Review from yesterday

Please answer PROBLEM 3 in Knight on page 716 while we are waiting to start.

“It takes 3.0 μJ to move a 15nC charge from A to B…”

Review from yesterday

Please answer PROBLEM 17 in Knight on page 717 while we are waiting to start.

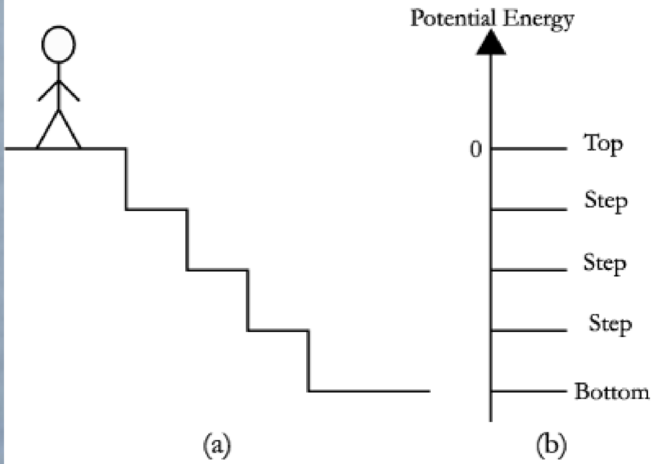
“What is the potential of an ordinary AA or AAA battery?...”

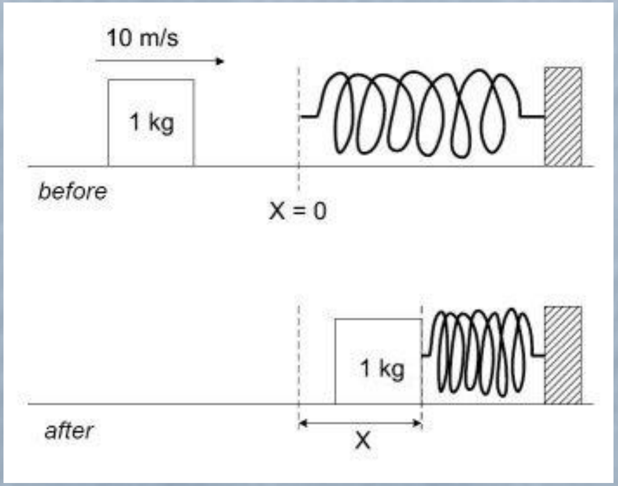
Electric Potential

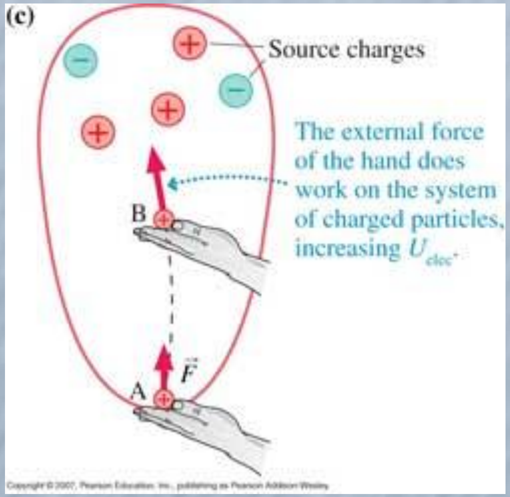
- Electric potential energy
- Electric potential
- Electric potential and electric field
- Capacitors
- Dielectrics
- Electric energy stored in capacitors

Potential Energy

- Energy stored in a system
- Different types of potential energy
  - Gravitational
  - Elastic
  - Electrical







The external force of the hand does work on the system of charged particles, increasing U_{elec}.

Electric Potential Energy

- Moving an electric charge in an electric field requires or releases energy, U (Joules).
- (Note we use U for energy because the electric field is E)
- The energy, U, is proportional to charge – just as the force is proportional to charge.

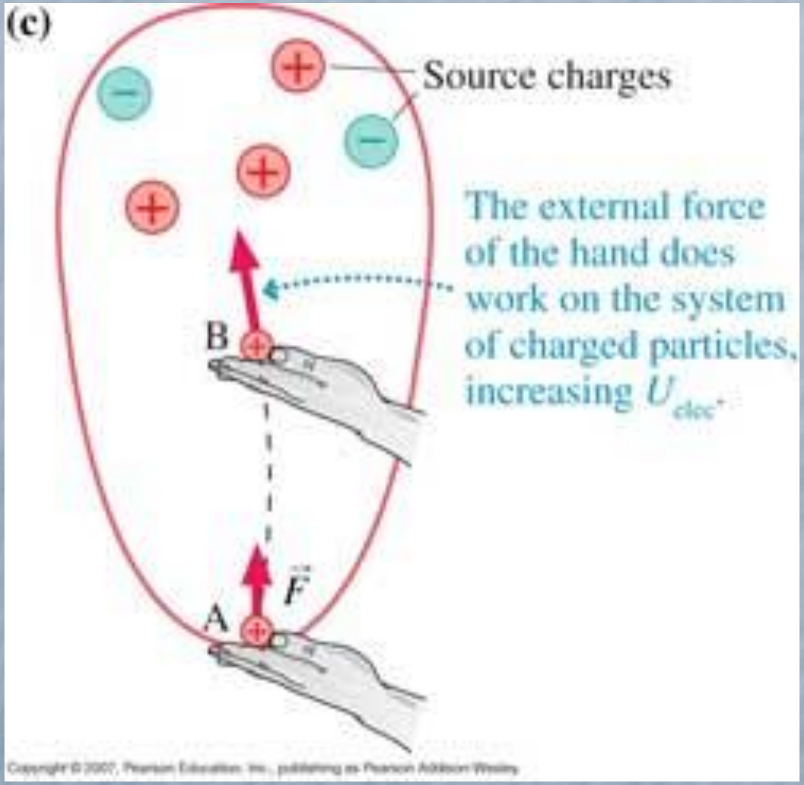
Electric Potential

- We define an Electric Potential, V, as the energy per unit charge, q:
- V = U/q
- Describes what would happen to a charge if it was placed in the electric field
- This electrical potential is a property of the system of the surrounding charges
- It has units of Joules/Coulomb, or Volts

Electric Potential

- Electric potential is a concept we use to be able to predict and calculate energies to move charges
- The energy needed to move a charge from one potential V_1 to another, V_2, is simply
- $\Delta U = q(V_2 - V_1)$
- It is the same physical quantity on batteries

Electric Potential



The external force of the hand does work on the system of charged particles, increasing U_{elec}.

- The electric potential is a property of the source charges, we exclude the charge we are moving.
- A contour map of points of equal potentials will give us lines where the potential energy of a charge is constant
- Electric potential has magnitude but no direction – it is a scalar

electronVolts

- U=qV, units are usually Joules
- Sometimes (especially in Atomic Physics) it is useful to express the energy in units of electrons*Volts
- 1 eV = Charge on electron * 1 Volt
- 1eV = 1.6×10^{-19} Joules
- The energy required to move an electron or proton through a potential of 1V

Electric Potential in a Parallel Plate Capacitor

- Recall Energy or Work = Force x Distance
- From yesterday, **F**=q**E**
- From today, Work = Electric Potential, U
- To move a distance *x* in constant field between plates : U=q|**E**|*x*
- The electric potential will be

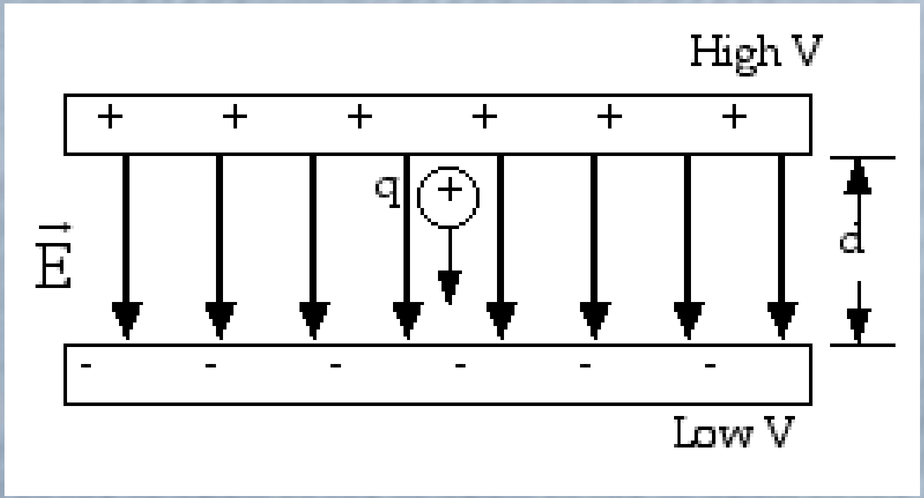
$$V = \frac{U}{q} = \left|\mathbf{E}\right| x = \frac{Q}{\varepsilon_0 A} x$$

Potential inside a Parallel Plate Capacitor

$$V(x) = \frac{Q}{\varepsilon_0 A} x$$

$$V_{Capacitor} = \frac{Q}{\varepsilon_0 A} d$$

- Electric potential is proportional to the distance, x, from the bottom plate
- Total Voltage across capacitor



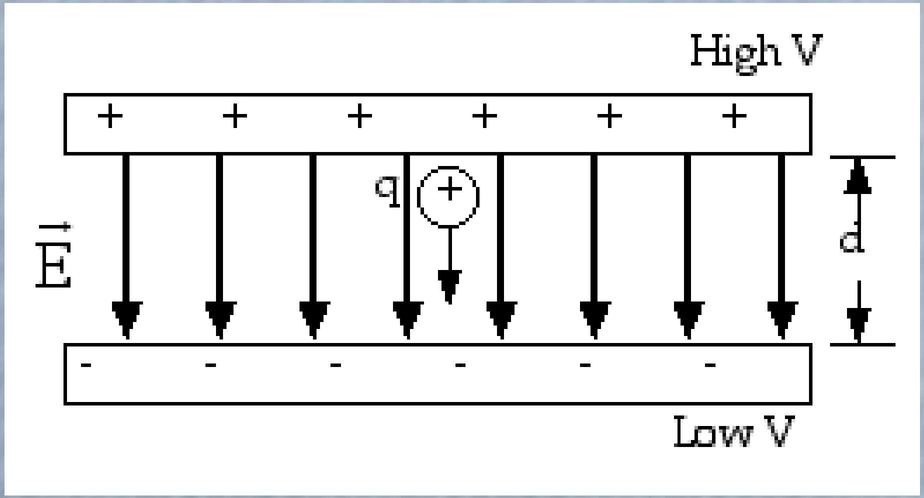
ActivPhysics

Field inside a Parallel Plate Capacitor

$$|\mathbf{E}| = \frac{V}{d}$$

- Electric field inside the plates is **constant**.
- inversely proportional to the plate separation

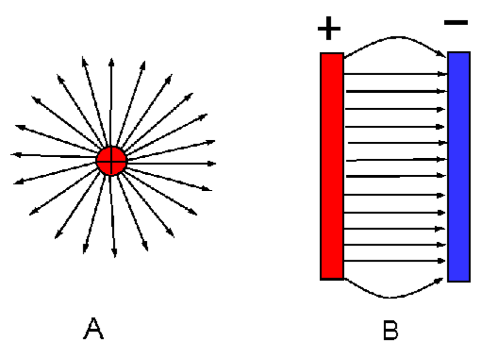
$$|\mathbf{E}| = \frac{Q}{\varepsilon_0 A}$$



Potential of a Point Charge

- The potential, V, is defined by V=U/q (Energy per unit charge)
- Energy is Force times distance
- For parallel plates, the field and force are constant, but near a point charge, force is inversely proportional to r^2.

$$|\mathbf{F}| = q|\mathbf{E}| = \frac{qQ}{r^2}$$

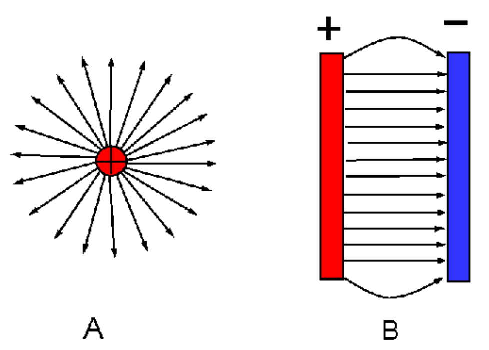


$$|\mathbf{F}| = q|\mathbf{E}| = \frac{qQ}{\varepsilon_0 A}$$

Potential of a Point Charge

- It can be shown that when a force is inversely proportional to r^2, the potential energy will be inversely proportional to r.
- Remember, U is the potential energy required to place q next to Q

$$U = K\frac{qQ}{r}$$



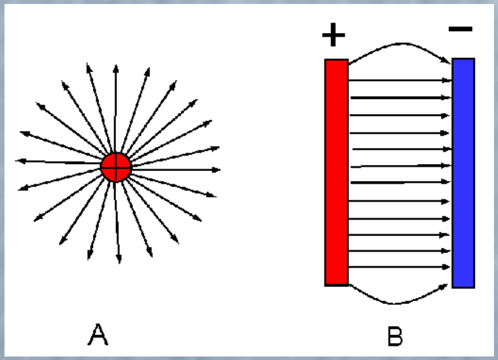
$$U = \frac{qQd}{\varepsilon_0 A}$$

Potential of a Point Charge

- Now we apply the definition of potential: V=U/q. Energy per unit charge
- The potential of a point charge is therefore

$$V = K\frac{Q}{r} = \frac{Q}{4\pi\varepsilon_0 r}$$

$$V = K\frac{Q}{r}$$



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

Electric Potential of a Charged Sphere

- For a point source we have
- Replacing with a metal sphere, the field outside the sphere stays the same.
- And we can calculate the charge on a sphere from its potential

$$V = K\frac{Q}{r}$$

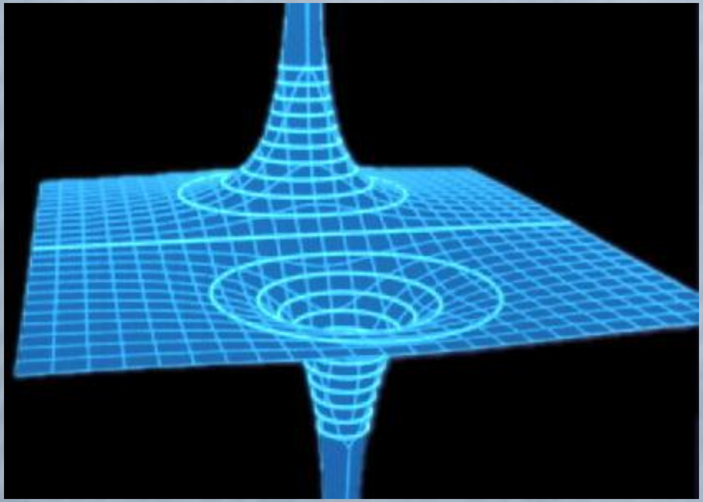
$$V = K\frac{Q}{R_{sphere}}$$

$$Q = V\frac{R_{sphere}}{K}$$

Electric Potential is a scalar

- Potential has magnitude but no direction
- The potential at a point is the sum of the potentials from all charges in the system

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



Electric Potential in a Conductor

We know that

- Excess charge in a conductor moves to the surface
- Electric field inside is Zero
- Exterior field is perpendicular to the surface
- Field strength is largest at sharp corners

We can add

- The entire conductor is at the same potential
- The surface is an equipotential surface

Capacitance

- Experimentally, the voltage across a capacitor, V, is proportional to the amount of charge on the plates, Q:
- $Q=CV$
- C is the capacitance and has units Coulombs/Volt or Farads

Parallel Plate Capacitor in a vacuum

- From the definition of Capacitance
- And the equations for the electric field
- We can find the capacitance of parallel plates

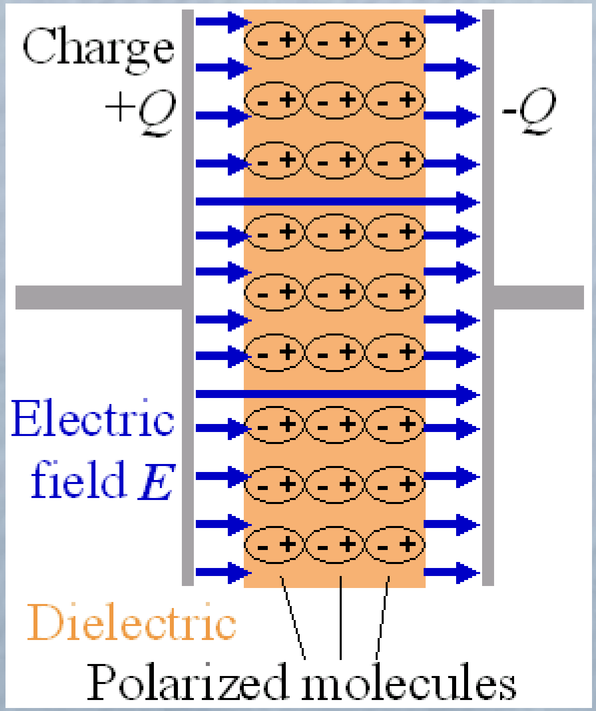
$$Q = CV$$

$$E = \frac{V}{d} = \frac{Q}{\varepsilon_0 A}$$

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

Dielectrics

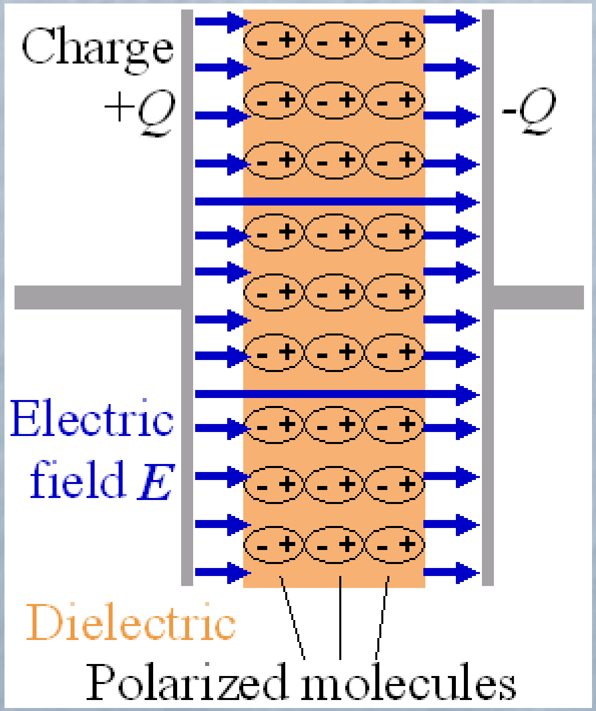
- Dielectrics can be used to increase the effects of a capacitor
- The dipoles align (polarize) to reduce the electric field inside the material
- The electric fields of the dipoles counteract the field from the plates



Dielectrics

- This property κ is expressed as the **dielectric constant** and is a property of the material
- Vacuum and Air = 1, de-ionized water=80

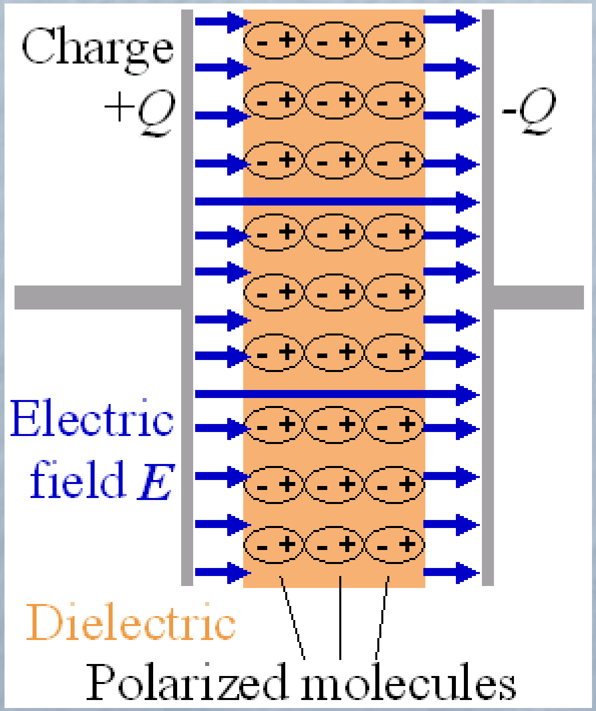
$$\kappa = \frac{E_{vacuum}}{E_{material}}$$



Dielectrics

- This will increase the capacitance – by factors of 100 for the best dielectric materials

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



Energy stored in capacitors

- When we charge a capacitor to a voltage V, work is being done against a voltage difference
- Starting Voltage = 0
- Ending Voltage = V
- Average Voltage $V_{ave} = V/2$
- Energy is $U=QV_{ave}=CV^2/2$

Energy stored in the field

The energy in the capacitor can be expressed as an energy density, u J/m^3, inside the capacitor

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\kappa\varepsilon_0(Ad)E^2$$

$$u = \frac{U}{Ad} = \frac{1}{2}\kappa\varepsilon_0 E^2$$

Summary

- Electric potential energy
- Electric potential
- Electric potential and electric field
- Capacitors
- Dielectrics
- Electric energy stored in capacitors

Homework

Knight Problems

51, 52, 61, 65, 68, 71, 74, 77.