EEE105 - Electronic Devices
Electrostatics Primer

Electric Fields

We will first consider electrons moving in a vacuum (or free-space). The motion of an electron can be changed if an electric field is present. Thus the first issue is to define what we mean by a field.

As Electric and Gravitational forces behave similarly let us for simplicity start with a gravitational field. In such a field objects are attracted due to their mass and the force on an object can be given by

$$F = \frac{GMm}{r^2}$$

where r is the distance between centres of mass, M and m are masses, G = gravitational constant.

The acceleration due to gravity , g can be given by GM/r^2

Consider the earth and a ball. If I take the ball away the earth's gravity is still present. Thus we can say that there is a gravitational ***FIELD*** around the earth pulling any object towards it. When the object comes near the earth it experiences an attractive ***FORCE***. The pull is in a particular direction, which can be represented using a ***VECTOR***. Similarly the field also must have direction and we call the field a ***VECTOR*** field.

- When the ball falls it gains kinetic energy.
- When it was raised up it had potential energy.

The potential energy is equal to mgh, where h is the height the ball has been raised, or more particularly *the difference in distance away* from the centre of the earth that the ball has been moved.

This difference between two points in space exists even if the ball is not present, and we say that there is a difference in potential between these points. In this (special case) the ***potential difference*** will be given by gh. Each point in space has a ***POTENTIAL***, V associated with is where V is a ***SCALAR*** quantity related to the objects energy. Each point also has a field, E, associated with it, which is a vector quantity related to the direction of attraction of the force produced by gravity.

Now charges in an electric field move in the same way as particles in a gravitiational field. Electrons are attracted to positively charged objects. We can think of this as there being an ELECTRIC field around the positively charged object which gives a force on any other charged particle close to it. Similarly there is a potential field in the same way.

The Electric Field is given by $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r^2}$ and

the Potential Field is given by $V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r}$

If we place a charge q_2 in the field it will have an energy Vq_2 and will experience a force $\underline{E}q_2$

Potential and Voltage

Potential and Voltage are closely related: The voltage between two points is simply the difference in potential between the points. The ***POTENTIAL DIFFERENCE*** (or ***VOLTAGE***) is a much more useful concept than the ***POTENTIAL*** as in order to measure the potential at a point we would need to reference it to a point where the potential is zero (which occurs an infinite distance away from the charged object creating the potential field).

The potential comes from the presence of the charge q_1

EE105 - Potential and Potential Difference

These two concepts can cause confusion, so here is a quick summary, using the gravitational case as an example.

If we raise an object from the floor to a height, *h*, we give it Potential Energy, *PE=m.g.h*. (where m is the mass of the object raised, and g is the acceleration due to gravity at the earth's surface).

Strictly speaking what we are actually doing is ***increasing its Potential Energy by an amount equal to m.g.h.*** After all if there was a hole in the floor it could fall further and hence release more energy. Thus the potential energy is the energy that can be gained (or lost) in the object moving from one point to another.

Now in the above equation the only term that depends on the object is its mass, m. The other terms are *g.h*, which will affect all objects by the same amount. In raising the object we have increased its potential energy. Therefore we can say there is a potential difference between the start position and the raised position. As we increase the height from the start position we will increase the potential difference and hence increase potential energy of any object that we can raise by that amount. We can write the equation:

$$PE = m.V \qquad [1]$$

Where V is the difference in potential between the start position and finish position.

Now in the above case we made the approximation that h, the height we raised the object, is small compared to r, the radius of the Earth. Clearly this only applies close to the earth's surface, and would fail if we were considering a rocket leaving the earth's surface. In such a case as the earth's gravitational field is weaker at height, h, so the gravitational force acting on the rocket will be weaker and so the change in potential energy will not rise linearly with height.

In this case the potential energy of the rocket when it reaches a height *h* can be more generally given by.

$$PE = m\left[\frac{GMr}{r^2} - \frac{GM(r+h)}{(r+h)^2}\right] \qquad [2]$$

where, g was replaced with GM/r^2. This represents the potential at the earth's surface minus the potential at height, *h* multiplied by the mass of the rocket, *m*.

This formula can be simplified to

$$PE = m\left[\frac{GMh}{r^2 + rh}\right] \qquad [3]$$

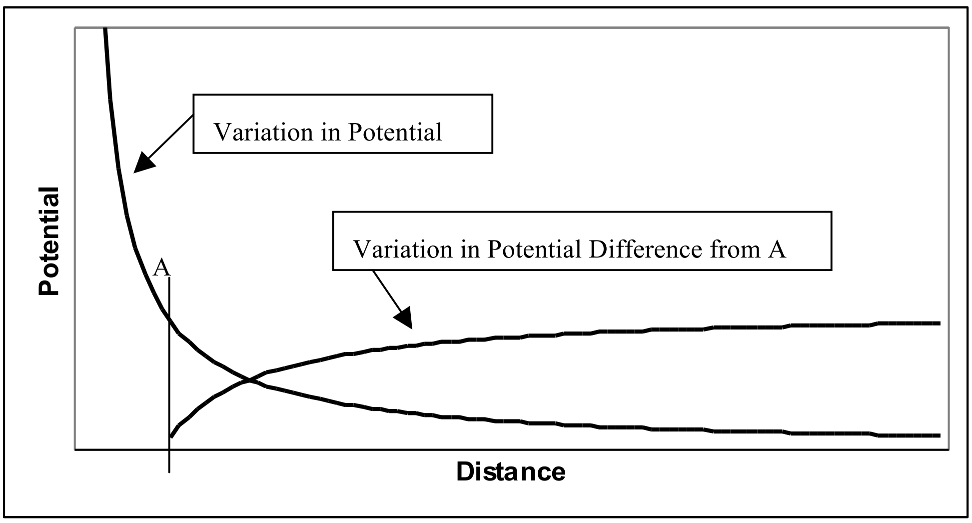
and it is simple to show that the approximation *m.g.h* will hold if $h \ll r$.

Consider equation [2]. The potential difference,

$$V = \left[\frac{GM}{r} - \frac{GM}{(r+h)}\right] \qquad [4]$$

which is literally the difference in potential the two points. **The formula for potential at any point away from the earth is *GM/x*** where *x* is the distance away from the earth's surface.

Note that the potential at a point will decrease with distance away from the earth, but that from some arbitary start point (e.g. 'A') the potential difference will increase if the relative distance away from the earth from that point increases. This can be seen in the plot of potential against distance below:



Summary:

We have reviewed electrostatics with regard to gravitational forces and potentials which are have a more “real world” feel.

Key Points to Remember:

1. We can consider there to be a field around any charge.
    2. The Electric field is a vector field and characterises the force that a particle will experience.
    3. The Potential field is a scalar field and characterises the energy we can extract from (or need to put in to) a particle in moving it from one position to another
4. Voltage is the difference in Electric Potential between two points
5. If a field is present a charged particle in a vacuum will continually accelerate.