Electricity and Magnetism

Potential due to a dipole, Electric potential energy.

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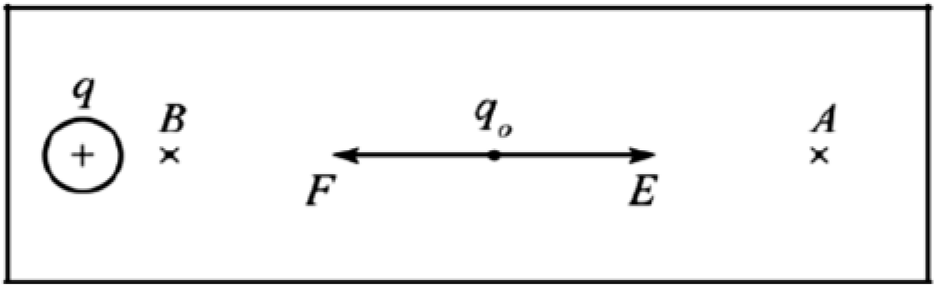
Outline

Electric potential

When a test charge q^0 is placed in an electric field E created by some other charged object, the electric force 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 done by the electric field on the charge is:

$$\boxed{W = \vec{F} \, . \, \vec{ds} \;\Rightarrow\; W = q_0 \vec{E} \, . \, \vec{ds}}$$

As this amount of work is done by the electric field, the potential energy 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

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

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

When the electric field E is directed downward as shown in Figure 1, a point B is at a lower electric potential than point A. When a positive test charge moves from point A to point B, its loses electric potential energy.

Electric field lines always point in the direction of decreasing electric potential, as shown in Figure 1.

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

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

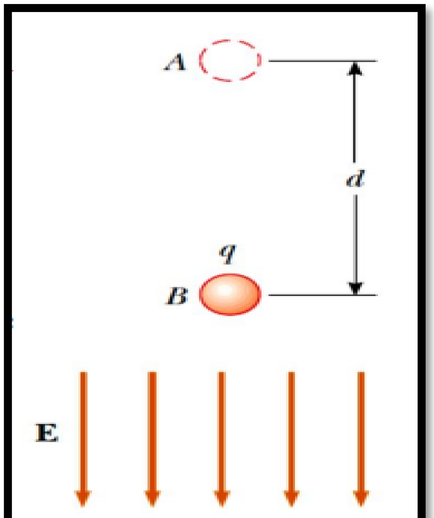


Fig. 1

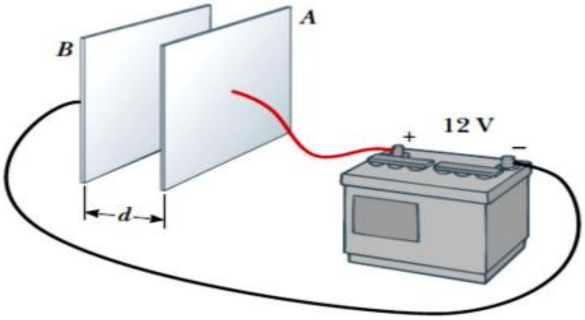
From this result, if q0 is **positive**, then **ΔU** is **negative**. We conclude that a **positive** charge **loses** electric potential energy when it moves in the direction of the electric field. While q0 is **negative**, then ΔU is **positive** and the situation is reversed: A **negative** charge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

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:

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

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



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The **potential energy U** when the two particles are separated by a distance r_{12} (see Figure 5)

$$U = k_e \frac{q_1 q_2}{r_{12}}$$

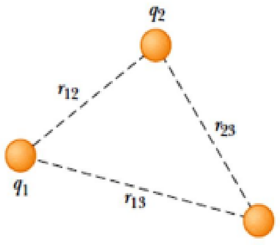

Fig. 5

Note that if the charges are of the **same sign**, **U** is **positive**. This is consistent with the fact that **positive work** must be done by an **external agent** on the system to bring the two charges near one another.

If the charges are of **opposite sign**, **U** is **negative**; this means that **negative work** is done by an external agent against on theirs.

If the system consists of more than two charged particles as shown in the Figure 5, then total potential energy of the system U is:

$$U = k_e \left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right)$$

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:

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

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

$$= \boxed{-6.29 \times 10^3\,\mathrm{V}}$$

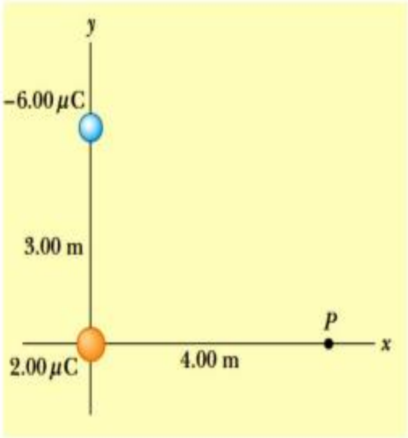

Fig. 6 (a)

(**b**) Find the change in potential energy of the system of two charges plus a charge $\boldsymbol{q_3 = 3.00\ \mu C}$ as the latter charge moves from infinity to point P (Figure 6b).

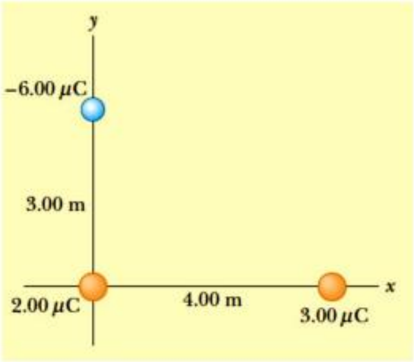

Fig. 6 (b)

Solution:

$$\Delta U = U_f - U_i$$

When the charge is at infinity, $U_i = 0$, and when the charge is at P, $U_f = q_3 V_P$; therefore,

$$\Delta U = q_3 V_P - 0 = (3.00 \times 10^{-6}\ \text{C})(-6.29 \times 10^{3}\ \text{V})$$

$$= \boxed{-18.9 \times 10^{-3}\ \text{J}}$$