

Lesson 13: Voltage in a Uniform Field

Most of the time if we are doing experiments with electric fields, we use parallel plates to ensure that the field is uniform (the same everywhere).

- This carries over to our study of voltage. If we use parallel plates, then we also get a uniform change in potential difference.
 - If a charged particle is released between the plates, it will move on its own from an area of high potential, to an area of low potential.
 - If the charge is moved a distance, d , the change in **electric potential energy** can be found with...

$$W = Fd \Rightarrow \text{which is the same as } \Rightarrow \Delta E_p = Fd$$

Combine that with $V = \frac{\Delta E}{q}$ to get...

$$V = \frac{\Delta E}{q} = \frac{Fd}{q} = \frac{F}{q} d$$

...and we know that $\vec{E} = \frac{F}{q}$ so...

$$V = \vec{E} d$$

Although you can certainly use the formula this way, we see it on the data sheet as...

$$|\vec{E}| = \frac{\Delta V}{\Delta d}$$

$|\vec{E}|$ = electric field (N/C)

ΔV = voltage (V)

Δd = distance between locations (m)

This formula is typically applied to situations where parallel plates are being used, since this is the easiest way to have a uniform electric field.

- The direction for the field is still determined by the direction a **positive** test charge would move.
- Also, notice that because of this formula, we can show that the electric field can also be measured in V/m, not just N/C.
 - Try to prove that the units for V/m are equivalent to N/C ... my hint is that you should try to break all the derived units down to base units.

Example 1: We have two parallel plates that are 16.0mm apart.

a) If we want a uniform field of 800 N/C between these plates, **determine** the voltage we must apply to the plates.

$$|\vec{E}| = \frac{\Delta V}{\Delta d}$$

$$\Delta V = |\vec{E}| \Delta d$$

$$\Delta V = 800(0.0160)$$

$$\Delta V = 12.8 \text{ V}$$

b) **Determine** how much work you need to do to move an alpha particle (see the info on your data sheet) from the negative plate to the positive plate.

$$V = \frac{\Delta E}{q}$$
$$\Delta E = Vq$$
$$\Delta E = 12.8(3.20\text{e-}19)$$
$$\Delta E = 4.10\text{e-}18 J$$

c) **Explain** if this energy is kinetic or potential?

Since I am moving a positive charge closer to the positive plate, it will be in a region where it has higher **electric potential energy**. It is true that in the act of moving it, the alpha particle will have kinetic energy, but the main thing to focus on is that from when I started moving it to when I finish moving it up against the positive plate, I have increased its **electric potential energy**. That's the stored energy you just calculated.

If the alpha particle was now released, then the **electric potential energy** would change into kinetic energy as the particle moved back over to the other plate.

All these formulas allow you to do a great variety.

- You might think that the individual formulas are easy, but be careful. There's lots of formulas to keep straight.

Example 2: An alpha particle moves between two parallel plates $2.7\text{e-}2$ m apart with a potential difference of 130 V between them. **Determine** the force that acts on the particle.

First we need to know how strong the electric field is...

$$|\vec{E}| = \frac{\Delta V}{\Delta d} = \frac{130}{2.7\text{e-}2} = 4815 \text{ N/C}$$

Then we can figure out the force that is needed...

$$\vec{E} = \frac{F_e}{q}$$
$$F_e = \vec{E} q = 4815(3.20\text{e-}19) = 1.5\text{e-}15 \text{ N}$$

Note that we only round off at the end of the question for sig digs.

Conservation of Energy in a Uniform Field

We can do a lot of questions if we keep in mind the Law of Conservation of Energy.

- If a charged particle is doing all this moving around, we can use the information we have to figure out how the **electric potential energy** of the particle can become **kinetic energy** as it moves, or the reverse.
 - The majority of these questions will involve electrons, so keep in mind that they have a charge of $1.60\text{e-}19$ C and a mass of $9.11\text{e-}31$ kg (both of which are shown on your data sheet)
 - It is also possible that a question could involve protons, alpha particles, or even some other charged particle that you are given information about.
 - For example, they might tell you that the question deals with a Calcium ion with a mass of $6.65\text{e-}26$ kg and a $2+$ charge ($+3.20\text{e-}19$ C).

Example 3: An electron is accelerated from rest between two parallel plates, 4.0 cm apart from each other. The voltage between the plates has been set at 20V.

a) **Determine** the velocity of the electron when it reaches the positive plate.

We know that the electron is going to be picking up a lot of kinetic energy as it is attracted to the positive plate and repulsed by the negative plate. We can calculate this energy this way...

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

$$\Delta E = Vq$$

$$\Delta E = 20(1.60e-19)$$

$$\Delta E = 3.2e-18 J$$

Since the electron started from rest, any energy it gained must be in the form of kinetic energy. We can figure out the velocity of the electron this way...

$$E_k = 1/2 mv^2$$

$$v = \sqrt{\frac{2E_k}{m}}$$

$$v = \sqrt{\frac{2(3.2e-18)}{9.11e-31}}$$

$$v = 2.7e6 m/s$$

Notice that this is about 1% the speed of light. If we were in a university level course, we would probably have to redo our calculations, taking into account Einstein's Special Theory of Relativity. At these sorts of speeds, lots of weird stuff starts to happen. You don't need to worry about it in this course.

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b) You have calculated the maximum velocity for the situation where the electron has accelerated all the way from the negative to the positive plate, going through the entire potential difference. **Determine** the electron's velocity when it has only moved 1.0 cm away from the negative plate.

Method 1

First, let's calculate the electric field between those plates...

$$|\vec{E}| = \frac{\Delta V}{\Delta d}$$

$$|\vec{E}| = \frac{20}{0.040}$$

$$|\vec{E}| = 500 = 5.0e2 V/m$$

I wrote the units as V/m, but that's ok since it is equivalent to N/C.

Second, let's calculate how many volts the electron has moved through by moving 1.0cm away from the negative plate. It hasn't gone through all 20 V, just a fraction.

$$|\vec{E}| = \frac{\Delta V}{\Delta d}$$

$$\Delta V = |\vec{E}| \Delta d$$

$$\Delta V = 500(0.010)$$

$$\Delta V = 5.0V$$

Knowing the voltage (potential difference) the electron has passed through and its charge, we can figure out the change in energy...

$$V = \frac{\Delta E}{q}$$
$$\Delta E = Vq$$
$$\Delta E = 5(1.60e-19)$$
$$\Delta E = 8.0e-19 J$$

Finally, we use that energy to figure out the velocity of the electron...

$$E_k = 1/2 mv^2$$
$$v = \sqrt{\frac{2E_k}{m}}$$
$$v = \sqrt{\frac{2(8.0e-19)}{9.11e-31}}$$
$$v = 1.3e6 \text{ m/s}$$

Method 2

We know that the electric potential (voltage) is spread out evenly over the whole space between the plates. So, we could set up a ratio based on the fact that the electric field is also a constant all the way in between the plates.

$$|\vec{E}| = \frac{\Delta V}{\Delta d}$$
$$\frac{\Delta V_1}{\Delta d_1} = \frac{\Delta V_2}{\Delta d_2}$$
$$\frac{20}{0.040} = \frac{x}{0.010}$$
$$x = 5.0 V$$

Now that we have the voltage, we can do the rest of the question the same as **Method 1**.

Homework

p561 #1, 2
p565 #1, 2
p566 #1, 2
p568 #1, 2
p571 #1
p573 #2
p574 Example 11.12