

Lesson 12: Electric Potential Energy & Voltage

Gravitational Potential Energy

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.

According to Newton's Second Law, if a force acts on an object it will accelerate.

- If you drop an object, the force due to gravity will cause it to accelerate down.
- At the top, we can say that the object has a high **gravitational potential energy**... in fact, it has its greatest potential energy at this point.
- While it is falling we know that the **gravitational potential energy** is being converted to **kinetic energy**, so that at the bottom (its reference point) it has no **gravitational potential energy** remaining.

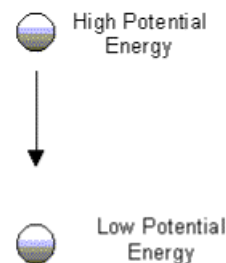


Illustration 1: Gravitational potential energy

Now if you want to move the object from its position of low potential energy to high potential energy, you must do work on the object.

- The work is necessary since you are adding **gravitational potential energy** to the object.
- You would do the work using...

$$W = Fd \quad \text{and} \quad F = ma$$

$$W = mad$$

$$\text{since } a = g \text{ and } d = h \dots$$

$$W = mgh$$

- So the the work you do to change the **gravitational potential energy** is...

$$E_p = mgh$$

- No big surprise there; it's just our good old **gravitational potential energy** formula.
- What is important to realize is that we are specifically looking at this in terms of how much work needs to be done to increase the object's potential energy, from an area where it has low potential to an area where it has high potential.
- This change in **gravitational potential energy** depends on...
 1. Mass of the object ($E_p \propto m$)
 2. Gravitational field strength ($E_p \propto g$)
 3. Height to which the object is moved ($E_p \propto h$)

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 charge in an electric field and release it.

- We expect the charge will begin to accelerate from an area of high potential energy, to an area of low potential energy.
 - This is because there is an electric force acting on the charge.
- Notice that this is just like the object dropped in the discussion above; the difference is that here the reason is electrical in nature.

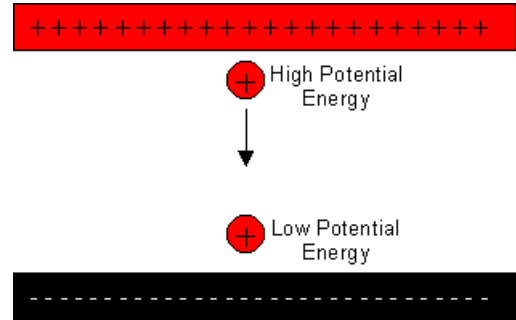


Illustration 2: Electric potential energy

If you want to move the charge from a position of low to high potential energy, you must do work on the object against the electric force.

- Again, this sounds exactly like what we were talking about above when we lifted the ball back up against the gravitational force.
- You would calculate it using...

$$W = Fd \quad \text{and} \quad \vec{E} = \frac{F_e}{q}$$

$$W = q \vec{E} d$$

- This looks very much like the formula we used to figure out **gravitational potential energy**.
- The change in the **electric potential energy** depends on...
 1. Charge of the object ($W \propto q$)
 2. Electric field strength ($W \propto \vec{E}$)
 3. Distance the object is moved parallel to the field lines ($W \propto d$)

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

Example 1: A positive charge of $2.3 \times 10^{-6} \text{ C}$ is between two parallel plates. It is close to the negative plate. The electric field between the two plates is 1500 N/C . If we move the particle 2.0 cm closer to the positive plate, **determine** how much work we need to do.

$$W = q \vec{E} d = 2.3 \times 10^{-6} \text{ C} (1500 \text{ N/C}) (0.020 \text{ m}) = 6.9 \times 10^{-5} \text{ J}$$

Example 2: In the example above, **determine** how much **electric potential energy** the charge gained. Since we did $6.9 \times 10^{-5} \text{ J}$ of work, we must have transferred that energy to the charge. That means it has gained $6.9 \times 10^{-5} \text{ J}$ of **electric potential energy**.

Example 3: If everything else was kept the same, **determine** how much work you would need to do to move a $4.6 \times 10^{-6} \text{ C}$ charge.

The only difference is that it is double the charge, so it would take double the work, $1.4 \times 10^{-4} \text{ J}$.

Voltage

I know that sometimes I might seem a little fixated on the history side of physics, but I have a good reasons. 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...

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

$$\begin{aligned} V &= \text{voltage (V)} \\ \Delta E &= \text{electric potential energy (J)} \\ q &= \text{charge (C)} \end{aligned}$$

Example 4: Determine the electric potential difference of a 3.4 C charged object that gains 2.6e3J as it moves through an electric field.

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

$$\begin{aligned} V &= \frac{\Delta E}{q} \\ V &= \frac{2.6e3 \text{ J}}{3.4 \text{ C}} \\ V &= 7.6e2 \text{ V} \end{aligned}$$

Example 5: Determine the voltage if an electron gains 2.34e-15 J as it moves between two parallel plates.

$$\begin{aligned} V &= \frac{\Delta E}{q} \\ V &= \frac{2.34e-15 \text{ J}}{1.60e-19 \text{ C}} \\ V &= 1.46e4 \text{ V} \end{aligned}$$

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.

$$\Delta E = qV$$

$$1 \text{ eV} = 1 \text{ electron}(1 \text{ Volt})$$

$$1 \text{ eV} = 1.60\text{e-}19 \text{ C}(1\text{V})$$

$$1 \text{ eV} = 1.60\text{e-}19 \text{ J}$$

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 6: Determine how many electron volts are needed to move an alpha particle through 20V.

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

$$\Delta E = qV$$

$$\Delta E = 2e(20\text{V})$$

$$\Delta E = 40\text{eV}$$

If you want to, you can use the conversion shown above (it's also on your data sheet) to show that 40eV is equal to $6.4\text{e-}18 \text{ J}$.

Warning!

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