Lesson 12: Electric Potential Energy & Voltage

To better understand **electric potential energy** it is a good idea to first review **gravitational potential energy** and figure out similarities between them.

- Understanding the parallels between (seemingly) unrelated things in physics is actually one of the best ways to learn physics.

Gravitational Potential Energy

Imagine holding a ball up in the air as high as you possibly can.

- At the top, we can say that the object has ***maximum*** **gravitational potential energy**.
- The ball doesn't want to be up there, so if you let go it will start to move down towards the ground on its own. It will accelerate all the way down.
  - While it is falling we know that the **gravitational potential energy** is being converted to **kinetic energy**.
- When it reaches the ground (its reference point) it has no **gravitational potential energy** remaining. It's all changed to **kinetic energy**.
  - Basically, the ball has gone through a change in energy from one form to another (ΔE).

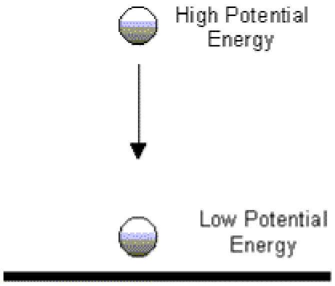

Illustration 1: Gravitational potential energy

If you want to get the ball back up in the air, you've got to do some work.

- As you do your work ($W = \Delta E$), you are giving back **gravitational potential energy** to the ball, until at the top it is back to having ***maximum*** **gravitational potential energy**.
- This change in **gravitational potential energy** depends on…
  1. Mass of the object ($\mathbf{E_p}$ α m)
  2. Gravitational field strength ($\mathbf{E_p}$ α g)
  3. Height to which the object is moved ($\mathbf{E_p}$ α h)

So, for example, if you needed to lift an object with twice the mass, you would need to do twice the work.

Electric Potential Energy

If we follow the same ideas that we did above, you might see that there are similarities between the **gravitational potential energy** described above and **electric potential energy**.

Lets say you place a positive charge near the positive plate in an electric field between two parallel plates.

- At the top, we can say that the charge has ***maximum*** **electric potential energy**.
- The charge doesn't want to be up there, so if you let it start to move it will be repelled away from the positve plate and attracted towards the negative plate. It will accelerate all the way down.
  - While it is falling we know that the **electric potential energy** is being converted to **kinetic energy**.
- When it reaches the negative plate (its reference point) it has no **electric potential energy** remaining. It's all changed to **kinetic energy**.

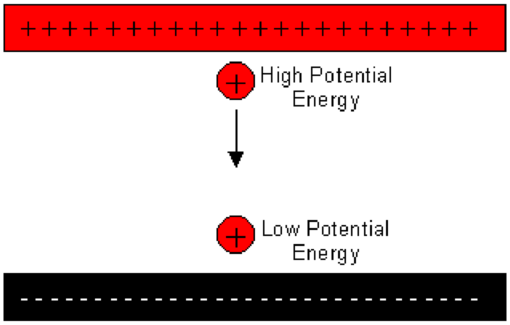

Illustration 2: Electric potential energy

  - Just like the ball, the charge has gone through the same kind of change in energy from one form to another (ΔE).

If you want to get the charge back up against the positive plate, you've got to do some work.

- As you do your work (W = ΔE), you are giving back **electric potential energy** to the ball, until at the top it is back to having ***maximum*** **electric potential energy**.
- This change in **electric potential energy** depends on...
  1. Charge of the object ($E_p \ \alpha \ q$)
  2. Electric field strength ($E_p \ \alpha \ \vec{E}$)
  3. Distance the object is moved parallel to the field lines ($E_p \ \alpha \ d$)

So, for example, if you needed to move a charge with twice the charge, you would need to do twice the work.

Voltage

I know that sometimes I might seem a little fixated on the history side of physics, but I have a good reason. One is that the names that were given to ideas when they first came out might be different from the ones used today, and those older names might still have a meaning that helps us.

- A great example is what we are looking at in this section... **voltage**. It is sometimes still referred to by different names like **electric potential difference**, **electric potential**, or **potential difference**.

But this still doesn't explain what **voltage** is about.

- **Voltage** is the change in **electric potential energy** ***per unit charge.***
  - When we were talking about **gravitational potential energy**, it would sort of be like saying "How much work do I have to do to lift up something against gravity per kilogram." Something that has more mass would need more work to be done to it.
- Now we are measuring the **voltage**... how much work is needed per Coulomb of charge. If something has more charge, it needs more work to move it.

The unit for voltage could be given in J/C, but instead it is a derived unit called the **Volt (V)** in honor of Alessandro Volta.

- This means that we have a formula for voltage that looks like this...

$$V = \frac{\Delta E}{q}$$

V = voltage (V)
ΔE = electric potential energy (J)
q = charge (C)

Example 1: A 3.4 C charged object gains 2.6e3J as it moves on its own through an electric field. **Determine** the electric potential difference. **Explain** if this is an increase in potential or kinetic energy.

Keep in mind that electric potential difference is the same as voltage...

$$V = \frac{\Delta E}{q}$$

$$V = \frac{2.6e3\,J}{3.4\,C}$$

$$V = 764.70588 = 7.6e2\,V$$

This is a charged particle moving on its own through an electric field, so it must be moving from an area of high to low potential energy. This means it is an increase in the kinetic energy of the charge.

Electron Volts

Sometimes it is not convenient to measure energy in Joules.

- This is quite often the case when we are dealing with charges like electrons moving through potential differences.
- Instead, we can use a different unit, that although it is not part of the metric system, is still useful... the electron volt.
  - If we look at the formula for voltage and solve it for energy, we get...

$$\Delta E = qV$$

- Typically we would just put in the value for the charge in Coulombs and the Voltage in Volts.
  - Instead, we will define one electron volt as the energy needed to move one electron through one volt of potential difference.

$$\begin{gathered}\Delta E = qV \\ 1\,eV = 1\,electron(1\,Volt) \\ 1\,eV = 1.60\text{e-}19\,C(1\mathrm{V}) \\ 1\,eV = 1.60\text{e-}19\,J\end{gathered}$$

If you need to do a calculation of energy in electron volts, you just figure out how many elementary charges you have multiplied by the voltage they moved through.

Example 2: Remember the parallel plates from example 1? **Determine** how may electron volts are needed to move an alpha particle through the 7.6e2V of potential difference from the negative to the positive plate.

As shown on your data sheet, an alpha particle has a +2e charge.

$$\begin{aligned}\Delta\ E &= qV \\ \Delta\ E &= 2e(7.6\mathrm{e}2\mathrm{V}) \\ \Delta\ E &= 1520 = 1.5\mathrm{e}3\,eV\end{aligned}$$

Warning!
When you do this, remember two things. First, "+2e" does not mean 2 electrons, it mean 2 elementary charges. Second, the answer in electron volts is not a metric unit and can not be used in any other formulas.

If you want to, you can use the conversion shown above (it's also on your data sheet) to show that 1.5e3 eV = 2.4e-16 J.

$$\frac{1.60\text{e-}19\,J}{1\,eV} = \frac{x\,J}{1520\,eV}$$
$$x = 2.4\text{e-}16\,J$$

Homework

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