Introduction to Electric Potential **Name** ______________________________

Physics II **Date** ____________ **Period** ___________

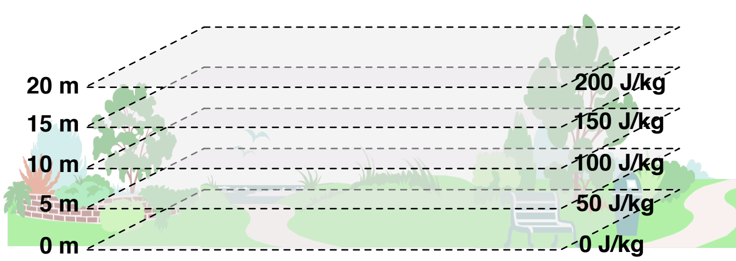
Electric potential is as important as any concept when it comes to understanding static electricity and electric circuits. It is measured in volts, which you have already heard of. It is something that is easy to measure and extremely useful for all electrical circuits and devices.

In order to get a basic understanding of electric potential we will first look at the idea of potential in a field that we already know something about, namely, the gravitational field. Gravitational potential is a lot like electric potential. Once we get the basic idea of gravitational potential, we will then deal with electric potential.

Gravitational Potential

Gravitational potential is related to gravitational potential energy. As you may remember, gravitational potential energy is energy stored in the gravitational field. When you lift something up, it costs you some energy. The gravitational field gains energy from you when you lift something up, and it loses energy when something descends. We calculate gravitational energy using $GPE = mgy$ where m is the mass of the object of interest, g is the strength of the gravitational field, and y is the vertical position of the object relative to the level we decide on to be $y = 0$.

If we put a 1 kg object at a height $y = 1$ m, the gravitational energy associated with this object is $GPE = (1 \text{ kg})(10 \text{ N/kg})(1 \text{ m})$. This is just 10 Nm, which is 10 Joules. If we put a 2 kg object at the same place, 1 m above $y = 0$, there will be 20 J of GPE. If we put 5 kg at that same location, then I hope you know that there will be 50 J. You may notice that there are 10 J of GPE for each 1 kilogram of mass *at* $y = 0$. The number of Joules of GPE per kilogram is what we call *gravitational potential*. And this gravitational potential is a property of a place in a gravitational field. For example, wherever $y = 2$ m, the gravitational potential will be 20 J/kg. Wherever $y = 5$ m, the gravitational potential will be 50 J/kg. Does this make sense?



Gravitational potential is the *potential energy load factor* for each kilogram of mass at a specific location in a gravitational field.

The only difference between gravitational potential and electric potential is that electric potential is a property of a place in an electric field, not a gravitational field. A gravitational field is created by the mass of one object, and it will exert a force on any other mass that is placed in it. Gravitational fields are made by and felt by objects that have mass. Therefore, we can think of mass as *gravitational charge*.

Electrical Potential

Electric fields are made by objects that have electric charge, and they exert forces on other objects that also have electric charge. Electric fields are made by and felt by objects that possess electric charge. Electric charge is to electric fields as mass is to gravitational fields. That means with electric potential, instead of mass, we will be concerned with electric charge, which we measure in Coulombs. [A Coulomb is a *lot* of electric charge. Ordinary objects such as a shirt from a clothes drier carry only microcoulombs of electric charge.]

Electric potential tells us how many joules of electric potential energy there are for each *Coulomb* of electrical charge at a particular place in an electric field. **Electric potential is therefore the *potential energy load factor* for each Coulomb of electric charge at a specific location in an electric field.**

Example

For example, a particular location in an electric field might have a potential of 120 Joules per Coulomb. **A volt is defined to be a Joule/Coulomb.** Therefore, 120 J/C is 120 Volts. That means for every Coulomb of electric charge that is placed at this location there are 120 J of electric potential energy. So if you put 3 C at that location, there will be 3 C $\times$ 120 J/C=360 J of electric potential energy associated with that 3 C of charge. This can be written mathematically, too:

$$EPE = qV = 3\ \mathrm{C} \times 120 \frac{\mathrm{J}}{\mathrm{C}} = 360\ \mathrm{J} \tag{1}$$

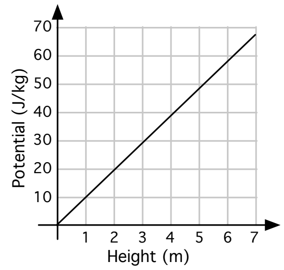
Problems

1. Calculate the electrical potential energy associated with an object that has a charge of 2 C that is at a position that has a potential of 15 V.
2. Calculate the electrical potential energy associated with an object that has a charge of 0.06 C that is at a position that has a potential of 1000 V.
3. Calculate the electrical potential energy associated with an object that has a charge of 4 μC that is at a position that has a potential of 3×10^4 V.

Using Potential to Find the Strength of a Field

Fields can be weak or strong. We have all been disappointed by magnets with weak fields and surprised by others that have strong fields. Similarly some objects can have weak gravitational fields, objects such as small asteroids. Other objects, like neutron stars, have monstrously strong gravitational fields. Electric fields come in different strengths, too. In this section we want to find out how we can use electric potential to find out how strong electric fields are at certain locations.

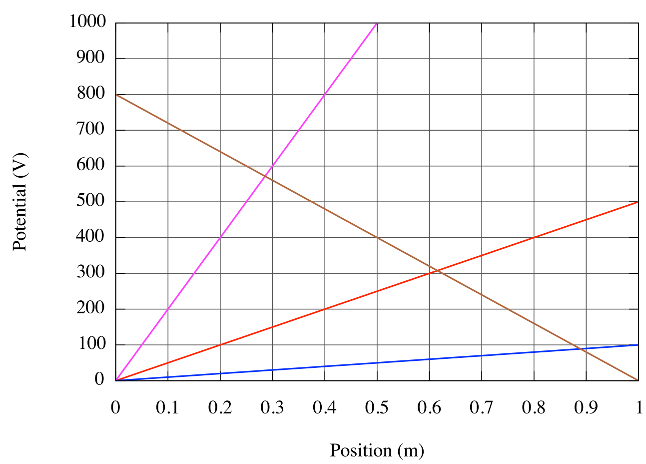
As before, we will start by thinking about gravitational potential. If we plot gravitational potential *vs* vertical position, we will get a graph that looks like this:



The slope of this graph turns out to be 10 N/kg, and that is just the strength of Earth's gravitational field. (For units, remember that the energy unit 'Joule' is the same thing as 'N·m.') In this same way, if we plot electric potential *vs* position, we will find the slope to be the strength of the electric field in that region.

Example 1

For example, we will find the strength of one of the four electric fields for which the potentials were measured at positions along a line as shown in the plots on the graph below. To get these plots, a student would just take a voltmeter to measure the potentials at various locations along a line in four different arrangements of charged objects.



All we need to do to find the strengths of these electric fields is to find the slopes of these four plots, just like we did on the gravitational potential plot shown above. Mathematically we can write the slope (rise over run) this way:

$$\mathbb{E} = \frac{\Delta V}{\Delta x} \tag{2}$$

As you may recall, V is the symbol for electric potential, and x is the symbol for position. $\Delta V = V_2 - V_1$ and $\Delta x = x_2 - x_1$.

For our example we will find the strength of the electric field that resulted in the line with a negative slope. To find the slope of this line I will select any two points along the line. The two points I will select are Point 1 = (0 m, 800 V) and Point 2 = (0.5 m, 400 V).

$$\mathbb{E} = \frac{\Delta V}{\Delta x} = \frac{V_2 - V_1}{x_2 - x_1} = \frac{400\text{V} - 800\text{V}}{0.5\text{m} - 0\text{m}} \tag{3}$$

$$\mathbb{E} = -800\frac{\text{V}}{\text{m}} = -800\frac{\text{N}}{\text{C}} \tag{4}$$

You may wonder about the minus sign. It has to do with the direction of the electric field, the way the field is pointing. This sign is not going to be important for us in this course, so don't worry about + or −. Reporting the absolute value is just fine.

About units for the strength of the electric field

Because V is measured in volts, and x is measured in meters, the slope will be in Volts/meter (V/m). Remember, a Joule is also a Newton·m, so a volt/meter is the same thing as a Newton/Coulomb. If you are an engineer you will prefer V/m, because you measure volts all the time. If you are a theoretical physicist, N/C is often used, because of its similarity to units for the strength of the gravitational field, N/kg. It makes no difference to me which you use. I use both.

Problem

4. Find the strengths of the other three electric fields for which the potentials were measured at positions along straight lines as shown in the graph above.

Example 2

Suppose you measure the potential at one position, $x = 0$, to be $V = 10$ V. Then you measure the potential 0.20 m away and find it to be 40 V. What is the strength of the electric field between these two points?

$$\mathbb{E} = \frac{\Delta V}{\Delta x} = \frac{V_2 - V_1}{x_2 - x_1} = \frac{40\text{ V} - 10\text{ V}}{0.20\text{ m} - 0} = 150\frac{\text{V}}{\text{m}} = 150\frac{\text{N}}{\text{C}} \tag{5}$$

Problems

5. Suppose the potential at one position, $x = 0$, is 100,000 V and the potential 0.10 m away is 0 V. What is the strength of the electric field between these two points?
6. Suppose the potential at one position is 9 V and the potential 0.01 m away is 0 V. What is the strength of the electric field between these two points?
7. The potential of a well-charged Van de Graaff generator can be −150,000 V. You are at about 0 V. As your index finger moves closer and closer to the generator, what happens to the strength of the electric field between your finger and the generator?
   increases / decreases / remains the same