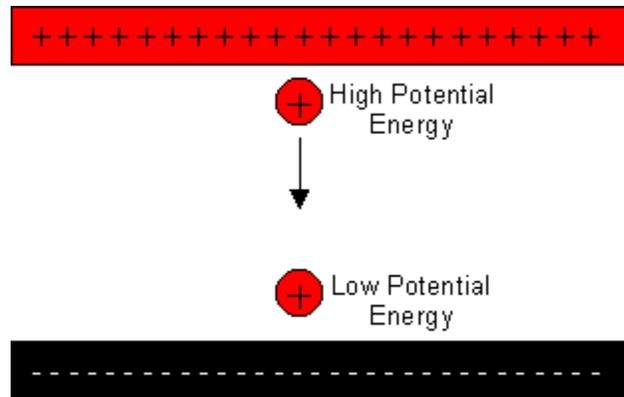


Note-A-Rific: Potential Difference

Electric Potential Difference (Voltage)

If you place a charge in an electric field and release it, the charge will begin to accelerate from an area of high potential energy, to one of low potential energy.

- This is because there is an electric force acting on the charge.



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 field.

- You would calculate it using...

$$W = Fd$$

Remember from before that $E = F/q \rightarrow F = qE$

So the change in potential energy of the charged object is...

$$W = qEd$$

Potential Energy of a charge depends on...

1. **Charge of the object ($W \propto q$)**
2. **Electric field strength ($W \propto E$)**
3. **Distance the object is moved parallel to the field lines ($W \propto d$)**

Example: 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 2.0cm closer to the positive plate, how much work do we need to do?

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

The **electric potential difference (voltage)** is the change in potential energy per unit charge...

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

The unit for voltage, J/C , is given the name **volt (V)** in honour of Alessandro Volta.

- Volta is best remembered for inventing the first electric battery, a topic we will be covering shortly.

Example: What is the electric potential difference of a 3.4 C charged object that gains $2.6 \times 10^3 \text{ J}$ as it moves through an electric field?

$$V = \frac{\Delta E}{q} = \frac{2.6 \times 10^3 \text{ J}}{3.4 \text{ C}} = 7.6 \times 10^2 \text{ V}$$

Electric Potential in a Uniform Field

What is the potential difference (voltage) between two points in an uniform electric field?

- If a charge is placed in a uniform field and is moved a distance, d , the change in potential energy can be found with...

$$\mathbf{W = Fd}$$

$$\mathbf{\Delta E_p = Fd}$$

- Remember that... $V = \frac{\Delta E}{q}$

- So... $V = \frac{Fd}{q} = \frac{F}{q}d$

- We also know that $E = F/q$ so, $V = E d$

- This formula is usually written out as $E = V/d$.

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

- a) If we want a uniform field of 800 N/C what voltage must we apply to the plates?

$$\begin{aligned} V &= Ed \\ &= (800 \text{ N/C}) (0.0160 \text{ m}) \\ V &= 12.8 \text{ V} \end{aligned}$$

- b) How much work do you need to do to move a helium nucleus ($q = 3.2 \times 10^{-19} \text{ C}$) from the negative plate to the positive plate?

$$\begin{aligned} V &= \frac{\Delta E}{q} \\ \Delta E &= Vq \\ &= (12.8 \text{ V}) (3.2 \times 10^{-19} \text{ C}) \\ \Delta E &= 4.1 \times 10^{-18} \text{ J} \end{aligned}$$

- c) Is this energy 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 potential energy.

With the formulas you now have there is great variety of questions you can do...

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

Example: An alpha particle (see your data sheet) moves between two parallel plates 2.7×10^{-2} m apart with a potential difference of 130 V between them. What force acts on the particle?

$$E = V/d = (130\text{V}) / (2.7 \times 10^{-2}\text{m}) = 4.8 \times 10^3 \text{ N/C} \quad \leftarrow \text{note the units can also be V/m !}$$

$$E = F/q \rightarrow F = Eq = 4.8 \times 10^3 \text{ N/C} (3.2 \times 10^{-19}\text{C}) = 1.54 \times 10^{-15} \text{ N}$$

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

a) What is 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...

$$V = \Delta E / q \rightarrow \Delta E = Vq = 20\text{V} (1.6 \times 10^{-19}\text{C}) = 3.2 \times 10^{-18} \text{ J}$$

- 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...

$$E_k = \frac{1}{2} mv^2 \rightarrow$$

$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2(3.2 \times 10^{-18})}{9.11 \times 10^{-31}\text{kg}}} = 2.7 \times 10^6 \text{ m/s}$$

- 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, but you folks don't need to worry about it in this course.

b) What was its velocity when it had only moved 1.0 cm away from the negative plate?

Method 1

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

$$E = V/d = (20\text{V}) / (0.040\text{m}) = 5.0 \times 10^2 \text{ V/m} \quad \leftarrow \text{Notice that the units for electric field can be V/m or N/C}$$

- Second, let's calculate how many volts the electron has moved through by going 1.0cm from the negative plate...

$$5.0 \times 10^2 \text{ V/m} (0.010\text{m}) = 5.0 \text{ V}$$

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

$$V = \frac{\Delta E}{q} \rightarrow \Delta E = Vq = (5.0V)(1.6 \times 10^{-19}C) = 8.0 \times 10^{-19} J$$

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

$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2(8.0 \times 10^{-19})}{9.11 \times 10^{-31} kg}} = 1.3 \times 10^6 m/s$$

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...

$$\frac{20V}{4.0cm} = \frac{x}{1.0cm}$$

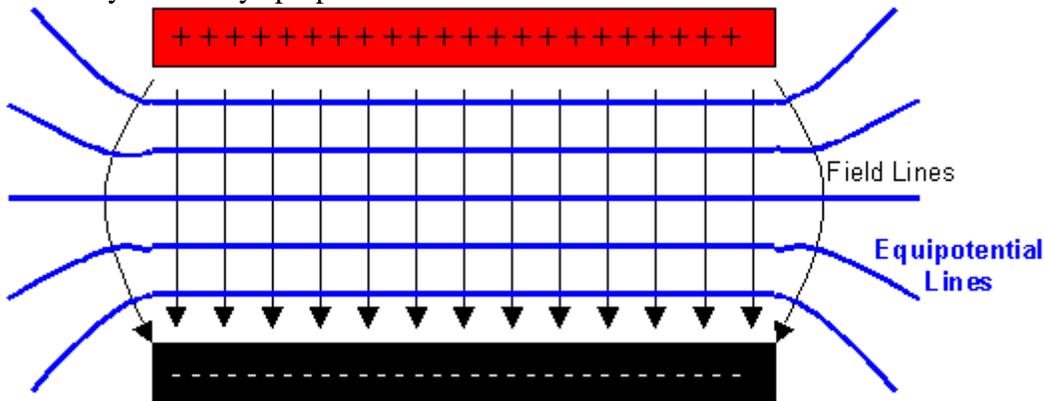
$$x = 5.0V$$

- From this point on you do it the same as method 1.

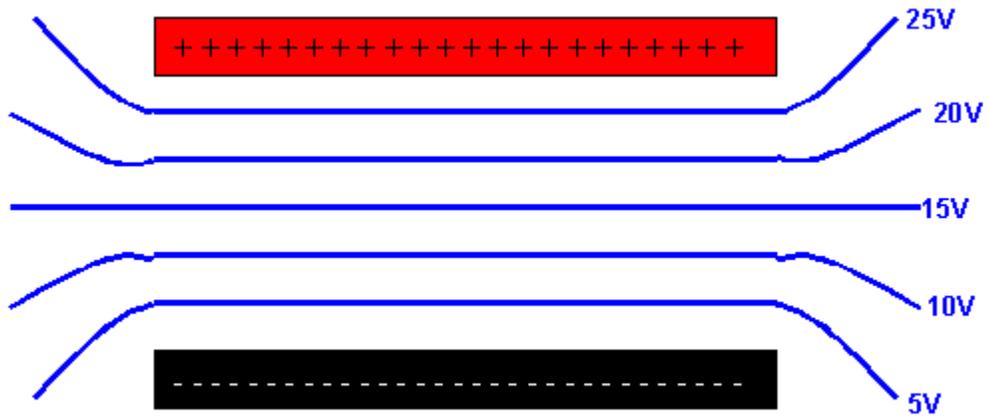
Equipotential Lines

The solution of the above problem depends on the idea that the voltage is spread out evenly.

- Equipotential lines show regions where the voltage is the same.
- They are always perpendicular to the field lines.



- So, if the total potential difference (voltage) between two plates is 30 V over a distance of 6.0cm, you could draw a diagram like this:



- Remember this when you have to do questions involving a charged particle moving part ways through an electric field.