Homework Solutions are posted in glass case near TH 124 (1st Floor Thornton Hall)

Lecture notes for each class appear on the class website:

http://www.physics.sfsu.edu/~chris/physics121/

...sometimes just before class!
A location’s **Voltage** is the amount of Potential Energy that one **Coulomb of (+) charge** would have at that location.

Voltage is Energy *per charge*. \[ V = \frac{U}{q_o} \]

The units of Voltage are: **Joules/Coulomb**

**Or, simply: VOLT.**

One Volt = One Joule/Coulomb \[ 1V = J/C \]

Note: we use “V” for Voltage (quantity) and Volt (unit)
Voltage by any other name......

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Units</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric energy</td>
<td>$U$</td>
<td>joules</td>
<td>energy associated with electric force</td>
</tr>
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</table>

Since Voltage is related to potential energy, it is sometimes called....

Electric Potential

or just

“Potential”

Confusing? Yes.
The Unit of Voltage is “Volts”

Like all SI units, we can have multiples of 1 Volt:

milliVolt = mV = 0.001 V

Volt = 1 V

kiloVolt = 1000 V

nerve cell: 70 mV

9 Volt Battery

BART’s Electric 3rd Rail: 1 MegaV  Do Not Touch!
On a flat table, a ball placed anywhere has the same potential energy...so, it will not move.

Similarly, if the Voltage \((V)\) is the same everywhere a charge will not move.

There is no Electric Field \((E)\) to push it around

However, if \(V\) is changing from place to place \((\Delta s)\), then an electric field is present.

\[
E = - \frac{\Delta V}{\Delta s}
\]

...corresponds to a decrease in the electric potential, \(V\).
E, U, and V

The Electric Field, and the Voltage ("electric potential") are a property of a given location.

Potential energy is a property of an object.

Tips:

Think about the potential energy (U) of a positive charge using the gravity analogy.

Then use:  \( V = \frac{U}{q} \)

Think about negative charges, if needed.
YOUR TURN: A and B are two locations within a capacitor (not charged particles)

1.) Where does a proton have more potential energy, A or B?
2.) Is the Voltage higher at point A or B?
3.) Where does an electron have more potential energy, A or B?
Free Floating Charges

If you release a charged particle, it will move....
  In the direction of the E field if it is positive.
  In the opposite direction of the E field if it is negative.

Equivalently, it will move....
  Toward decreasing voltage (V) if it is positive.
  Toward increasing voltage (V) if it is negative.

But, in both cases, the freely-moving charge loses potential energy (U), as it gains kinetic energy.
Conservation of Energy

The **total energy** of a system *never changes*. 

*(Initial Total Energy = Final Total Energy)*

**Total Energy =** Kinetic \( (1/2 \, m \, v^2) \) + Potential \( (U) \) + ...  

\[
\begin{align*}
U_{\text{gravity}} &= m \, g \, h \\
U_{\text{spring}} &= 1/2 \, k \, x^2 \\
U_{\text{electric}} &= q \, V = q \, E \, d
\end{align*}
\]

If there’s *before* and an *after*, then **total energy** \((ET)\) doesn’t change:

\[
ET_A = ET_B
\]
We can use this to determine the velocity of a particle released in an electric field.

Example: What would be the speed of a proton released from rest, at the positive terminal of a 9V battery when it reached the negative terminal?

\[
\frac{1}{2}mv_A^2 + U_A = \frac{1}{2}mv_B^2 + U_B
\]

\[
\frac{1}{2}mv_B^2 = \frac{1}{2}mv_A^2 + U_A - U_B
= \frac{1}{2}mv_A^2 + q(V_A - V_B)
\]
New Unit of Energy: electron Volts (eV)

A free electron in an electric field will pick up kinetic energy.

This allows us to define a new unit of energy. Suppose two places have a voltage difference of 1 Volt. (ΔV = 1 V). If we allow one electron to accelerate through this voltage difference, it will gain kinetic energy (KE). How much?

It gains as much KE as the PE it lost: PE = U = q * ΔV = (1 e)*(1V)

This amount of energy is called one “electronVolt” (symbol: eV).

The electron-Volt is a unit of energy:

\[ 1 \text{ eV} = (1.60 \times 10^{-19} \text{ C})(1 \text{ V}) = 1.60 \times 10^{-19} \text{ J} \]

Chemical Bonds have energy ~ 1 eV
X-rays have energy : ~10,000 eV (10 KeV)
Nuclear reactions’ energy: ~1,000,000 eV (MeV)
You must expend energy to push a test charge (+q₀) close to a charge (+q) at the origin.

So, q₀’s **potential energy** depends on distance (r) *inversely*.

If its distance *increases*...

Then its potential energy will *decrease* by:

\[
U_A - U_B = \frac{kq_0q}{r_A} - \frac{kq_0q}{r_B}
\]

“Chemical Energy” is just the re-arrangement of charged particles.
Voltage around a Charge

Now, using our definition: \( \Delta V = \Delta U / q_0 \)

We can compute the Voltage at any location, a distance \( r \) from a point charge (+q):

\[
U_A - U_B = \frac{kq_0 q}{r_A} - \frac{kq_0 q}{r_B}
\]

\[
V_A - V_B = \frac{kq}{r_A} - \frac{kq}{r_B}
\]

Only Changes in \( V \) matter. We can define \( V=0 \) wherever we want.
Important Convention:
We define $V=0$ at $r=\infty$

$r_B=\infty; \ V_B = 0$

$V_A - 0 = kq/r_A - 0$

The Voltage produced by a charge $q$, a distance $r$ away is:

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

(Note: $q$ can be + or -; $r$ is always +)
Superposition Principle  
**E** and **V**

1. The Electric Field Vector (\( \mathbf{E} \)) at a given location is the **vector sum** of all electric fields at that point.

2. The Voltage (\( V \)) at a given location is the **scalar sum** of the Voltages at that point due to all nearby charges.

Example: If charges \( q_1 \) and \( q_2 \) affect the voltage at a point (P), then that voltage is the sum of the voltages caused by \( q_1 \) and \( q_2 \):

\[
V(P) = \frac{kq_1}{r_1} + \frac{kq_2}{r_2}
\]

Where: \( r_1 = \text{dist. from } q_1 \text{ to } P \)  
\( r_2 = \text{dist. from } q_2 \text{ to } P \)
Consider 2 positive charges on the x-axis:

What is the Voltage at the origin, where $x = 0$?
Consider 2 positive charges on the x-axis:

What is the Voltage at other points along the x-axis, \( V(x) \) ?
Positive everywhere. (and sometimes infinite!)
Electric potential of two point charges of opposite sign.
Electric Field due to a point charge.

Suppose the Voltage at Point X is:
\[ V = 2 \text{ Volts}. \]

Where else would the voltage be the same?
Lines that connect points of \textit{equal} Voltage (V) are called: \textbf{Equipotential lines}

They are like contours of elevation on a topographic map.
Equipotential Surfaces & Electric Field

On a map, **contours** mark constant elevation; a ball will roll downhill: perpendicular to the curves. The closer together the curves, the steeper the slope.
“Heat maps” are another form of contour maps
Equipotential lines on a capacitor. Where are they the highest?