Electricity and Magnetism

Fifth Lecture

Electric potential

Potential and the electric field

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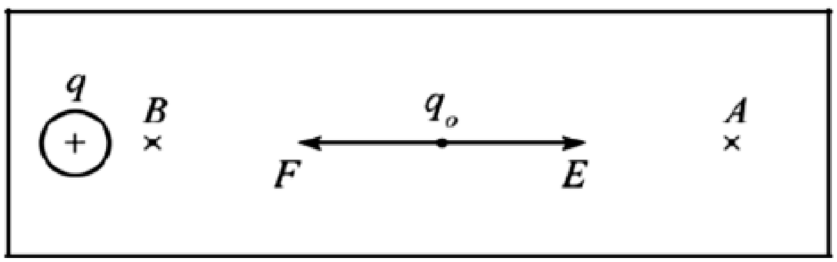
Outline

1. Electric potential

When a **test charge q^0** is placed in an **electric field $\vec{E}$** created by some other charged object, the **electric force $\vec{F}$** acting on the test charge **is q^0E.**

The force q_0 E is conservative, because the force between charges described by Coulomb's law is conservative. If the test charge is moved in the field by some external agent from point A to point B by a displacement *ds*, the work done by the electric field on the charge is equal to the negative of the work done by the external agent causing the displacement.



For an infinitesimal displacement ds, the work W done by the electric field on the charge is:

$$W = \vec{F} \cdot \vec{ds} \Rightarrow W = q_0 \vec{E} \cdot \vec{ds}$$

Electric potential is defined as the amount of work needed to move an electric charge from one point to the anther point in an electric field.

2. Electric potential energy

Electric potential energy is the energy that is needed to move a charge against an electric field.

As this amount of work is done by the electric field, the potential energy *U* of the charge field system is decreased by an amount:

$$dU = -q_0 \vec{E}.\vec{ds}$$

The change in potential energy of the system is:

$$\Delta U = U_B - U_A$$

$$\Delta U = -q_0 \int_A^B \mathbf{E} \cdot d\mathbf{s} \qquad \text{................ (1)}$$

The potential energy per unit charge U/q0 is independent of the value of q0 and has a value at every point in an electric field. This quantity U/q0 is called the **electric potential V**.

Thus, the electric potential at any point in an electric field is:

$$V = \frac{U}{q_0} \qquad \text{................. (2)}$$

$$V = V_B - V_A = -\int_A^B E.dS$$

Note: The fact that potential energy U is a scalar quantity means that electric potential V also is a scalar quantity.

The electric potential, or voltage (V): is the difference in potential energy per unit charge between two locations in an electric field.

3. Potential and the electric field

Now suppose that a test charge q^0 moves from A to B. We can calculate the change in its **potential energy:**

$$\Delta U = q_0 \Delta V = -q_0 E d$$

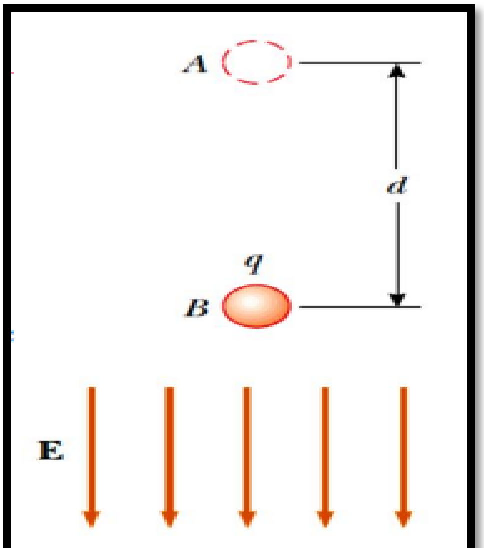


Fig. 1

From this result, if q0 is **positive**, then **ΔU** is **negative**. We conclude that a **positive** charge **loses** electric potential energy when it moves in the direction of the electric field.

While q0 is **negative**, then ΔU is **positive** and the situation is reversed: A **negative** charge **gains** electric potential energy when it moves in the direction of the electric field.

$$V = V_B - V_A = -\int_A^B E.dS$$

$$\Delta V = -E\int_A^B dS\cos\theta = -E\int_A^B dS\ \cos 0$$

$$\Delta V = -E\,\Delta r \quad \text{uniform field}$$

The electric field vector points from higher potential toward lower potential.

Potential due to a charged particle (point charge):

The electric potential V due to a particle of charge q at any radial distance r from the particle.

$$V = k\,\frac{q}{r}$$

A positively charged particle produces a positive electric potential. A negatively charged particle produces a negative electric potential.

4. Potential due to a group of point charges

We can find the net electric potential at a point due to a group of **charged particles (n charged particles)** with the help of the superposition principle:

$$V = \sum_{i=1}^{n} V_i = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \frac{q_i}{r_i} \quad (n \text{ charged particles}).$$

$$V = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \cdots\right)$$

5. potential due to an electric dipole

The electric potential due to an electric dipole at a given point is equal to:

$$V = k\,\frac{qd\cos\theta}{r^2}$$

where d is the distance between the charges and r is the distance from the dipole’s midpoint to P, θ is measured from the dipole axis to field direction.

6. Reference

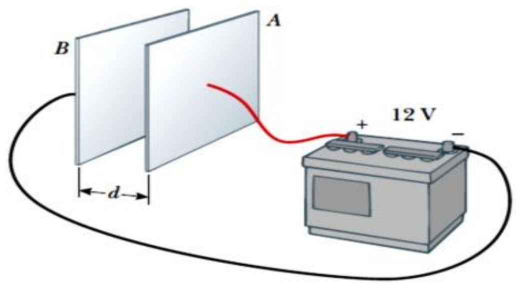
Walker, Jearl, Robert Resnick, and David Halliday. Halliday and resnick fundamentals of physics. Wiley, 2014.

Example 1: A battery produces a specified potential difference ΔV between conductors attached to the battery terminals. A 12 V battery is connected between two parallel plates. The separation between the plates is **d** = 0.3 cm. Find the magnitude of the electric field between the plates.

Solution:

$$E = \frac{|V_B - V_A|}{d} = \frac{12\text{ V}}{0.30 \times 10^{-2}\text{ m}}$$

$$= 4.0 \times 10^3\text{ V/m}$$



Example 3: A charge q_1 = **2.00 μC** is located at the origin, and a charge q_2 = **- 6.00 μC** is located at (0, 3.00) m, as shown in Figure 6a. **(a)** Find the total electric potential due to these charges at the point *P*, whose coordinates are (4.00, 0) m.

Solution:

$$V_P = k_e\left(\frac{q_1}{r_1} + \frac{q_2}{r_2}\right)$$

$$= 8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\left(\frac{2.00 \times 10^{-6}\text{ C}}{4.00\text{ m}} + \frac{-6.00 \times 10^{-6}\text{ C}}{5.00\text{ m}}\right)$$

$$= -6.29 \times 10^3\text{ V}$$

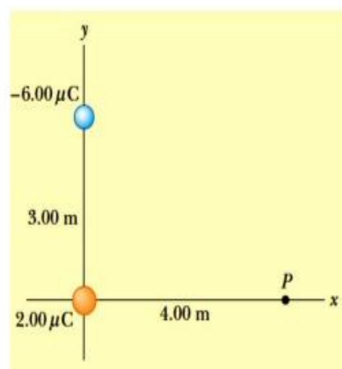


Fig. 6 (a)