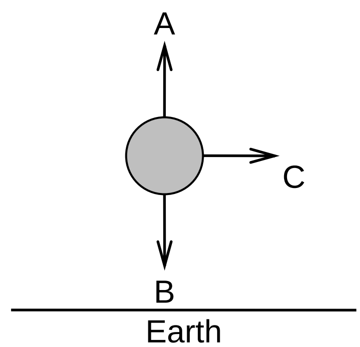
Physics 30 Lesson 16 Electric Potential

I. Gravitational potential energy – revisited

There are many similarities between gravitational potential energy and electric potential energy. To help us understand electric potential energy, it may be helpful to review gravitational potential energy and extend the concepts we have learned.

When a **mass** is placed in a **gravitational field** it has a certain amount of potential energy relative to a starting position. In the diagram to the right:



⇒ If the mass is moved toward A, there is a **gain** in gravitational potential energy.

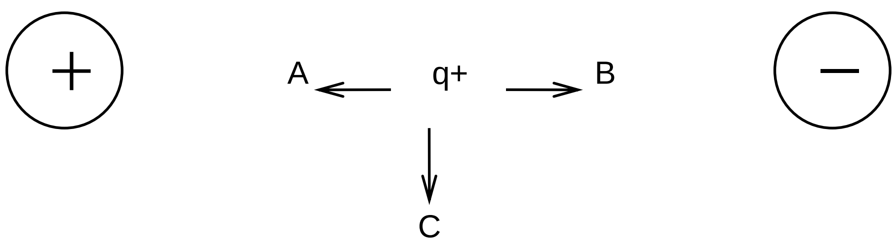
⇒ If the object is moved toward B, there is a **loss** of gravitational potential energy.

⇒ If the object is moved toward C, there is **no change** in the energy.

II. Electric potential energy

Refer to Pearson pages 560 to 566.

Charged objects in electric fields behave in a similar way to masses placed in gravitational fields. For example, a small positive charge (q+) is placed in the electric field created by the positive and negative charges as shown in the diagram below.



⇒ If q+ is moved toward A, work (i.e. W = F d) must be done **against** the electric field – the electric potential energy of the charge **increases**.

⇒ If q+ is moved toward B, **work is done by** the electric field – the electric potential energy of the charge **decreases**.

⇒ If q+ is moved toward C, **no work is done** since no force is required to move it in that direction – the electric potential energy of the charge **does not change**.

> ***Electric Potential Energy*** (E_P) *is the energy of a charged object due to its position in an electric field.*

III. Electric potential

When we were working with gravitational potential energy, we were interested in changes in gravitational potential – a change in the position of a mass within a gravitational field. In a similar manner, a change in **electric potential** is due to a **change in the position of a charge within an electric field**. The symbol for electric potential is V and its unit is the **Volt**. In reality, it is not possible to measure the *absolute* electric potential at a point in an electric field, but we can measure the ***electric potential difference*** (ΔV) between two points. Consider the following diagram

A positively charged particle, with a charge of q, has a certain amount of electric potential at position B (V_B) and a different amount of electric potential at position A (V_A). The difference in potential is given by:

$$\Delta V = V_B - V_A$$

Thus, when a charged particle is allowed to move from position B to position A the electric field does work on the particle and the particle's kinetic energy increases. Conversely, if the particle is moved from A to B work must be done against the electric field. **Electric potential is the change in electric potential energy per unit of charge**.

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

$$\Delta V = \frac{\text{Joule}}{\text{Coulomb}} = \frac{J}{C} = \text{Volt (V)}$$

Note:

⇒ Electric potential (V) is a scalar term. (Direction does not matter.)

Example 1

If 5.0 μJ of energy is required to move a 1.0 μC charge in an electric field, then the potential difference between the two points is?

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

$$\Delta V = \frac{5.0\mu J}{1.0\mu C}$$

$$\Delta V = \mathbf{5.0\,V}$$

Example 2

If 1.0 x 10^{-18} J of energy is required to move a proton in an electric field, what is the potential difference between the starting point and the finishing point in the field?

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

$$\Delta V = \frac{1.0 \times 10^{-18}\,J}{1.6 \times 10^{-19}\,C}$$

$$\Delta V = \mathbf{6.25\,V}$$

Example 3

The potential difference between two points is 120 Volts, what is the work required to move a 6.0 x 10^{-4} C against the field?

$$W = q\Delta V$$

$$W = 6.0 \times 10^{-4}\,C(120V)$$

$$W = \mathbf{7.2 \times 10^{-2}\,J}$$

Example 4

An alpha particle is placed in an electric field with a potential difference of 100 V. If the alpha particle is released within the field, what is the maximum speed that the alpha particle could attain?

From the formula/data sheet:

	Rest Mass	Charge
Alpha particle	m_α = 6.65 x 10^{-27} kg	α^{2+}

The 2+ charge is converted to a charge in Coulombs by multiplying it by the elementary charge.
q = 2+ x 1.6 x 10^{-19} C = + 3.2 x 10^{-19} C

Using the principle of the conservation of energy, the electric potential energy of the particle in the electric field (ΔE_p = q V) is transformed into kinetic energy (E_k).

$$E_p = E_k$$

$$qV = \tfrac{1}{2}mv^2$$

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

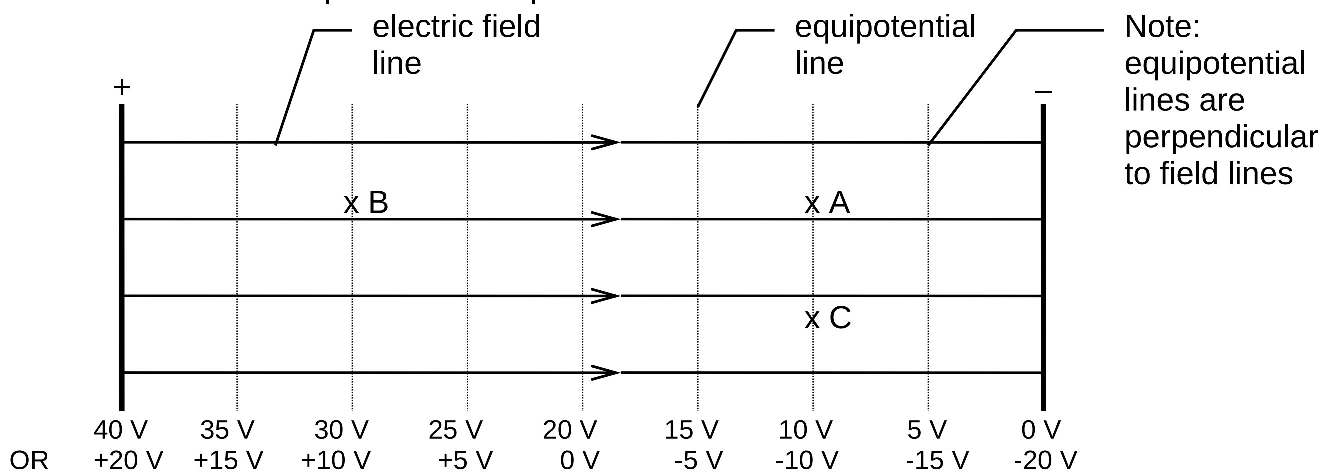
$$v = \sqrt{\frac{2(3.2 \times 10^{-19}\,C)(100\,V)}{6.65 \times 10^{-27}\,kg}}$$

$$v = \mathbf{9.81 \times 10^4\ m/s}$$

Note: This example is a very common application of converting electric potential energy into the kinetic energy of a charged particle. We will be using this idea throughout the rest of the course.

IV. Equipotential Lines

Quite often, two parallel plates are a simple way to create a potential difference (we will discuss parallel plates in detail in Lesson 17). In such an electric field, one can map out what the electric potential is at different points. Along an imaginary line parallel to the plates, the electric potential is the same or "equal." The subsequent "equipotential lines" have the same potential at all points on the line.



The diagram above shows electric field lines and equipotential lines for a parallel plate system consisting of a (+) plate and a (–) plate. The dotted lines represent the equipotential lines which are always perpendicular to the electric field lines. For this particular example there is a potential difference of 40 volts between the two plates. Note that what we call our 0 V potential line is quite arbitrary, it is the **difference** in potential between two points that really counts.

If, for example, a proton were to move from A to B, work would have to be done and its potential energy would increase. Similarly, since C and A lie on the same equipotential line, moving a proton from C to B would require the same amount of work as moving it from A to B. Conversely, if a proton is moved from B to A or B to C, its potential would decrease. Moreover, moving the proton from A to C would not result in any energy change.

Example 5

Using the parallel plate system shown above:

A. If an alpha particle is moved from A to B, what energy would be required?

$$\Delta E = qV$$

$$\Delta E = 3.20\times10^{-19}\,C(20V)$$

$$\Delta E = \mathbf{6.4\times10^{-18}\,J}$$

B. If a 7.0 μC charge is allowed to move from B to A and its mass is 2.0 mg, what is its final speed if it starts from rest?

$$E_p = E_k$$

$$qV = \tfrac{1}{2}mv^2$$

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

$$v = \sqrt{\frac{2(7.0\times10^{-6}\,C)(20\,V)}{2.0\times10^{-6}\,kg}}$$

$$v = \mathbf{11.8\,m/s}$$

Example 6

A beryllium ion (Be^{2+}) is accelerated through a 0.150 MV potential difference. If its final speed is 2.53 x 10^6 m/s what is its mass?

The 2+ charge is converted to a charge in Coulombs by multiplying it by the elementary charge.

q = 2+ x 1.60 x 10^{-19} C = + 3.20 x 10^{-19} C

$$E_p = E_k$$

$$qV = \tfrac{1}{2}mv^2$$

$$m = \frac{2qV}{v^2}$$

$$m = \frac{2(3.20\times10^{-19}\text{ C})(0.150\times10^{6}\text{ V})}{\left(2.53\times10^{6}\ \text{m/s}\right)^2}$$

$$m = \mathbf{1.50\times10^{-26}\ kg}$$

V. Practice problems

1. If 50 J of work is required to move a 0.50 C charge in an electric field, what is the potential difference between the two points? (100 V)

2. If an electron starting from rest falls through a potential difference of 500 V, what is its final speed? (1.33 x 10^7 m/s)

3. A completely ionized aluminium nucleus (i.e. all of the electrons have been stripped from the atom) is accelerated through a 0.25 MV potential difference. What is its final speed? (4.8 x 10^6 m/s)

VI. Hand-in assignment

1. 0.020 J of work is done on a charge of 80 μC as it jumps across a spark gap in the spark plug of a car. What was the potential difference across the gap? (250 V)

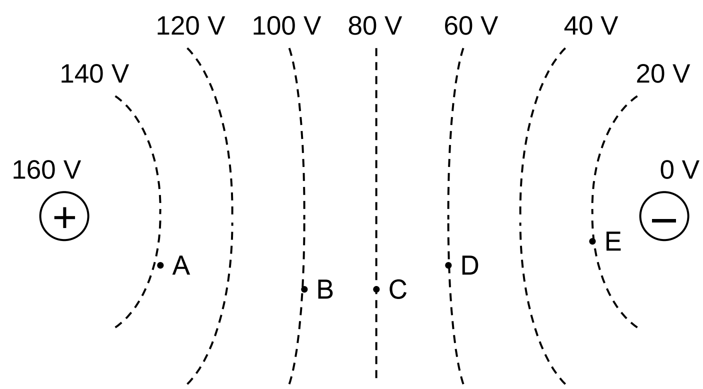
2. What maximum speed will an alpha particle reach if it moves from rest through a potential difference of 6500 V? (7.9×10^5 m/s)

3. How much kinetic energy does a completely ionized fluorine nucleus have when it is accelerated by a potential difference of 0.60 MV? What is it speed? (Note: The term "completely ionized" means that all of the electrons have been stripped away from the nucleus of an atom. Therefore, its charge is equal to the number of protons in the nucleus.) (8.64×10^{-13} J, 7.4×10^6 m/s)

4. An alpha particle is accelerated to 1/10th the speed of light. What minimum potential difference is required to do this? (9.35 MV)

5. Assuming that it started from rest, what is the momentum of a proton after it has gone through a potential difference of 20.0 kV? (3.27×10^{-21} kg·m/s)

6. Consider the following diagram of equipotential lines



   A. What energy is required to move an alpha particle from E to C?
   B. If an electron were placed at D, what would its maximum speed be at B?
   C. What is the energy required to move a proton from C to A?
   D. What is the energy required to move a neutron from E to A?

7. An electron is released from rest adjacent to the negative plate in a parallel plate apparatus. A potential difference of 500 V is maintained between the plates, and they are in a vacuum. With what speed does the electron collide with the positive plate? (1.3×10^7 m/s)

8. An electron with a velocity of $5.0 \times 10^{\mathbf{6}}$ m/s is injected into a parallel plate apparatus through a hole in the positive plate. It moves across the vacuum between the plates, colliding with the negative plate at $1.0 \times 10^{\mathbf{6}}$ m/s. What is the potential difference between the plates? (68 V)