Phys 135B Activity 4: Electric Potential

By now, you are familiar with the electrostatic force and field. Next thing we will tackle is the energy considerations. Remember how we linked force and energy last semester: through work (**work = force\*distance\*cosθ,** the meaning of which was the amount of energy transferred) and potential energy (being **mgh** for gravitational case). So as we spoke in our last class, we are slowly borrowing concepts we learned in mechanics last semester to be able to have a complete, working picture of electricity. Let me remind you the gravitational case first.

**Basic definitions**

**Gravitational case:**

Suppose you are trying to lift a stone of mass m from point a to point b at constant velocity as shown below.

1. What would be the work required of you as an external agent?
2. What would be the work done by the gravitational field?

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|  | Wyou = Fyou\*dcosθ = (mg) (yb – ya) cos0° =  Wgr. field = Fgr. field\*dcosθ = (mg)h cos180°= |

We define the gravitational potential energy from these as P.E. = mgh. Since h must be measured from somewhere, P.E. is really the potential energy difference between two points whose heights differ by h. In short, keep in mind that it is only the change in potential energy that has a meaning. That is why we use the symbol ∆, meaning final value –initial value.

With these in mind, we define the change in the potential energy of a particle as it is moved from one point to another at constant velocity (no acceleration) in two equivalent ways:

**∆PE = Wext, (1)**

**∆PE = - Wfield. (2)**

For gravitational potential both of these equivalent equations would then give

∆PE = mgh.

**Work energy principle:**

The net work done on a system goes to changing its kinetic energy:

**Wnet = ∆KE (3)**

**Conservation of energy:**

The net work can be done by conservative forces and non-conservative forces. So in general

**∆KE = Wnet = WC + WNC. (4)**

Since WC = - ∆PE, we get

**∆PE + ∆KE = WNC, (5)**

which is the general conservation of energy principle. WNC is the work done by any non-conservative force such as the friction force, air drag, or the force you apply as a person. If the type of forces is conservative such as the gravitational force or electric force, then the work is called WC. To illustrate the meaning of (5), ask your self what would happen if the person moving the particle accelerated it, i.e., at the end of its travel the particle gained some kinetic energy. Then (1) is not valid, rather (5) is valid as **Wext** = **WNC = ∆PE + ∆KE**.

If there is no non-conservative force present than the right side of Eq (5) is zero giving us

**∆PE + ∆KE = 0. (6)**

Both (5) and (6) are forms of conservation of energy depending on the type of the forces involved.

**Electric case:**

In the electric case, we will also have a potential energy, and call it the electric potential energy. If a charge q moves from point a to point b, the change in its electric potential energy is given as

**∆PE = PEb – PEa. (7)**

Let us choose the PEa as our reference or ground (just like in the gravitational case), then

**∆PE = PEb-a, (8)**

where PEb-a means it is the potential of point b measured with respect to point a. Here we will define a very useful tool or concept, that is, the electric potential or voltage as

**PEb-a = q ∆Vb-a. (9)**

Or simply

**PE = q ∆V, (10)**

where ∆V is the difference in potential in going from a to b. All this means that the electric potential energy of a point (with respect to another point) is charge times the electric potential of the point with respect to that other point. The unit of voltage is volts (V), 1V = 1J/C.

Using Eq (1), (10) can be also written as

**Wext = q ∆V. (11)**

The meaning of this last equation is that it tells you how much work must be done to move a charge q under a potential difference of ∆V if one wants to move it with no acceleration.

Electric potential or voltage can be thought of as the potential energy per unit charge. So it is closely related to the potential energy, as such it is not a vector quantity, rather a scalar quantity. So, in general, it is easier to deal with. Furthermore, it is what you are most familiar with, as in the case of your 5-volt adapter/charger for you cell phone.

**Relation between electric potential and electric field**

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| There is a simple relation between the electric potential and electric field especially for uniform electric fields inside a pair of charged parallel plates. Given the setup at the right, |  |

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Since and , we would have

**∆V = ∆PE/q = E\*d (12)**

where ∆V is the difference in potential in going from a to b (Note that from now on, we will use the shorthand notation of V for ∆V).

**A word on the units:** As you probably have noticed the standard energy unit joules is too large for energies involved at the atomic scale. Therefore, we define a convenient unit for that scale. It is called the electron-volt (eV). 1 eV =1.6x10-19 J. From the definition of potential energy, 1 eV is the amount of energy required to move a proton (+e) through a potential difference of 1 V.

Let us work out the following examples:

**Example 1:** An electron is released from rest next to the negative plate of a pair of charged parallel plates. The potential difference between the plates is 110 volts. The electron accelerates toward the positive plate, which is d = 50 cm away from the negative one.

(a) What is the change in the potential energy of the electron?

(b) What is the kinetic energy of the electron when it reaches the positive plate?

(c) What is the electric field (magnitude and direction) the electron experiences?

(d) What is the force the electron experiences?

(e) What is the speed of the electron when it reaches the positive plate?

**Example 2:** Suppose an electron in the picture tube of a television set is accelerated from rest through a potential difference Vba = 5kV

(a) What is the change in its potential energy?

(b)What is the final speed of the electron at the positive plate? me = 9.11x10-31 kg.

**Electric potential of a point charge at a distance r:**

**V = kQ/r, (13)**

Note: V is a scalar quantity, but it can take a positive sign and a negative sign depending on the sign of its source charge.

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| **Example 3:** Determine symbolically the electric potential at the origin (right figure) given that three charges are situated at the shown corners of a square of side a. |

**THE EQUIPOTENTIAL LINES or SURFACES**

**Usefulness of electric potential:**

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| The concepts of electric field, electric potential, the amount of work that needs to be done as a charge moves through a potential difference are all related. The linking word is the equipotential lines in 2D and surfaces in 3D. To learn more about the equipotential lines, let us first answer a few questions for the figure at right. |  |

Investigative Question 1: What is the work required of an external force to move a positive charge from point a to point b?

Investigative Question 2: What would be the work required if we wanted to move the charge from point a to point a’?

Investigative Question 3: What would be the work required if we wanted to move the charge from point b to point b’?

Investigative Question 4: What would be the work required if we wanted to move the charge from point a to point b’?

The points such as a and a’ are at the same potential. We say a and a’ sit on an equipotential line. If you move the charge along such a line, it is a “free lunch,” that is, you are allowed to do that without having to do any work. Similarly points b and b’ themselves sit on their own equipotential line. In three dimensions, equipotential lines become equipotential surfaces.

Investigative Question 5: Can we say that if there is not electric field (E = 0), then there is no work (energy) required? Do we know any object that has zero electric field inside?

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| The equipotential lines are perpendicular to the electric field lines as can be inferred from our current discussion. The equipotential lines are shown as dashed lines in the figure below. |  |

Below you will do an activity to map out equi-potential lines and, from them, obtain the electric field lines.

We will use the following simulation program to do that

<http://phet.colorado.edu/sims/charges-and-fields/charges-and-fields_en.html>

Dr. Zorba will describe to you the simulation. The patterns that will be mapped out are

1. Two point charges: + and –
2. Two Point charges + and +
3. Charged parallel plates