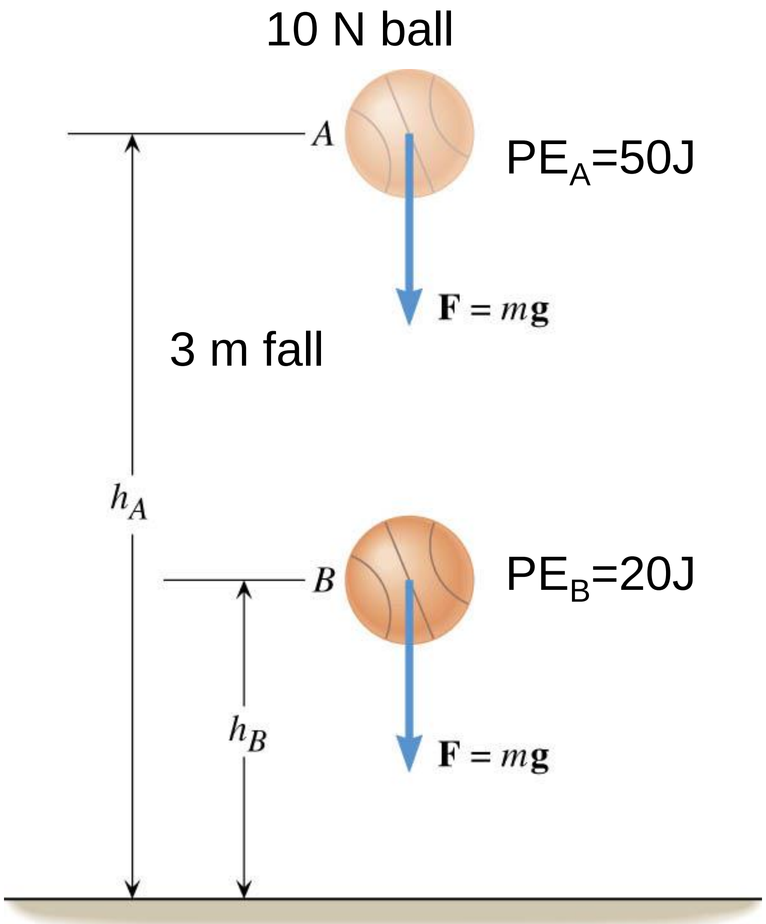
Chapter 17 Scalar Quantities

No directions but +/– are important

1) Work by electric field to move charge
2) Work changes the electric potential energy of the system
3) Electric potential based on potential energy
4) Potential difference between 2 points in field is driving force for charge flow



Work by gravitational field



ΔPE= 20 J – 50 J = – 30 J

Work $_{\text{by field}}$ = 10 N x 3 m = +30 J

Work $_{\text{by field}}$ = $-\Delta$PE

- gravitational PE is a property of a system of masses – Earth and ball

Gravitational PE similar to Electric PE

• Rocks gained PE when external force did work against gravity field to move then to height h.
$\text{Work}_{\text{field}} = -\Delta \text{PE}$

• Large rock has more PE than small rock

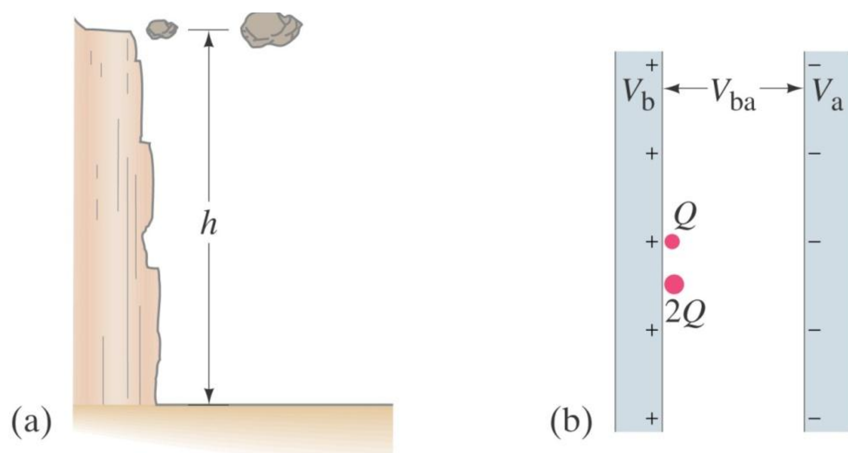
• height h is a measure of how much energy <u>any</u> rock would have

• h is the "gravitational potential" = a measure of how much energy a rock would have if placed there

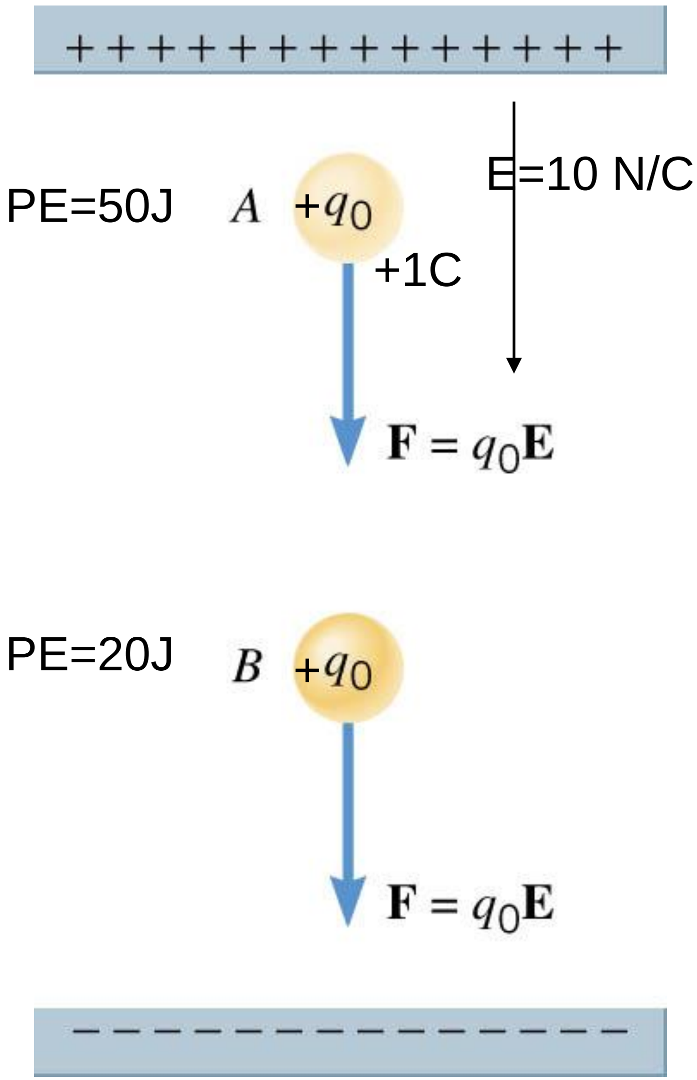
• + Charges gained PE when external force (battery) did work against electric field to move then to + plate

• 2Q has twice the PE as Q

• V is electric potential = a measure of how much energy <u>any</u> charge would have at that point in field



Work by Electric Field



$\Delta PE = 20\text{ J} - 50\text{ J} = -30\text{ J}$

$Work_{\text{by field}} = F \bullet d = qE \bullet d$

$Work_{\text{by field}} = 10\text{ N/C} \times 1\text{ C} \times 3\text{ m} = +30\text{ J}$

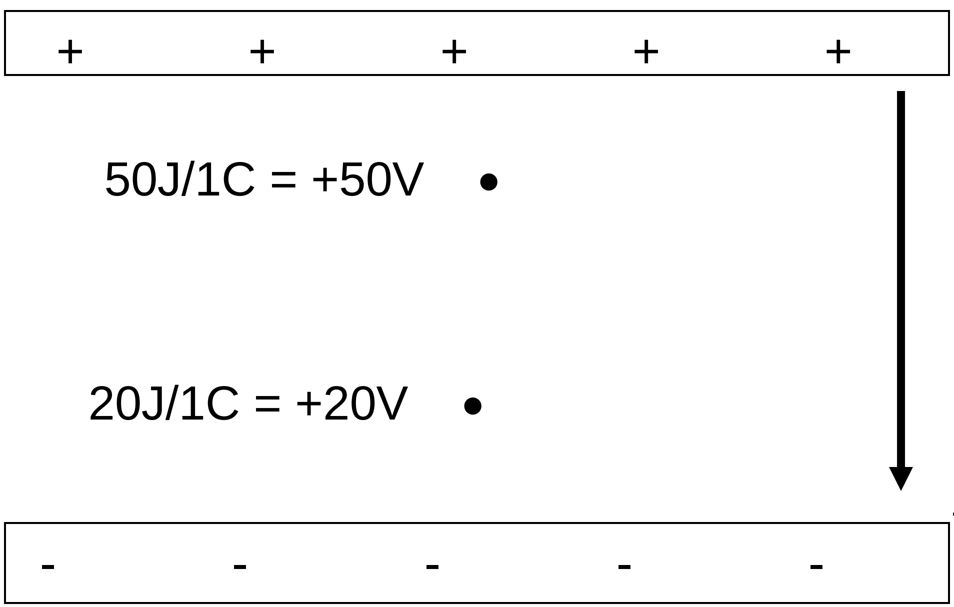
$Work_{\text{by field}} = -\Delta PE$

- For the + charge to have PE the charged plates must be present to create field
- PE is a property of a system
  - charge must be present in field for there to be PE

Electric Potential

- Need to define a property of the field that is energy related but does not require a charge to be present in the field
- Electric Potential

$$V = \frac{PE}{q} \qquad \frac{1\,Joule}{1\,Coulomb} = 1\,\text{Volt}$$

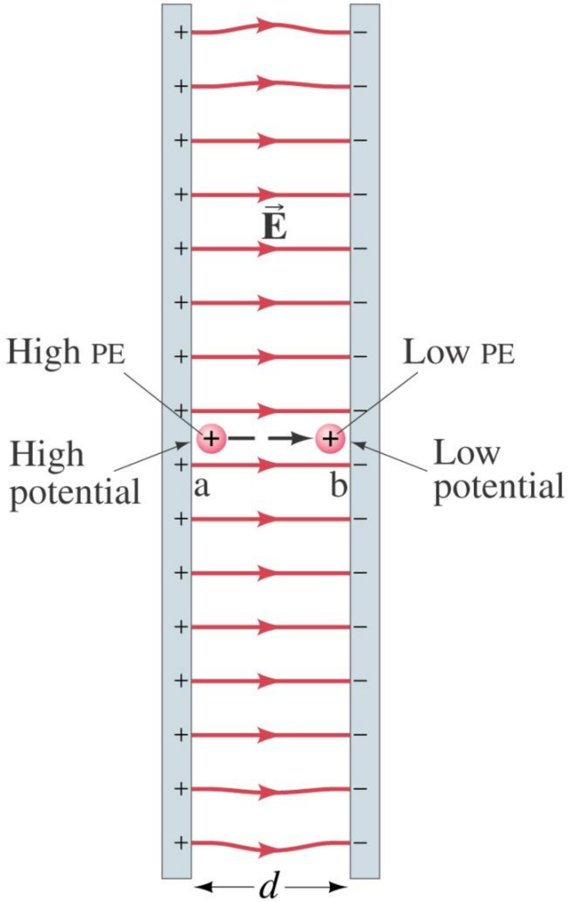


Electric field vector always points from points of higher potential to lower potential in an electric field

Even though E is constant at all points V will decrease from + to – plate

Easy way to think of V is in terms of PE

- + charge will move from high V to low V just as a ball will roll from high PE to low PE down a hill



Conservation of energy

- Total energy stays constant
- As +q moves from a to b it loses PE and gains KE

Potential Difference

$$\Delta V = V_b - V_a = \frac{PE_b}{q} - \frac{PE_a}{q} = \frac{\Delta PE}{q}$$

$$\text{since } Work_{byfield} = -\Delta PE \quad \text{then } \Delta V = \frac{-Work_{byfield}}{q}$$

$$Work_{byfield} = -(q)(\Delta V)$$

must use the +/- sign of q to get correct sign of work done

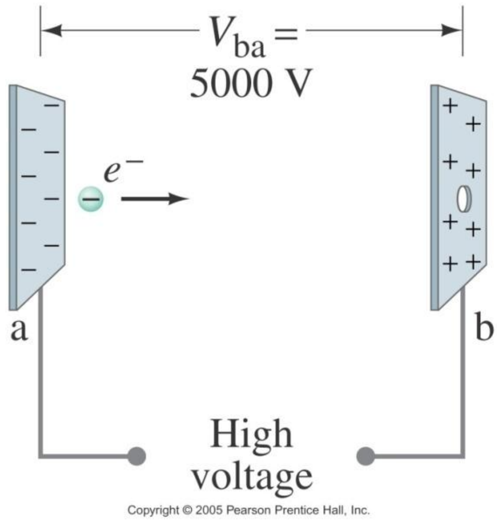
This is a <u>very</u> useful relationship since Work = Δ KE it allows you to calculate KE gain when q moves through a ΔV

17.4 The Electron Volt, a Unit of Energy

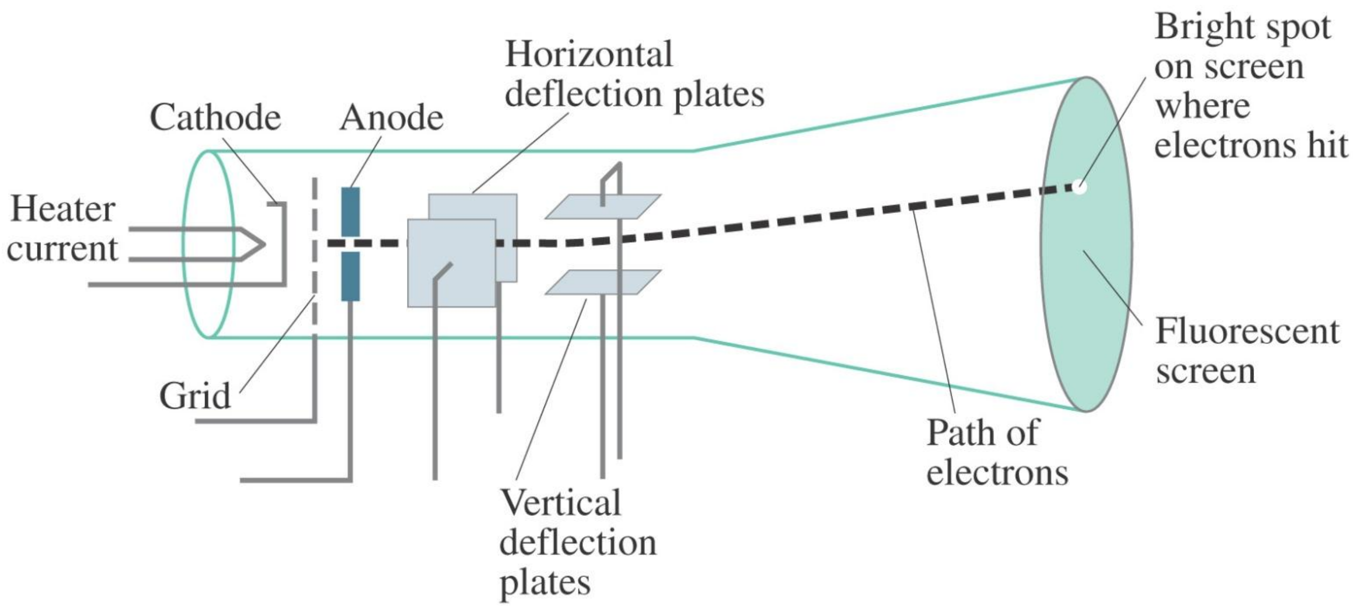
One electron volt (eV) is the energy gained by an electron moving through a potential difference of one volt.

$$Work_{byfield} = \Delta KE = -\Delta PE = -q\bullet\Delta V$$

$$= -(-e\bullet\Delta V) = -(-1.6x10^{-19}C \times 1J/C) = 1.6x10^{-19}J$$

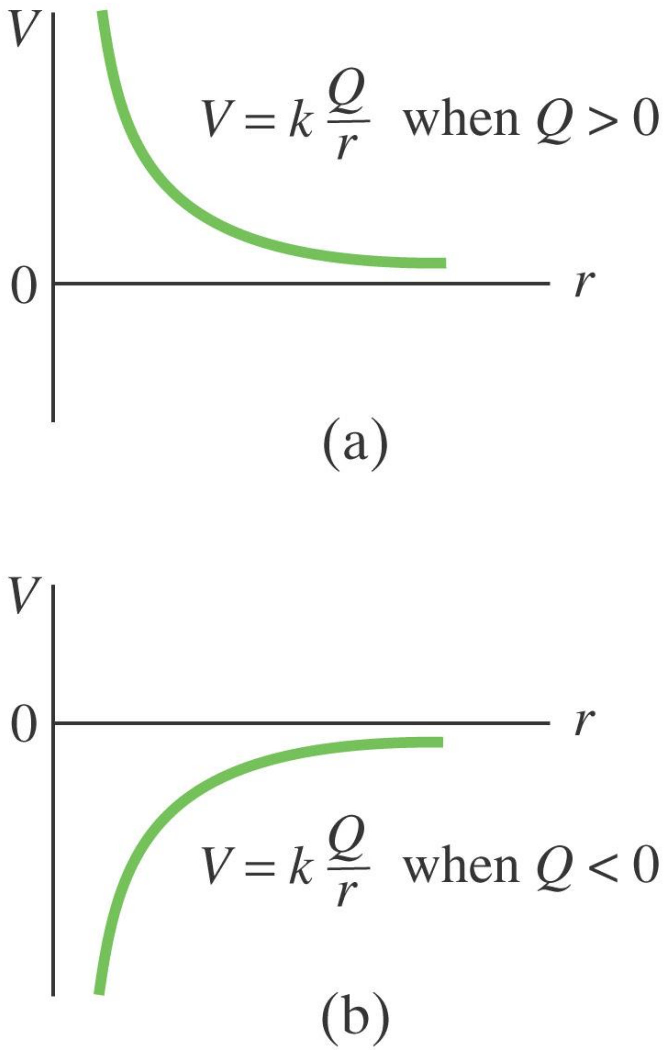


$\frac{1}{2}mv^2 = q\bullet\Delta V = 5000\, eV's$ of KE when accelerated between plates


Horizontal
deflection plates
Cathode
Anode
Bright spot
on screen
where
electrons hit
Heater
current
Grid
Fluorescent
screen
Path of
electrons
Vertical
deflection
plates

CRT demo

17.5 Electric Potential Due to Point Charges



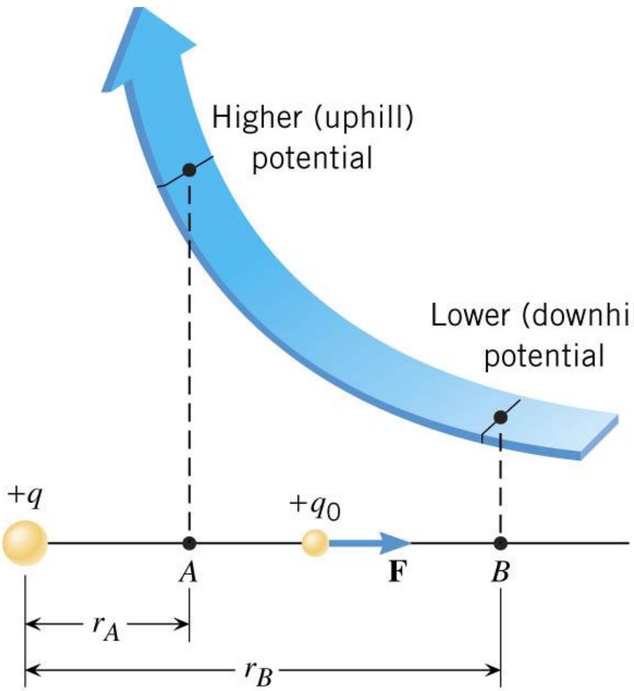
Must keep the sign of the point charge Q creating the region of potential in the calculation

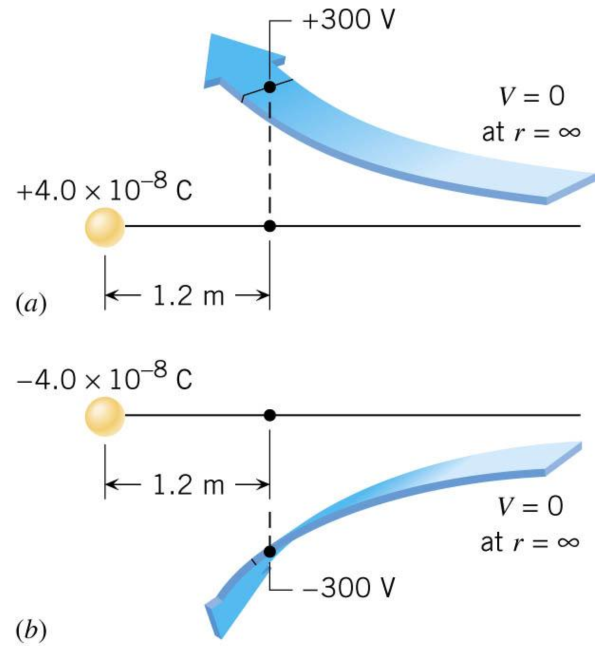
+ Q creates + V

– Q creates – V

V vs r is inverse relationship

All definitions based on + charge





+ charge gains PE closer to +Q

+ charge loses PE closer to –Q

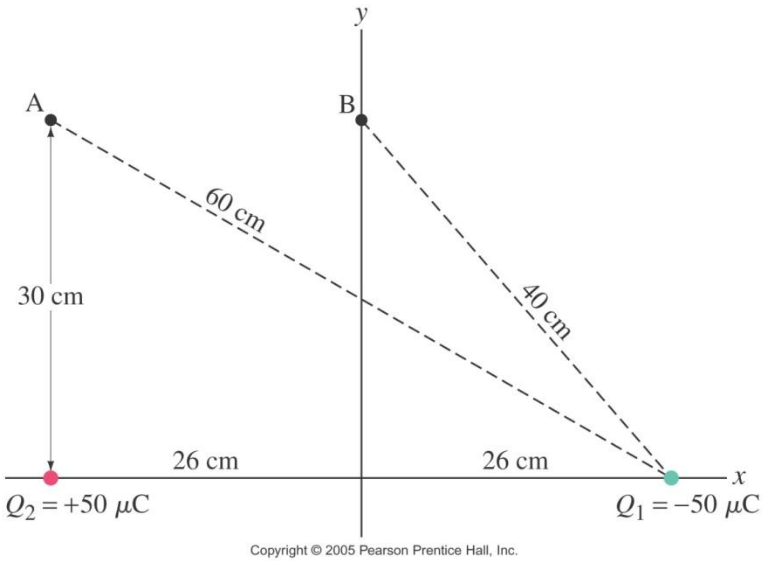
$$V = \frac{kQ}{r}$$

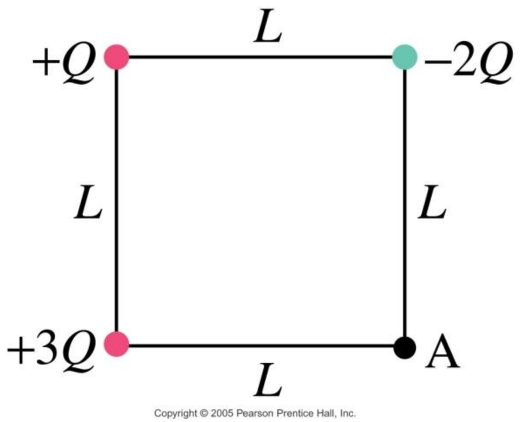
sign of Q determines if V is + or –

Potential due to multiple point charges

Scalar not vector sum – must keep +/– signs in calculations

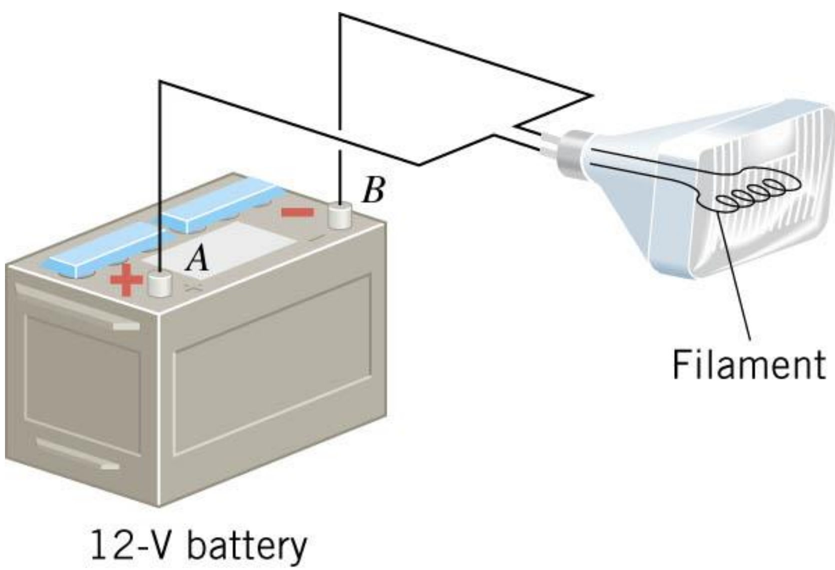
$$V_{total} = \sum_{i=1}^{n} \frac{kQ_i}{r_i}$$



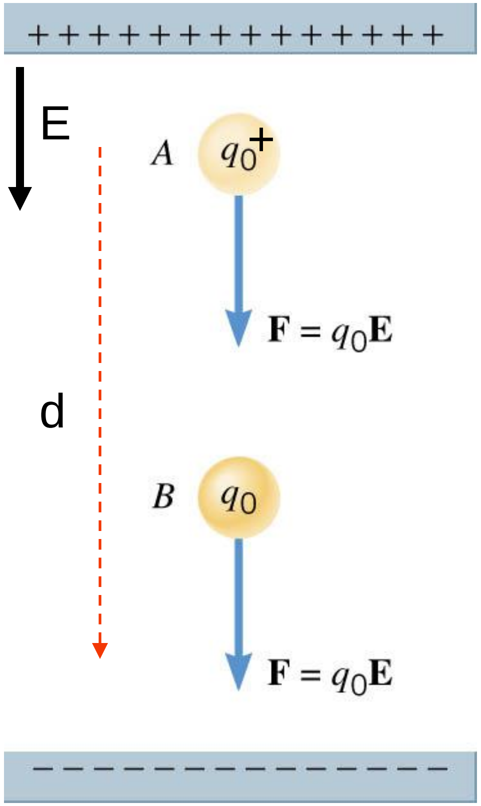


Electric Potential Difference

- Potential difference ΔV "voltage"
  + charges will move through a potential difference from higher V (+ terminal of battery) to lower V (– terminal of battery) just as a ball rolls from higher to lower elevation down a hill



Electric Field & Potential



Work $_{\text{by field}}$ $= -(q_0)(\Delta V)$

Force x distance$= -(q_0)(\Delta V)$

$(q_0E) \times d = -(q_0)(\Delta V)$

$E \times d = -\Delta V$

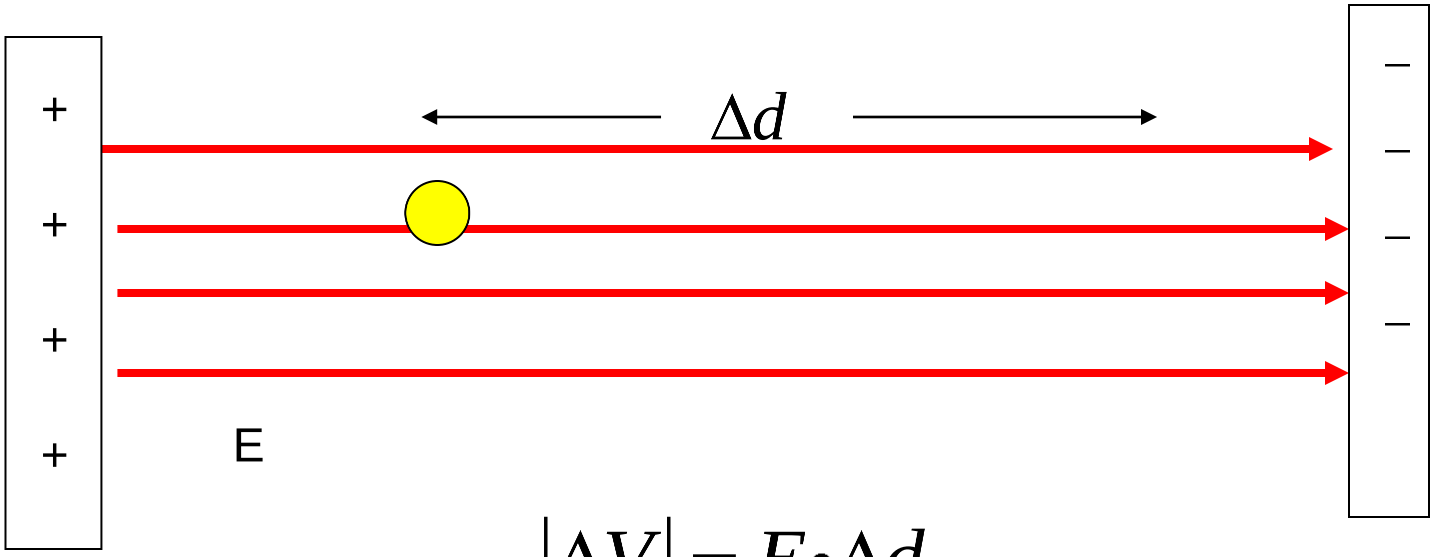
$$E = -\frac{\Delta V}{d} \qquad \frac{V}{m} = \frac{N}{C}$$

Caution:

- this only holds for uniform electric field between oppositely charged parallel plates
- d is not the r in kQ/r or kQ/r^2

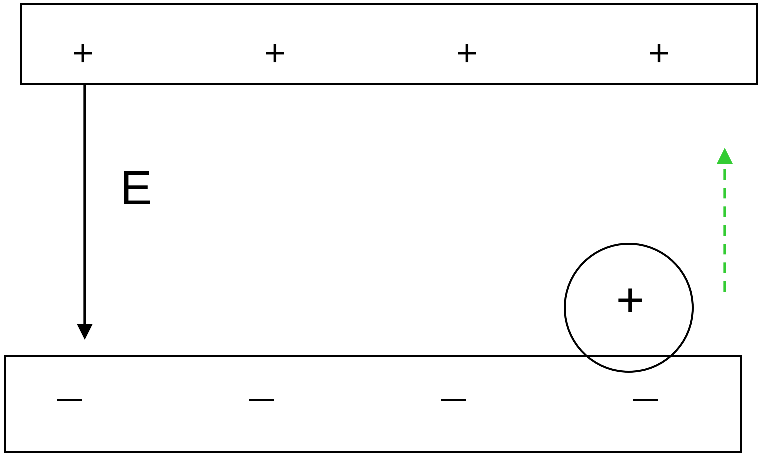
Electric potential in uniform field

uniform electric field exists between parallel plates



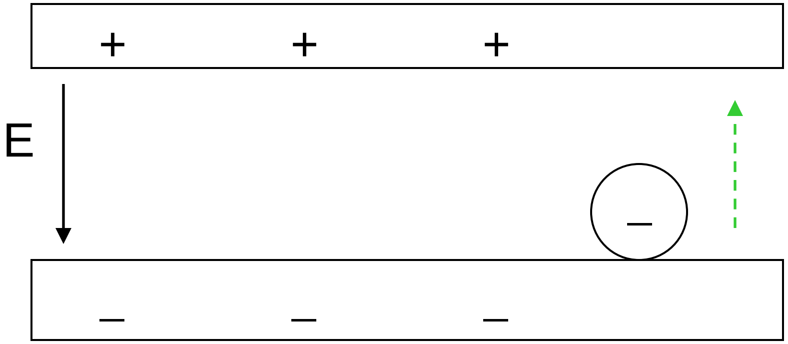
$$|\Delta V| = E \bullet \Delta d$$

E field lines point from higher to lower electric potential

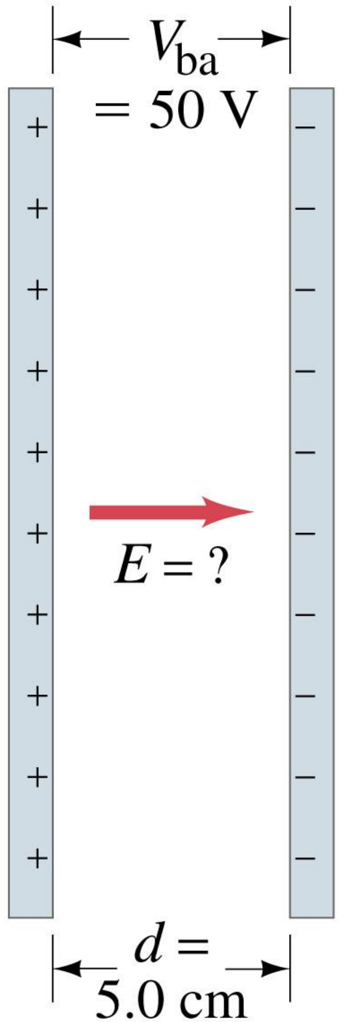


Higher PE for a positive charge at + plate; it gains energy as it is moved closer to + plate

definitions of E, V based on + test charge q



electron loses PE as it moves towards + plate

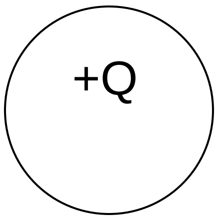


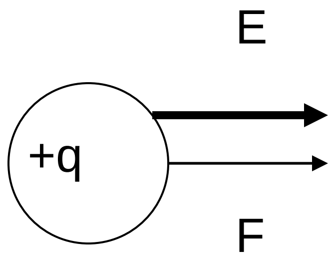
$$E = \frac{50V}{.05m} = 1000\frac{V}{m}$$

FORMULA SUMMARY

Vectors

Force

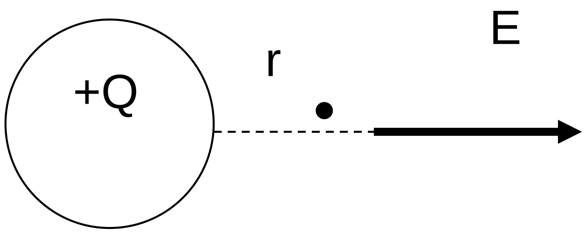




$$F = \frac{kQq}{r^2} = qE$$

created by system

Field

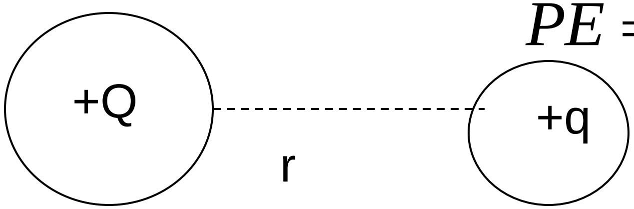


$$E = \frac{F}{q} = \frac{kQ}{r^2}$$

property of point in field

Scalars

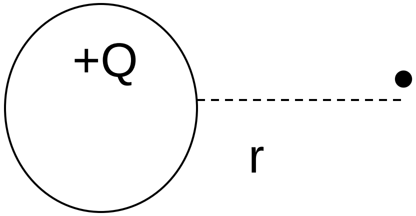
Potential energy



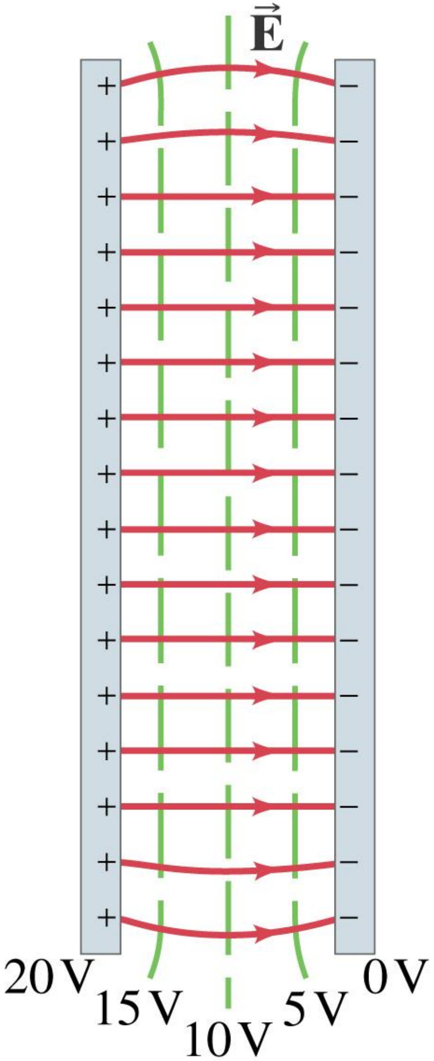
$$PE = qV = \frac{kQq}{r}$$

Potential

$$V = \frac{PE}{q} = \frac{kQ}{r}$$



17.3 Equipotential Lines



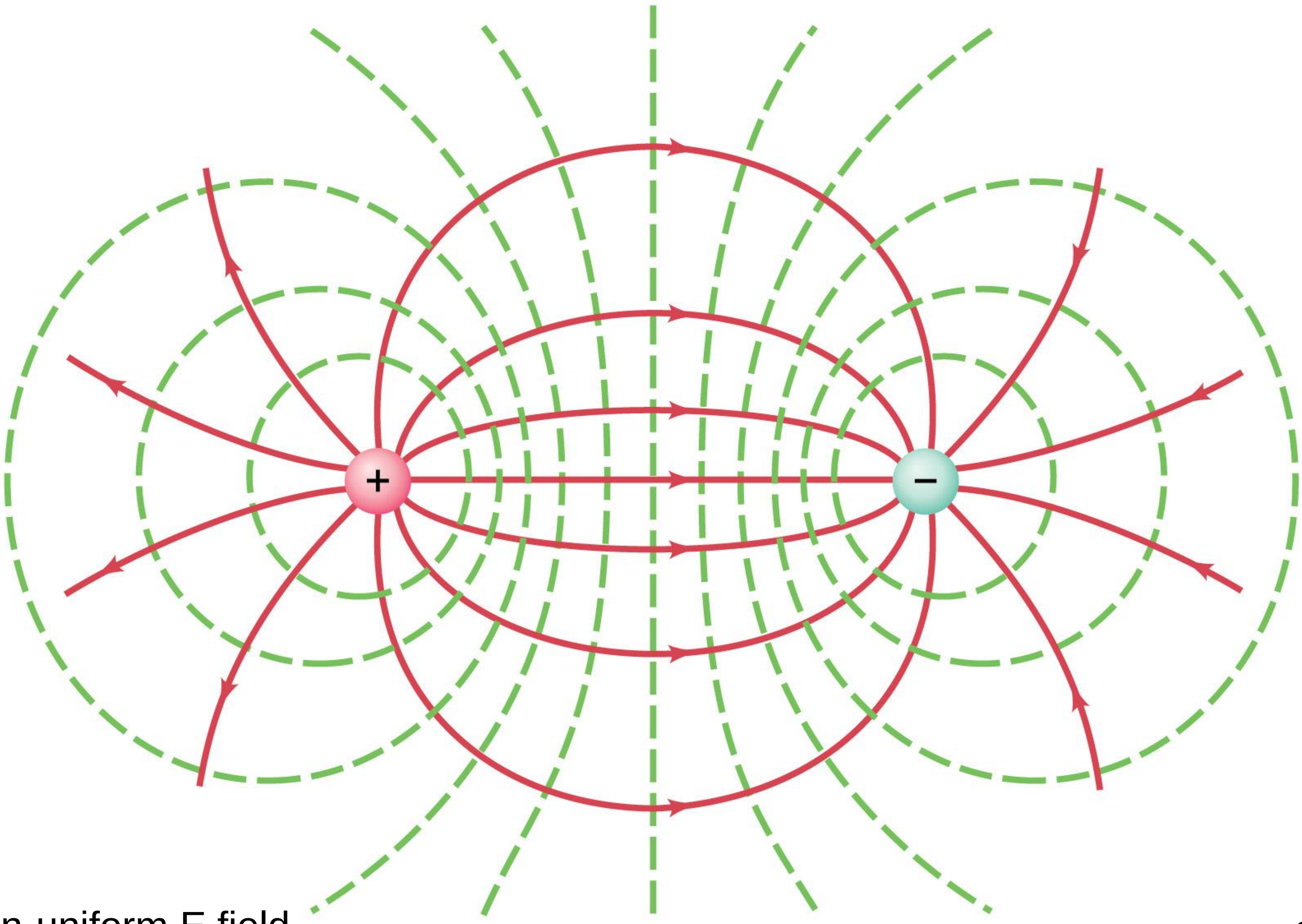
An equipotential is a line or surface over which the potential is constant (voltage is equal at all points)

Electric field lines are perpendicular to equipotentials.

The surface of a conductor is an equipotential.

uniform E field

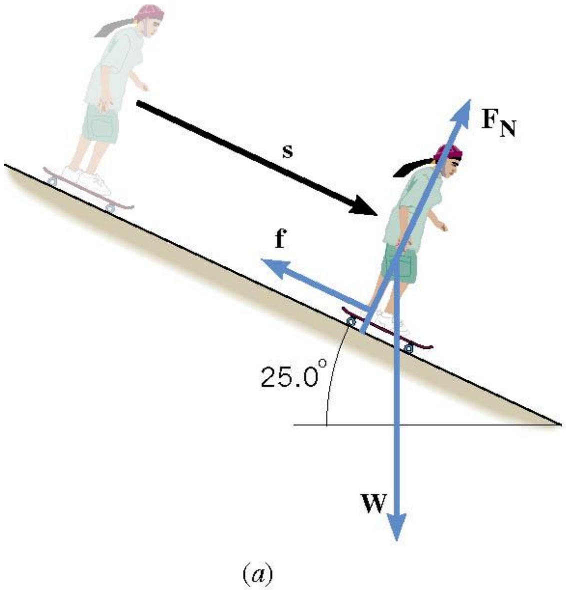
17.3 Equipotential Lines

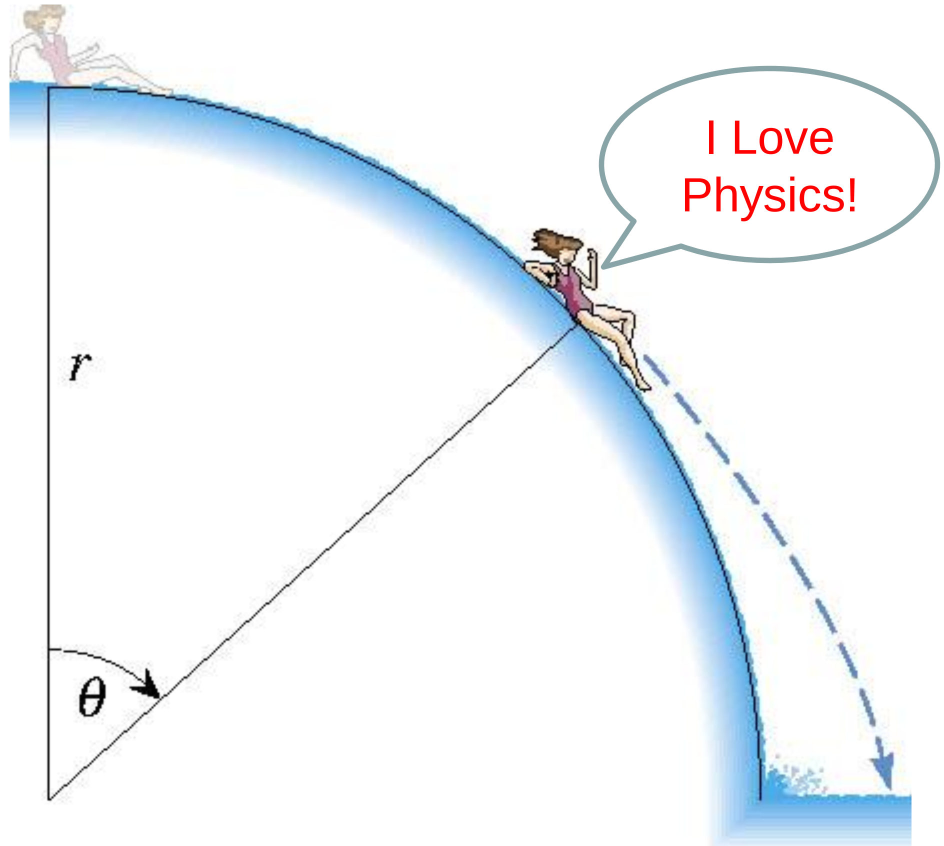


non-uniform E field

Which person is going to experience the greater pull from gravity?

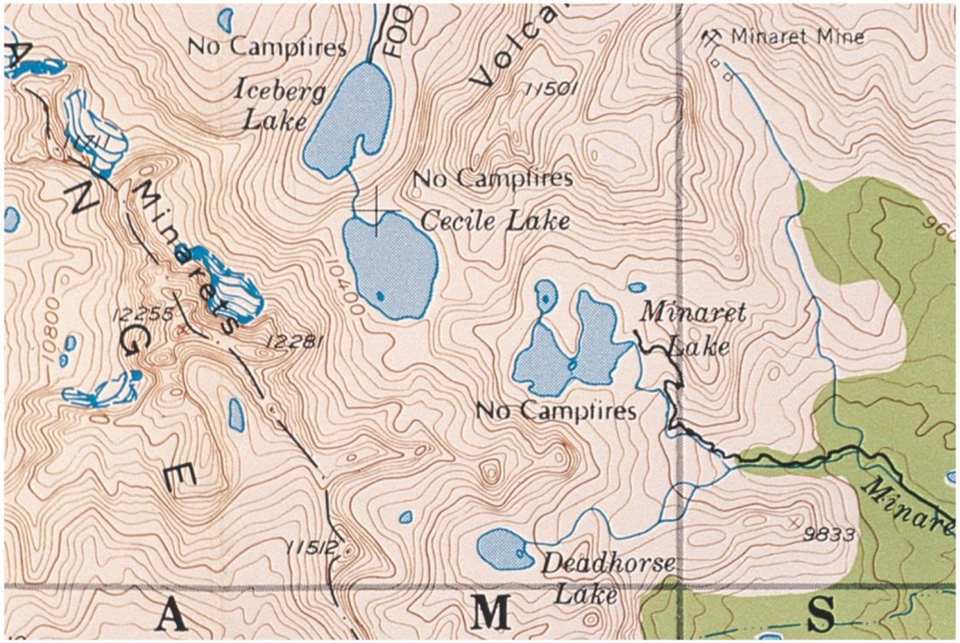
The skateboarder or the physics chick on the water slide?





The gravitational gradient (slope) of the field is greater for the girl.
Constant elevation lines are closer together when slope is greater.
Therefore gravitational field is stronger

Equipotential lines similar to constant elevation lines on a topographical map



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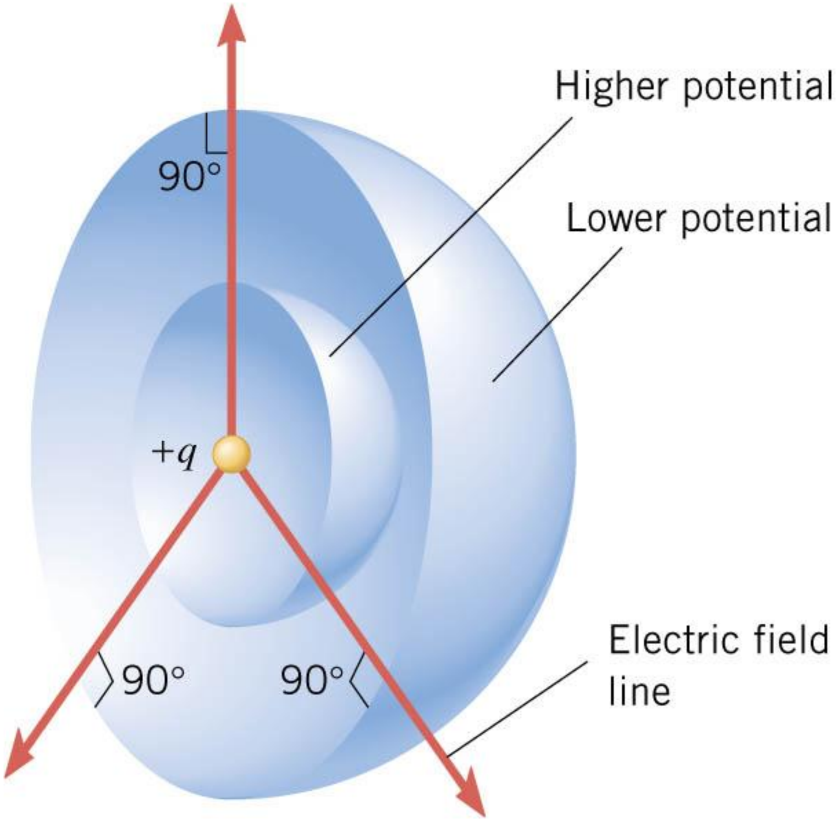
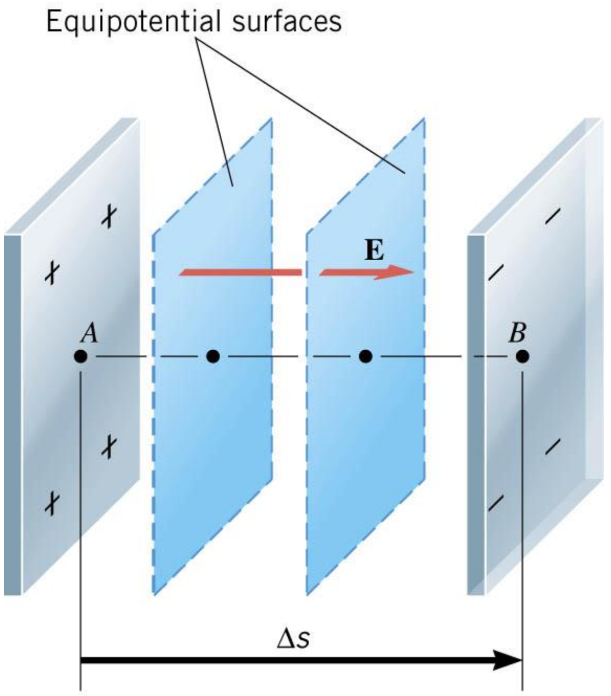
lines are closely spaced near peak of a hill

lines are spread apart in flat regions

Electric field lines ⊥ equipotential lines

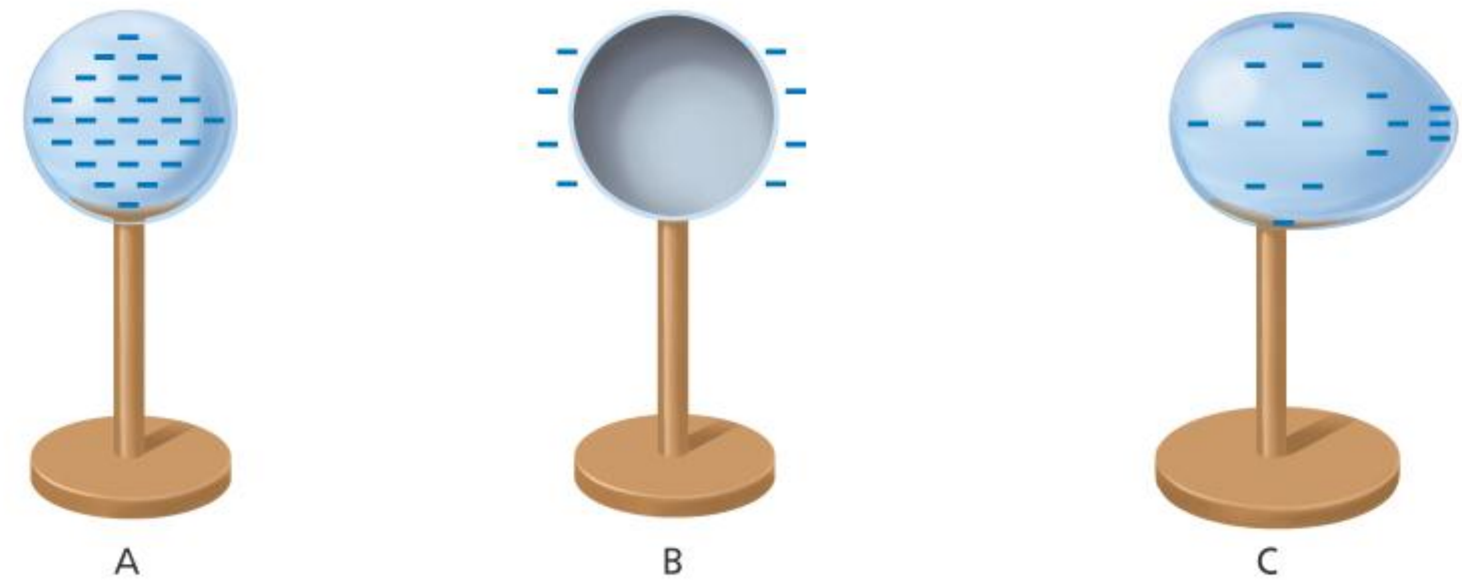




uniform E field

non-uniform E field

Potential of a Charged, Isolated Conductor



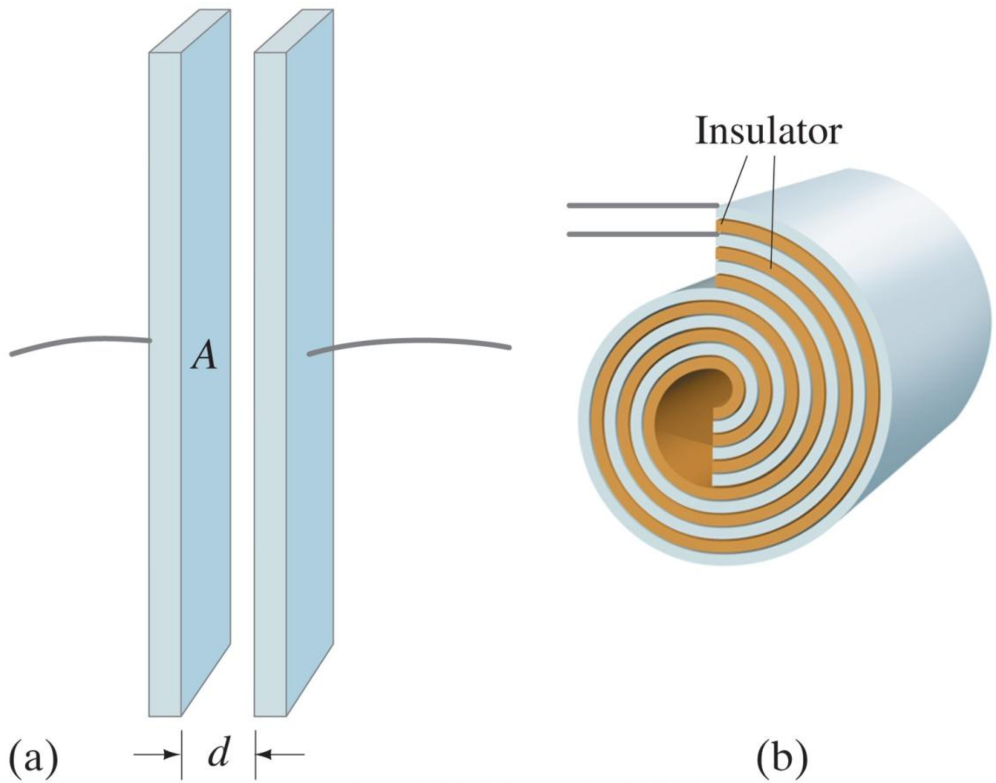
• Conductor surface becomes an equipotential surface since no charges are moving

• E = 0 in bulk of conductor

• Equilibrium reached quickly, no charge motion across surface

17.7 Capacitance

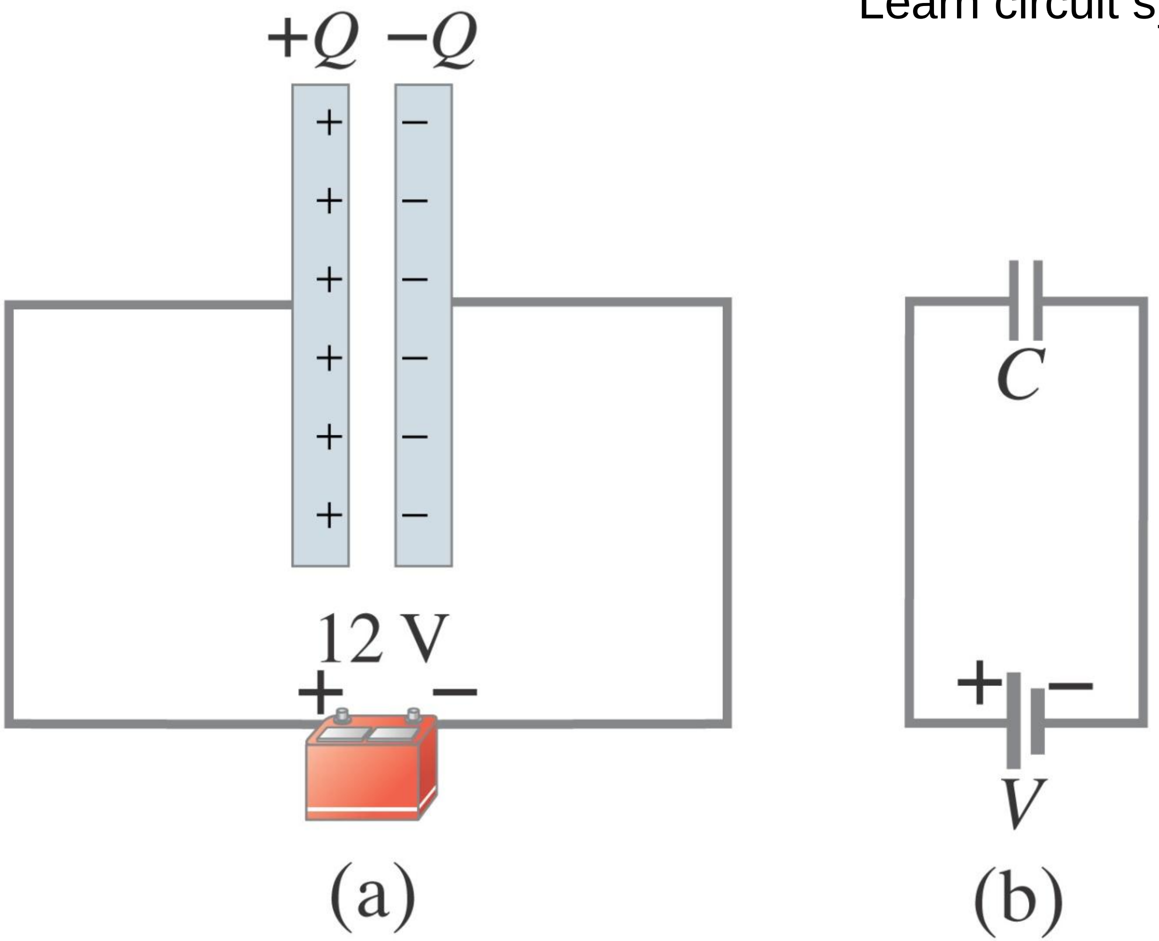
A capacitor consists of two conductors that are close but not touching. A capacitor has the ability to store electric charge.



17.7 Capacitance

Parallel-plate capacitor connected to battery. (b) is a circuit diagram.

Learn circuit symbols



17.7 Capacitance

When a capacitor is connected to a battery, the charge on its plates is proportional to the voltage:

$$Q = CV$$

The quantity *C* is called the capacitance.

Unit of capacitance: the farad (F)

1 F = 1 C/V

What does capacitance depend on?

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

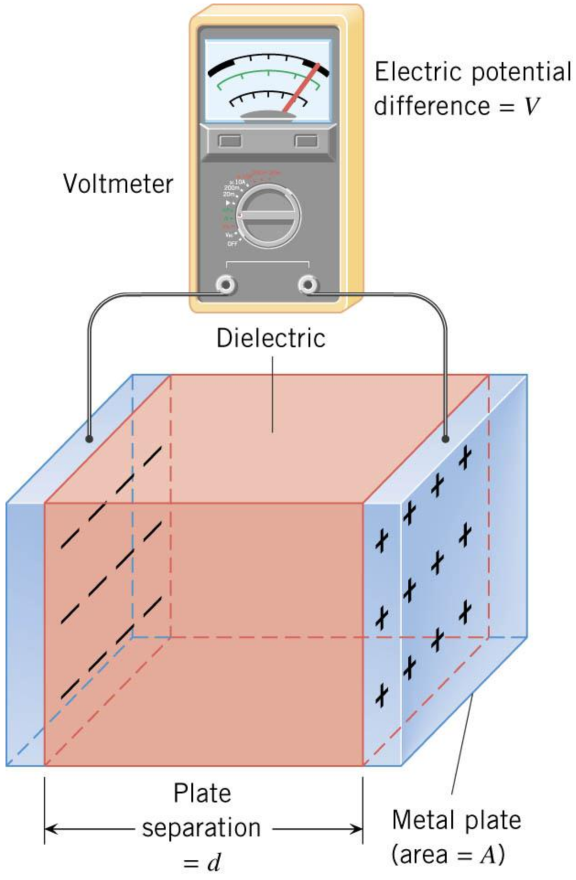
The capacitance does not depend on the voltage; it is a function of the geometry and materials of the capacitor.

For a parallel-plate capacitor the amount of charge Q increases with greater voltage V so C stays constant

Capacitance does depend on geometric factors:

$$C = \epsilon_0 \frac{A}{d}$$

Parallel plate capacitor



$$C = \epsilon_0 \frac{A}{d}$$

Capacitance increases with greater plate area A

- more room for charges to be stored

- Capacitance decreases with greater separation d because E field weakens due to E = V/d

17.9 Storage of Electric Energy

A charged capacitor stores electric energy; the energy stored is equal to the work done to charge the capacitor.

$$Work_{\text{by external agent}} = \Delta\text{PE} = \text{Q}\bullet\Delta\text{V}$$

$$\text{Q}=\text{C}\bullet\text{V}$$

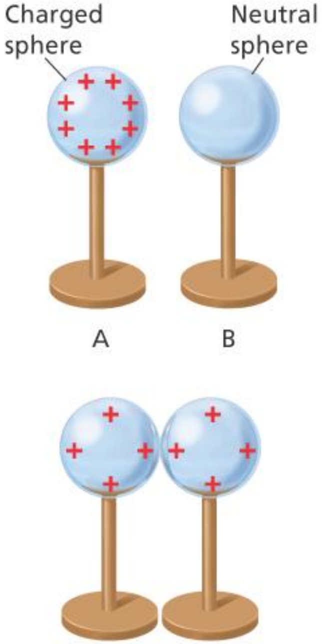
$$\Delta\text{V} = \text{V}_{\text{avg}} = \frac{\text{V}_{\text{f}} + 0}{2}$$

$$PE = \frac{1}{2}V \bullet Q = \frac{1}{2}V \bullet CV = \frac{1}{2}CV^2$$

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\frac{Q^2}{C}$$

Charge Sharing

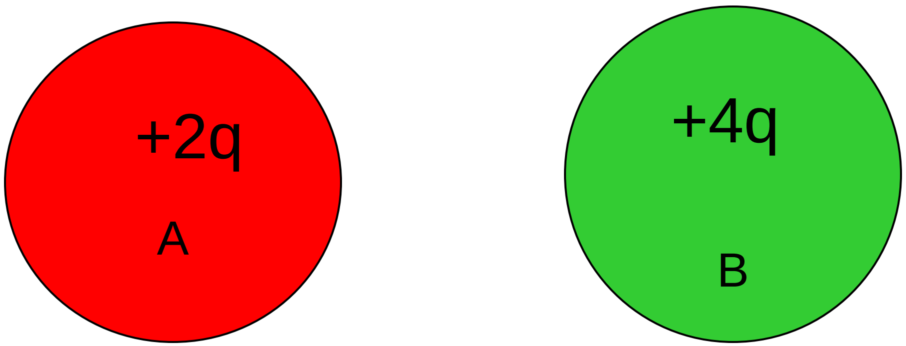
- Same size objects
  - charged objects brought together
  - charge migrating so equipotential surface is created



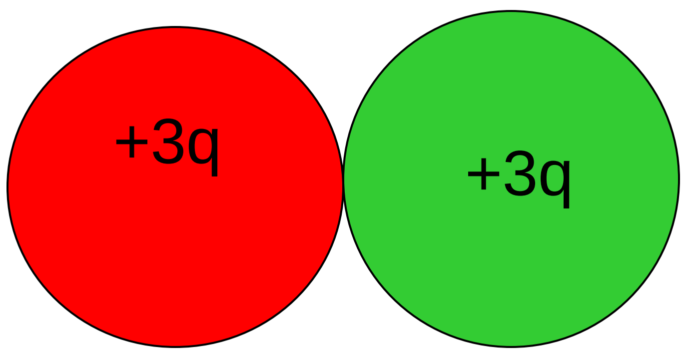
Driving force is from higher to lower potential

Same size objects share charge equally

Charge Sharing

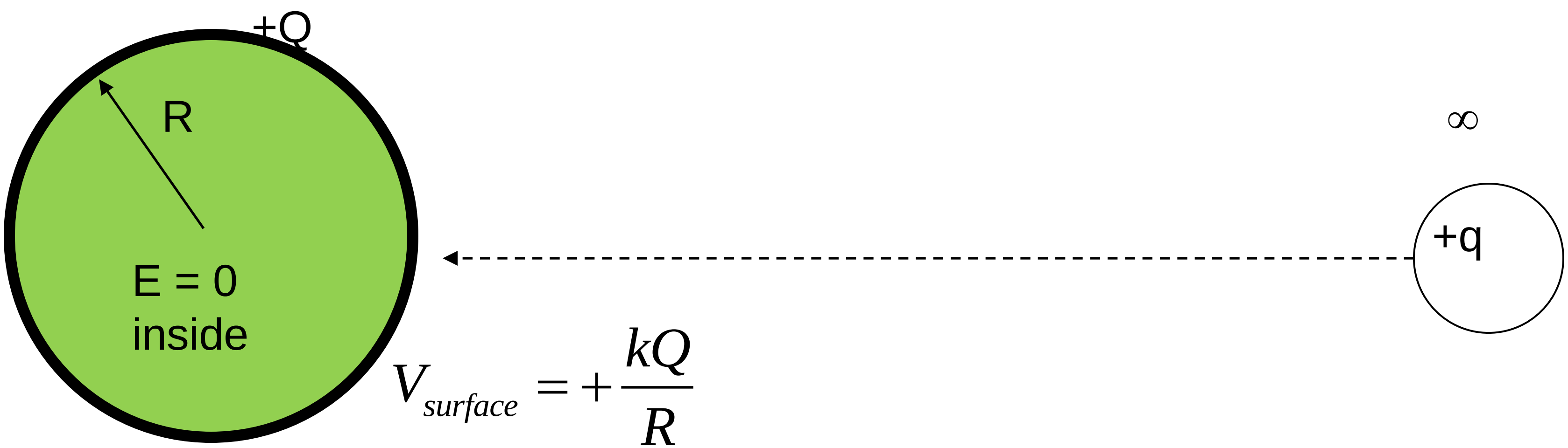


sphere of same radius



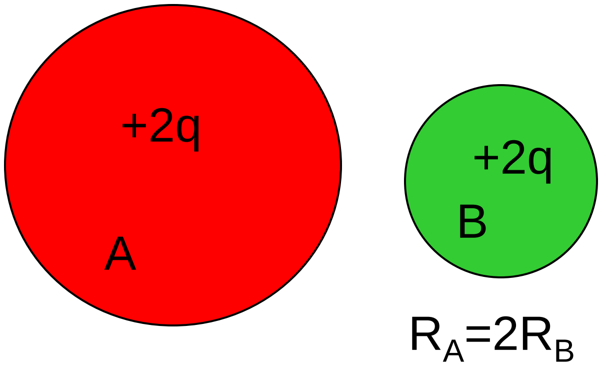
- when touched they become one conductor
- $V_A = V_B$
- $V = kQ/r$ and r’s = then Q’s must be equal

Charged Conductor



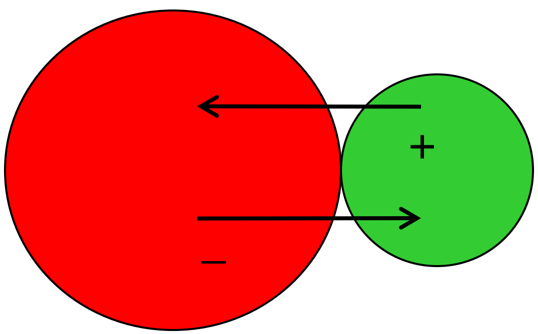
$$V_{surface} = +\frac{kQ}{R}$$

The potential V of the surface of the conductor is just the same as if a point charge +Q is located at the center a distance R away from the surface.



- Spheres of unequal radius will have different potentials

$$V = \frac{kQ}{R}$$



Smaller radius sphere is at a higher + V.

When brought into contact + charge will move from Higher V to lower V by electrons moving from lower to higher V, just as between parallel plates, so that equipotential surface is created.