Chapter 21 **Electric Potential due to** Point Charges And

Capacitors

(a) The force on charge q is zero. No work is needed to move it from A to B, so there is no potential difference between A and B.



(b) The capacitor still has no net charge, but charge has been *separated* to give the plates charges +Q and -Q.



Now, because the separated charge exerts an electric force, the hand must do work on q to push it from A to B. The charge's electric potential energy increases, so there must be an *electric potential difference* ΔV between A and B.

Potential Difference, commonly called Voltage

Recall:

E = F/q_o = force per unit charge (units: N/C)
 ΔV = W/q_o = work per unit charge (units: J/C)
 ΔV = ΔEPE/q_o = W/q_o = F·d/q_o = E·q_o·d/q_o = E · d

$\Delta V = E \cdot d$

(true for a uniform electric field)
 Note: This solves for ∆V not V!

Potential of a Point Charge

- Also recall... $E = F/q_o = kqq_o/(q_o r^2)$
- $\blacksquare E = kq/r^2$
- Where the electric field of a positive (point) charge is radially outward, and a negative (point) charge is radially inward.
- $\Delta V = E \cdot d = [kq/r^2] \cdot d$
- and d = r...
- △V = kq/r Potential DIFFERENCE of a *Point* Charge at a distance r from the point charge.
 true for small r values since E (and F) varies with r
 V=kq/r →V (compared to ΔV)is the amount by which the potential at a distance r from a *point* charge differs from the potential at an infinite distance away.
 What is the V and r relationship? Graph shape?

Potential and Energy Conservation



Particles speed up as they lose potential energy!!!

A proton is released from rest at point Q, where the potential is 0V. Afterward the proton...



- A) Remains at rest at Q
- B) Moves toward P with a steady speed.
- C) Moves toward P with an increasing speed.
- D) Moves toward R with a steady speed.
- E) Moves toward R with an increasing speed.

- Recall: $\Delta V = \Delta EPE/q_o$ so: $\Delta EPE = \Delta Vq_o$
- What is the U and V relationship? Graph shape?
- And: $W = F \cdot d$
- And : $F = k (q q_0)/r^2$
- So if we substitute the two last equations into each other....
- $W/d = F = k (q q_0)/r^2$
- We get $W = \triangle EPE = \triangle U = k (q q_0)/r$
- Note that PE depends on the interaction of a pair of particles!!!
- Note that ΔU can be +/- depending on q and $q_{0.}$
- What is the U and r relationship? Graph shape?

∆ Electric Potential Energy for a Point Charge

- Recall that changes in PE are not path dependent!
- If you walk up stairs to the second floor and another student climbs a rope, which student obviously does more work?
- So ΔV must not be path dependent also because ΔV depends on changes in EPE $\Delta V = \Delta EPE/q_0$
- AV is always independent of path taken between two locations.





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Voltage or Electric Potential

An electric charge alters the space around it. Throughout the space around every charge is a vector thing called the electric field. Also filling the space around every charge is a scalar thing, called the voltage or the electric potential. Electric fields and voltages are two different ways to describe the same thing.

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Recall: \Delta V = \Delta EPE/q_o
electron volt (eV): instead of measuring energy in
Joules we can measure energy in eV (when
energy is small).
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A positive point charge, +q on the far left, creates an electric potential...



The positive *test charge*, $+q_{o}$ (in between A & B), experiences a repulsive force **F** due to the positive point charge +q. As a result, work is done by this force when the test charge moves from A to B. Electric potential is higher (uphill) at A and lower (downhill) at B for this positive test charge.



Using a zero reference V=0at $r=\infty$ potential at infinity, because potential decreases with inverse of distance, determine the amount by which a point charge of 4.0X10⁻⁸ C alters the electric potential at a spot 1.2 m away when the charge is (a) positive and (b) negative.



A point charge q alters the potential at every location in the surrounding space. The effect of the charge in increasing or decreasing the potential is determined by whether the point charge, q, is positive or negative. When compared to a zero potential reference value $(r=\infty)$, a positive $(+4.0X10^{-8}C)$ point charge raises (or increases) the potential and a negative point charge decreases the potential. V = kq/r = $(8.99X10^{9}Nm^{2}/C^{2})(4.0X10^{-8}C)/(1.2m)$ = 300 V(a) V = +300 V (increasing the potential)

(b) V = -300V (decreasing the potential)

Summary

Signs of ΔV and direction of path relative to E

- Path going in the direction of E: Potential is decreasing (∆V< 0)</p>
- Path going opposite of E: Potential is increasing (ΔV> 0)
- Path perpendicular to E: Potential does not change (△V= 0)

Find the electric potential at locations A and B...



When two or more charges are present, the potential due to all the charges is obtained by adding together the individual potentials...

- Location A: Total V_A = (V contribution from positive charge) + (V contribution from negative charge)
- $V_{A} = [k(+q)/r_{A \rightarrow +}] + [k(-q)/r_{A \rightarrow -}]$ $V_{A} = [(8.99X10^{9}Nm^{2}/C^{2})(+8.0X10^{-9}C)/(0.2m)] + [(8.99X10^{9}Nm^{2}/C^{2})(-8.0X10^{-9}C)/(0.6m)]$
- $V_A = (0.55)(0.0000) + (0.0000)$
- Makes sense since A is closest to the positive charge... increasing the total potential at point A V_B =[(8.99X10⁹Nm²/C²)(+8.0X10⁻⁹C)/(0.4m)] +[(8.99X10⁹Nm²/C²)(-8.0X10⁻⁹C)/(0.4m)]
 V_B = 0 V
- Makes sense since point B is exactly in the middle between two equal and opposite point charges.

Potential and E Field



- There is an electric field at point B BUT consider how much work it would take to move a test charge from the left charge to point B AND how much work it would take to move a test charge from the right charge to point B....
- $V = (-W/q_o) + (+W/q_o) = 0V!$

Concept Attainment

- A single point charge raises, (+) or lowers, (-) the potential at a given location. When two or more charges are present, the potential due to ALL the charges is obtained by adding together the individual potentials. So it is possible for potential at a certain point to equal zero.
- Potential (voltage) is not a vector quantity so potentials from more than one point charge add together.

Voltage in a conductor

- Recall that the electric field inside of a conductor is zero as seen with the scotch tape and the aluminum can activity.
- Even though E = 0 inside a conductor at equilibrium there is still a voltage based on the potential from all of the charges on the outside surface of the conductor and this potential is uniform throughout the conductor!

On the line that passes through these charges, there are two places at which the total potential is zero...



Total potential = 0 = +V + (-V) = 0 +V = -V $V = kq/r \quad \therefore \quad V \propto q/r$ +Q/r = -q/r

What is the electric potential at the point indicated below?



Answer...

- $V = kq_1/r_1 + kq_2/r_2$
- V = $(9 \times 10^{9} \text{ Nm}^{2}/\text{C}^{2}) [(2\times 10^{-9} \text{C}/0.050 \text{m}) + (-1.0\times 10^{-9} \text{C}/0.040 \text{m})]$
- V = 140 V
- Remember, Potential is a scalar quantity... just add the potentials to get the net electric potential!



Capacitors: store electric charge & electric energy



A parallel plate capacitor consists of two metal plates, one carrying a charge, +q, and the other a charge of –q. The plates are equal, but oppositely, charged. The potential of the positive plate exceeds that of the negative plate by an amount V. The region between the plates is filled with a dielectric. When the magnitude of q is doubled, V also doubles...

■ q ∝ V.

q = CV, where C is the capacitance; a measure of the "capacity" for separating and storing charge for a given potential difference.



A capacitor stores electrical charge. C = q/VUnits: 1 Coulomb/Volt = 1 Farad 1 C/V = 1 FUsually deal with microfarads (10⁻⁶) or picofarads (10⁻¹²) since 1 Farad is a huge amount of capacitance for use in an electric circuit.





- Capacitance, C, is affected by the distance between the plates, the area of the plates, and the material in-between the plates...
- The material in-between the plates is called the "dielectric". It is an insulating material (sheet) placed between the plates that alters (decreases) the electric field between the plates.
- The capacitance, C, increases by an amount κ over the capacitance without the dielectric.

 $\Box C = \kappa \varepsilon_0 A/d$

- κ= dielectric constant; dependant on material of dielectric
- Table 21.3 on page 698 has values of κ for different materials.



 $C = \kappa \epsilon_0 A/d$ κ = dielectric constant; dependant on material of dielectric (Table 21.3 on page 698 has values of κ for different materials) $e_0 = 8.85 \times 10^{-12} \text{ F/m}$ (And... $F/m = C^2/Nm^2$) A = area of one plate (m²)d = distance between plates (m)

Capacitors store electrical energy, U... W = q (V/2)

- Think of q as "the force"
- Think of (V/2) as "the average distance"... in the beginning, it's easier to add charge, near the end, it's harder to add charge to the capacitor.
- $\blacksquare W = \frac{1}{2}qV$
- The work to charge the capacitor with charge q is equal to the (electrical) energy stored in the capacitor which, in turn, once again can do work!
- $= W = U = \frac{1}{2} qV = \frac{1}{2} CV^2_{(q = CV)} = \frac{1}{2}q^2/C_{(q/c=V)}$
- U=nrg stored in capacitor
- V=potential difference between the plates
- q=charge on each plate

A computer keyboard uses capacitors...



One common kind of computer keyboard is based on the idea of capacitance. Each key is mounted on one end of a plunger, the other end being attached to a movable metal plate. The movable plate is separated from a fixed plate, the two plates forming a capacitor. When pressed, the separation distance changes between the plates of the capacitor. Electronic circuitry enables the computer to detect the change in capacitance, thereby recognizing which key has been depressed.

A computer keyboard uses capacitors...



The separation of the plates is normally 5.00 X 10⁻³ m but decreases to 0.150 X 10⁻³ m when a key is pressed. The plate area is 9.50 X 10⁻⁵ m², and the capacitor is filled with a material whose dielectric constant is 3.50.

Determine the *change* in capacitance that is detected by the computer.

And the answer is...

$$\begin{split} \mathbf{C} &= \kappa \varepsilon_o \mathbf{A} / \mathbf{d} = (3.5)(8.85 \times 10^{-12} \text{ F/m})(9.50 \times 10^{-5} \text{ m}^2) / (5.00 \times 10^{-3} \text{ m}) = 5.88 \times 10^{-13} \text{ F} \\ \mathbf{C} &= \kappa \varepsilon_o \mathbf{A} / \mathbf{d} = (3.5)(8.85 \times 10^{-12} \text{ F/m})(9.50 \times 10^{-5} \text{ m}^2) / (0.150 \times 10^{-3} \text{ m}) = 1.96 \times 10^{-11} \text{ F} \\ 10^{-5} \text{ m}^2 \text{ m} \text{ C} &= 5.88 \times 10^{-13} \text{ F} - 1.96 \times 10^{-11} \text{ F} \\ &= 1.90 \times 10^{-11} \text{ F} \end{split}$$