Section 16: Electric Potential

In this lesson you will

- express an understanding of the way that the electric potential energy of a charge changes if work is done to move it against an electric field
- define *electric potential energy*, *electric potential*, and *electric potential difference* and write appropriate mathematical expressions
- express an understanding of the subtle differences among work done (*W*) by or against an electric field, the electric field itself (***E***), electric potential energy (**E**), electric potential (*V*), and electric potential difference (Δ*V*) in a uniform electric field and in the electric field that surrounds a point charge
- define *volt* and ~~*electron-volt*~~
- do introductory exercises

Recall: Electric Potential Energy (E_e) in a Uniform Field

Electric field or **electric field strength** at a particular point in the field is defined as the **electric force per unit charge** at that point. There were two mathematical expressions that grew out of the definition:

$$E = \frac{F}{q} \quad and \quad E = \frac{kq}{r^2}$$

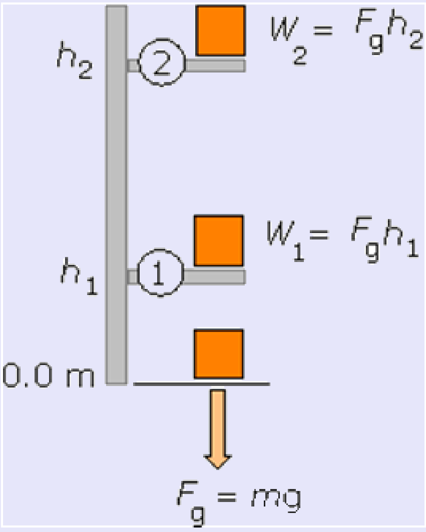
Electric Potential Energy (E_e) in a Uniform Field

To understand electric potential energy, let's revisit gravitational potential energy.

Any change to gravitational potential energy (E_g) comes as a result of lifting something, and is equal to the work done against the gravitational field. In the picture

$$E_{g1} = W_1 = F_g h_1$$

and $E_{g2} = W_2 = F_g h_2$.



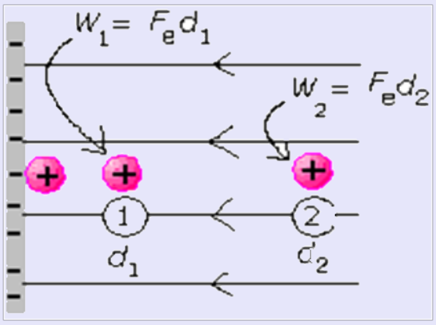
The work done in lifting the block from level 1 to level 2 (say W_{12}) is equal to the **change in** potential energy from level 1 to level 2:

$$W_{12} = \Delta E_g = E_{g2} - E_{g1} \text{ or}$$
$$W_{12} = \Delta E_g = F_g h_2 - F_g h_1$$
$$W_{12} = \Delta E_g = mg\,(h_2 - h_1),$$

where g = 9.8 N/kg and is called the gravitational field strength.

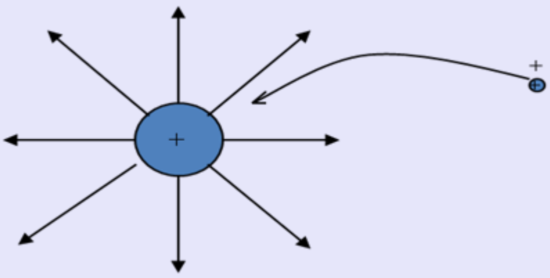
We say that gravitational potential energy is the energy gained when the object is moved against the gravitational field. If the object falls, then it is the field that is doing the work on the object and gravitational potential is lost.

Electric Potential Energy



The picture above shows a charge in **a uniform field**. In a uniform field, the lines of force are parallel which means that the electric field strength E is constant. E is analogous to g, the gravitational field strength in auniform gravity field. In the electrical situation to the right the positive charge would just love to stay on the negative plate. So, to get the charge to level 1 and then to level 2, work has to be done.

This time the force to overcome is not the force due to gravity, but is the electrical force, $\boldsymbol{F}_e$. And, the change in potential energy is not a change in gravitational potential energy (ΔE_g), but is called **a change in electrical potential energy, ΔE_e.**



When we move the charge against the electric field we will experience a repulsive force. The magnitude of the force varies with the distance from the center of the field, the strength of the field and the size of the charge being moved.

As we move the charge we do work. ($W = F_{AV}\ x\ d$) The field generates repulsive forces and attempts to repel the charge. If the charge is then held in position in the field the **work** we have **done is** transformed into potential energy, **Electrical Potential Energy**.

As with gravitational potential energy and elastic potential energy the energy is measured in Joules.

$$1\text{J} = 1\text{Nm} = 1\text{kg m}^2/\text{s}^2$$

Electric Potential Energy of a charge is equal to the work done in moving a charge against the electric field (or the total energy required to move a charge against an electric field).
Symbol: **W** or **E**

Voltage

Electric Potential is defined as the **electric potential energy per unit charge** (or **work done per unit charge**) as the charge is moved against the electric field. The electric potential is always considered to be with reference to the zero potential level. The **zero reference level for electric charge** is any location where the **potential energy is zero**. (An electron sitting on the surface of a positively charged object is at the zero reference level.) **Symbol: V**

Electric Potential Difference: is the electric potential energy required (or work done) per unit charge to move that charge from any point of low potential to any point of higher potential.

Formula: $V = \frac{W}{Q}$ **or** $V = \frac{E}{Q}$ Memorize

Where: **V:** is the Electric Potential in Volts (V or J/C)
E: or W is the Electric Potential Energy or work in Joules (J)
Q: is the unit of charge in coulombs (C)

The formula to calculate electric potential difference is the same as the one used to calculate electric potential.

A charge experiences an increase in electric potential energy because energy is expended to move it against some electric field. A charge can fall in an electric field as well. In this case, work is not being done on the charge. Rather, the charge does work as it falls from high potential to low potential.

Two main differences between electric potential and electric potential energy:

Electric potential (V) is

(i) electric potential energy per unit charge and
(ii) it is always with reference to a zero level of potential while

electric potential energy (E or W) is the total energy of the charge.

Examples:

1. In order to move a charge of 0.08 C from point A to point B in an electric field, 0.24 J of energy are required. What is the electric potential difference between the two points?

$Q = 0.08C$
$W = E = 0.24J$
$V = ?$

$$V = \frac{W}{Q} = \frac{0.24J}{0.08C} = 3.0V$$

2. The electric potential difference between two point charges in an electric field is 1.5 V. If 0.80 J of electric energy was expended in moving one of the charges, what must be the size of one charge?

$V = 1.5V$
$E = W = 0.80J$
$Q = ?$
$\left[\frac{J}{V} = \frac{J}{J/C} = J \times \frac{C}{J}\right]$

$V = \frac{W}{Q}$

$Q = \frac{W}{V}$

$= \frac{0.80J}{1.5V} = 0.53C$

3. As a charge of 3.0μC moves into an electric field, it experiences a potential difference of 2.0 x 10^{-6} V. What electric potential energy was required to move the charge?

$Q = 3.0\mu C$
$V = 2.0 \times 10^{-6} V$
$E = W = ?$

$V = \frac{W}{Q}$

$W = VQ$

$W = (2 \times 10^{-6} V)(3 \times 10^{-6} C)$

$W = 6 \times 10^{-12} J$

4. At certain point in an electric field, a charge of 2.0 μC has electric potential energy of 18 J. What would be the electric potential energy at the same point for a charge of 6 μC?

$Q_1 = 2\mu C$ $Q = 6\mu C$
$E = 18J$ $E = ?$

$V_1 = V_2$

$\frac{W}{Q_1} = \frac{W}{Q_2}$

$\frac{18J}{2\mu C} = \frac{W}{6\mu C}$

$W = 54J$

$V \propto \frac{W}{Q}$

$W \propto VQ$