**Announcements 2/18/10**

Handouts: midterm information, conductors in electric fields

No lab next week

PS 5 will be posted later and distributed in class on Tuesday.

If you didn't do the feedback questionnaire on web site under "Reading", you can get part of the credit if you finish it by the end of the weekend (I will reset the deadline to Sunday evening)

## Key ideas from last time

Potential difference from A to B in a nonuniform electric field:

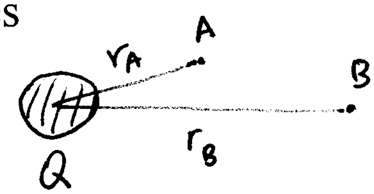
$$\Delta V_{AB} = -\int_{r_A}^{r_B} \vec{E} \bullet d\vec{r}$$

adding up work along a series of short steps $d\vec{r}$

(in uniform field $\Delta V_{AB} = -\vec{E} \circ \Delta\vec{r}_{AB}$

In the field of a point charge or a spherical arrangement of charge with charge $Q$, this becomes

$$\Delta V_{AB} = kQ\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$




Potential $V(r)$ = potential difference from a reference point to location $r$

Point charge/spherical arrangement: choose reference point infinitely far away, giving

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

Note that

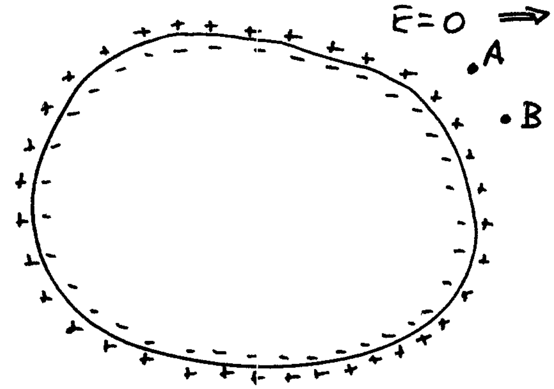
$$\Delta V_{AB} = V(r_B) - V(r_A)$$

Equipotentials: surfaces of constant potential, perpendicular to $\vec{E}$

- Any region where E = 0 is also at constant potential! (inside hollow sphere of charge, inside conductor, outside cell)

$E=0 \Rightarrow V$ constant

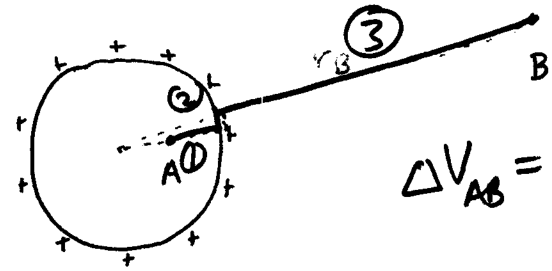
$\Rightarrow \Delta V_{AB} = 0$



**Strategies for calculating potential difference $\Delta V_{AB}$:**

- Identify starting and ending locations A and B
- If field between A and B is uniform or field of a point charge/sphere, use that result
- If there are regions with zero electric field, break up the path from A to B into segments and add up potential differences for each segment

Hollow spherical shell of charge +Q



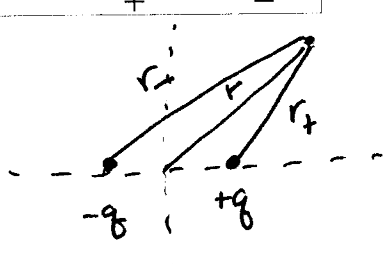

$$\Delta V_{AB} = \Delta V_{seg\,1} + \Delta V_{seg\,2} + \Delta V_{seg\,3}$$

Strategies are the same for potential, using the reference location as the starting point

Potential can also be calculated by superposition — by adding potentials of individual charges

Only case we will use this for is dipole: as Wolfson shows,

$$\boxed{V_{dipole}(r) = \frac{kq}{r_+} + \frac{k(-q)}{r_-}} \qquad (1ab)$$




11:30

**Conductors in electrostatic equilibrium—Physics 4L Spring 2010**
**(See also Wolfson 21.6)**

In a conductor (metal, ionic solution), many of the charges making up the conductor are free to move anywhere in the conductor. As a result, in a steady electric field, they will move until there is no electric force on them, or until they are at the surface of the conductor and can't move any farther.

Therefore, the total electric field due to all sources must be zero inside a conductor. If there *was* a nonzero field inside the conductor, charge would keep moving until there wasn't! The charge on the surface of the conductor produces a field that exactly cancels the other electric fields inside the conductor, and typically strengthens the electric field outside.

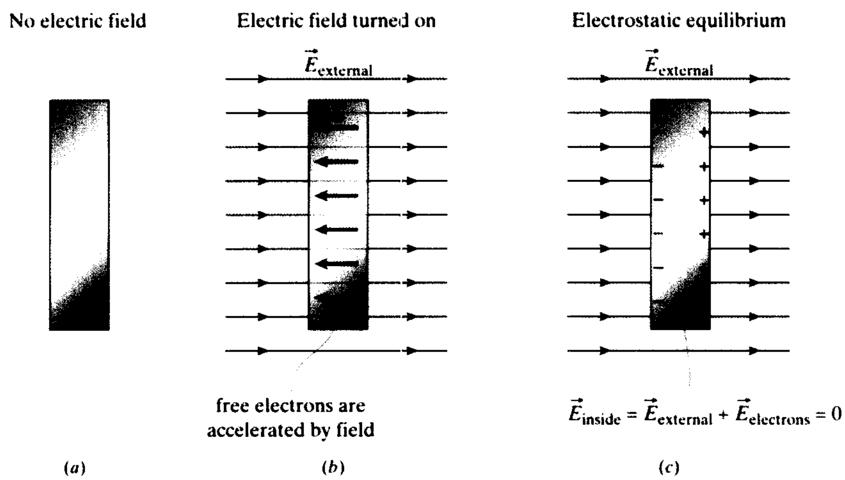



**Figure 28.16** A metallic object contains many so-called "free electrons" — electrons that are not bound to a particular location in the metal. (*a*) When the object is not subject to an electric field, there is no force on the electrons. (*b*) When an external electric field is applied, the field accelerates these free electrons in a direction opposite that of the field. (*c*) The electrons accumulate on the left side leaving positively charged ions on the right. The flow of electrons stops once the electric field set up by the accumulated charges cancels the external field.

Figure from Mazur, *Principles and Practice of Physics*

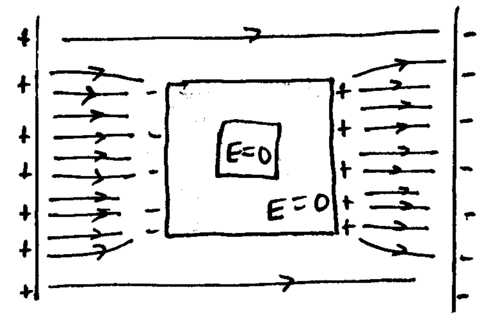
Consequences:

1. There are no unbalanced charges in the interior of a conductor. (The conducting material is made of equal amounts of positively and negatively charged matter, this means that negative and positive charge are evenly distributed throughout the interior.)
• Any added charge on a conductor goes to the surface.
• If a conductor polarizes, again the unbalanced charge is only at the surface.

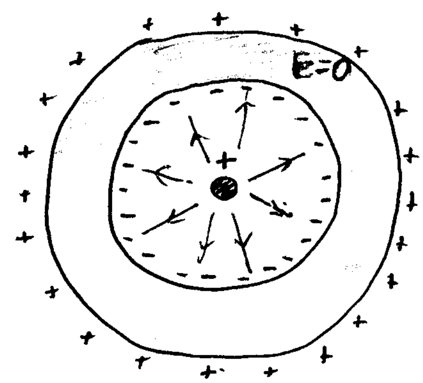
2. Conductors are equipotentials — the potential is constant throughout a conductor.

3. Right at the surface, the electric field must be perpendicular to the surface of a conductor. (If there was a component of the electric field parallel to the surface, it would push charge along the surface.)

4. In a *hollow* empty conductor, the external electric field is also canceled by the field of charges on the surface of the conductor. So, inside a hollow empty conductor, the electric field is zero. This is sometimes called "shielding".
This principle is used to protect sensitive electrical systems and measurements from unwanted electric fields — sensitive electrical measurements, such as neurophysiology measurements of nerve electrical activity, are encased in metal boxes.




5. If there is charge inside a hollow conductor, then the electric field in the empty part is not zero and charge from the conductor collects on the inner surface of the conductor. The electric field is still zero in the interior of the conductor.




(These consequences are no longer true if we have an electrical circuit around which current can flow, which we'll start to discuss in a couple of weeks.)

J.J.

2/18/2010

1. More discussion of conductors in $\vec{E}$
2. Review problem from self-test 3: thinking about how to find $\vec{E}$ and $\Delta V$
3. Energy storage and electrical potential energy
   - capacitors

Conductors in electric fields: summarized on handout (1-4)

11:40 → Consider a couple of questions to help us put together ideas from potential difference, electric fields, and conductors:

review up to here

**CT 1** $\vec{E}$ due to conductor polarizing

We know $\vec{E} = 0$ inside conductor

outside, $\vec{E}$ gets stronger

**CT 2** $\Delta V_{AB}$? positive: moving from A to B is moving in opposite direction as $\vec{E}$

⇒ ~~on a positive charge~~

③ $\Delta V_{AB} = -\int_A^B \vec{E} \cdot d\vec{r}$ is ⊕ b/c $\vec{E}$ is in opposite direction as motion

② $\Delta V_{AB} = -\frac{W_E}{q}$ consider moving a ⊕ ⊖ from A to B
$\vec{E}$ does ⊖ work: Force in opp. direction as motion

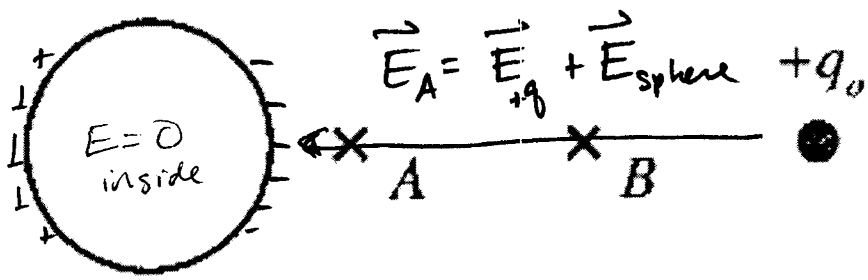
∴

① $\Delta V_{AB} = \frac{\Delta U_{AB}}{q}$ a ⊕ particle will gain electric potential energy b/c you have to push it toward the +q

If it started at A w/some KE, it would lose that KE toward B

11:50 → **CT 3** $\Delta V_{AB}$ greater b/c E stronger

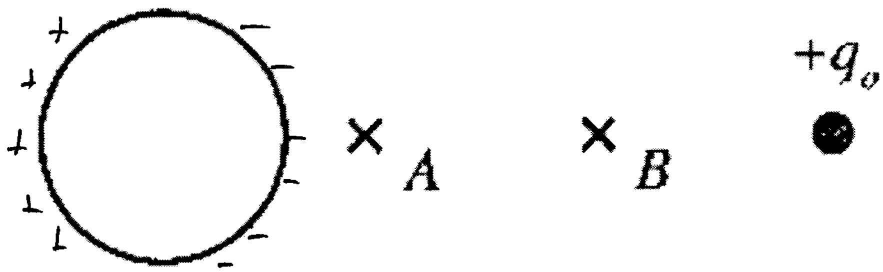
A conducting sphere is placed in the electric field of a charged particle of charge $+q_0$. Charge on the conducting sphere consequently rearranges so that the electric field inside the sphere is zero.




Compared to the electric field of just $+q_0$, the total electric field at A is

1. The same
2. Stronger
3. Weaker

A conducting sphere is placed in the electric field of a charged particle of charge $+q_0$, and charge on the conducting sphere consequently rearranges.




The potential difference between points A and B, $\Delta V_{AB}$, due to both the sphere and the particle, is

1. positive
2. negative
3. zero

$$\Delta V_{AB} = \frac{\Delta U_{AB}}{q}$$

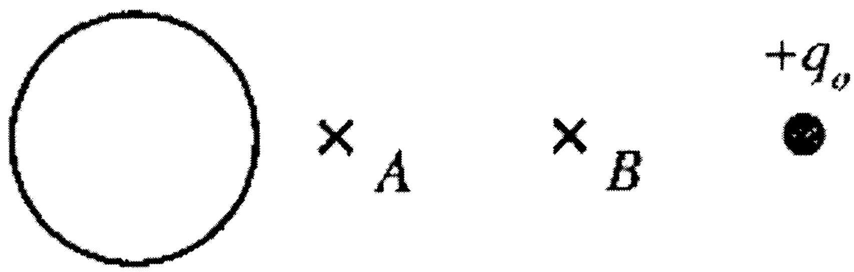
imagine putting ⊕ at A
would require an additional force
to push it to B $\rightarrow$ $\Delta U_{AB}$ increasing (⊕)

$\Rightarrow \Delta V_{AB}$

$$\Delta U_{AB} = -\int_{r_A}^{r_B} \vec{E} \cdot d\vec{r}$$

$\vec{E}$ is always opposite to motion from A to B
so integral is ⊖ ~~aa~~ ($\vec{E} \cdot d\vec{r}$ ⊖)
and $\Delta V$ is ⊕

A conducting sphere is placed in the electric field of a charged particle of charge $+q_0$, and charge on the conducting sphere consequently rearranges.




The potential difference between points A and B, $\Delta V_{AB}$, due to both sphere and particle, is

1. greater than $\Delta V_{AB}$ due to just the charged particle
2. less than $\Delta V_{AB}$ due to just the charged particle
3. the same as $\Delta V_{AB}$ due to just the charged particle

$\vec{E}$ stronger so $\Delta V_{AB} = -\int \vec{E} \cdot d\vec{r}$ increases if $\vec{E}$ increases

PS 3 self-test: example of charge inside hollow conductor
conductor polarizes
Total field between wire & chamber = field of wire + field of chamber
Hollow cylinder: E = 0 inside just as ~~$~~ hollow sphere
so $\vec{E} = \vec{E}_{wire}$ only

$\lambda = Q/L$

$$\vec{E}_{wire} = \frac{\lambda}{2\pi\epsilon_0 r}\hat{r}$$

distance from axis of wire
so field at surface = ~~field~~ E(r = wire radius)

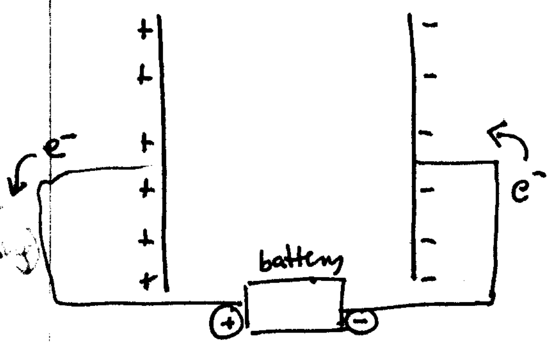
Any time you have a charged wire or rod, if it is very long compared w/distance away, can use this

## Electrical energy in arrangements of charge

How much energy does it take to create a certain arrangement of charge?

We just said we had two sheets of charge

(added wire to drawing)




How does this actually get made?

In lab: we use a power supply to take ⊖ charge off the ⊕ sheet and put it on the ⊖

Requires energy from battery / power supply

Think about biological cell example:

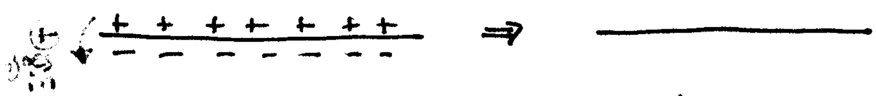
How does this arrangement get created?

proteins move ⊕ charged ions from inside to outside

they use chemical energy to do this

Get lots of energy stored in this arrangement of charge that can then be used to stimulate muscle contraction (do mechanical work!) or send nerve signals.

To release that energy in a cell, open up channels across membrane that lets the membrane discharge



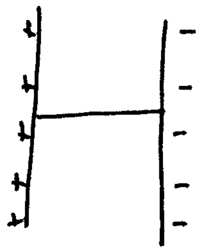
In the process energy is liberated!

$\boxed{\text{Demo: capacitor hoist}}$

$\boxed{\text{Show || plate capacitor 1st}}$

Use same principle with an object called a capacitor: two conducting plates. (Big blue thing – plates wrapped up inside the insulating cover)

Attach a battery – charge plates



Then connect plates w/a wire – allows ⊖ to flow from ⊖ to ⊕ – gain KE as lose $U^E$

That energy is used to power a motor!

So our question for the next few classes is: how much energy can we store in arrangements of charge

As usual, start simple: ask how much energy is stored just having two opp charges near each other – for example, in a salt dimer $Na^{\oplus}Cl^{\ominus}$. Call them $q_1$ & $q_2$

$q_1 \quad q_2$

~~PE~~

~~We already know $\Delta V_{AB}$ for charge moving through field of a point charge~~

Define $U^E = 0$ when so far apart that there is no interaction

$q_1 \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad q_2$

Ask: ~~what amount of energy is gained/lost~~ what is change $\Delta U^E_{\infty r_{12}}$ to bring $q_2$ to be a distance $r_{12}$ away?

$q_1 \xrightarrow{r_{12}} q_2$

We know $\Delta U^E_{AB} = q\Delta V_{AB}$

change in PE of a charge $q$ moving through $\vec{E}$ is given by

We know potential diff in field of a point charge Q:

$$\Delta V_{AB} = kQ\left(\frac{1}{r_B} - \frac{1}{r_A}\right)$$

so what is $\Delta V_{\infty r_{12}}$ in field of $q_1$?

$$\Delta V_{\infty r_{12}} = kq_1\left(\frac{1}{r_{12}} - \frac{1}{\infty}\right) = \frac{kq_1}{r_{12}} = V(r_{12})$$

Thus the change in potential energy of $q_2$ is

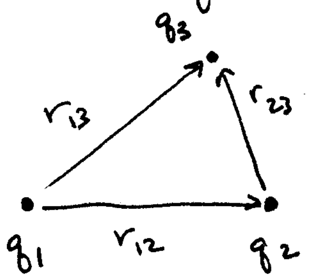
$$\Delta U^E_{\infty r_{12}} = q_2 \Delta V_{\infty r_{12}} = \frac{kq_1 q_2}{r_{12}}$$

CT

If $q_1, q_2$ both same sign, $\Delta U$ is ⊕ — increased PE — will fly apart if you let go

BUT if opp sign, $\Delta U$ is ⊖
this is the binding energy of an ionic bond

If you want to add a third charge, then need to figure out how much more energy is required to add the third due to its interaction with $q_1$ and with $q_2$




$$\Delta U_{\text{to add 3}} = q_3 \Delta V_{\infty 3}$$

This is the potential due to $q_1$ & $q_2$ at the location where $q_3$ is

Use superposition:

$$V_{\text{due to } q_1 \& q_2}(r_3) = V_{q_1}(r_{13}) + V_{q_2}(r_{23})$$
$$= \frac{kq_1}{r_{13}} + \frac{kq_2}{r_{23}}$$

$$\Rightarrow \Delta U_{\text{to add 3}} = q_3\left(\frac{kq_1}{r_{13}} + \frac{kq_2}{r_{23}}\right)$$