PHYSICS IN MOTION
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Unit 5D
Electric Potential Energy and Electric Potential
Practice Problems TEACHER

Work each of the following problems. SHOW ALL WORK.

1. **For a source charge Q and a test charge q separated by a distance r, the electric potential energy of the test charge is kQq / r. If two alpha particles (each with two protons and two neutrons) are 0.5 m apart, what is the electric potential energy of the system?**

The system consists of two identical objects, so Q = q.

The charge of each object is two times the charge of a proton:

$$Q = 2(1.6 \times 10^{-19}\,C) = 3.2 \times 10^{-19}\,C$$
$$k = 9 \times 10^{9}\,Nm^2/C^2$$
$$r = 0.5\,m$$

The $PE_{electric}$ of the entire system is:

$$PE_{electric} = \frac{kQQ}{r}$$
$$PE_{electric} = \frac{kQ^2}{r}$$
$$PE_{electric} = \frac{(9 \times 10^{9}\,Nm^2/C^2)(3.2 \times 10^{-19}\,C)^2}{0.5\,m}$$
$$PE_{electric} = 1.8 \times 10^{-27}\,J$$

2. **Two protons approach each other from very far away with an initial speed of 500 m/s. How close do they come to each other before turning around?**

The protons begin with kinetic energy but no electric potential energy. At the point of closest approach, their kinetic energy has been converted entirely into electric potential energy.

Begin with the law of conservation of energy:

$$KE = \tfrac{1}{2}mv^2 \qquad KE_i + PE_i = KE_f + PE_f$$
$$PE_{electric} = \frac{kq_1q_2}{r} \qquad KE_i + 0 = 0 + PE_f$$
$$KE_i = PE_f$$

Solving for r, the distance between the protons when they are closest, substitute the equations for KE and $PE_{electric}$ into the conservation of energy equation:

$$k = 9 \times 10^{9}\,Nm^2/C^2 \qquad \tfrac{1}{2}mv^2 = \frac{kq_1q_2}{r}$$
$$m = 1.7 \times 10^{-27}\,kg \qquad \tfrac{1}{2}mv^2 r = kq_1q_2$$
$$v = 500\,m/s$$
$$q_1 = q_2 = 1.6 \times 10^{-19}\,C \qquad r = \frac{2kq_1q_2}{mv^2}$$

$$r = \frac{2(9 \times 10^{9}\,Nm^2/C^2)(1.6 \times 10^{-19}\,C)(1.6 \times 10^{-19}\,C)}{(1.7 \times 10^{-27}\,kg)(500\,m/s)^2}$$
$$r = 1.1 \times 10^{-6}\,m$$

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3. A 4 V battery is connected to two parallel plates that are separated by a distance of 0.25 mm. Find the magnitude of the electric field created between the plates.

Electric potential is another name for voltage. Electric potential is equal to electric potential energy per unit charge. For point charges:

$$\text{Electric potential} = \frac{kQ_{source}}{r}$$

$$V = \frac{kQ_{source}}{r}$$

According to Coulomb's law, electric force equals a source charge's electric field times the charge experiencing the field:

$$F_{electric} = Eq_{test}$$

Substitute Coulomb's law for $F_{electric}$:

$$\frac{kq_{test}Q_{source}}{r^2} = Eq_{test}$$

$$E = \frac{kQ_{source}}{r^2}$$

Rearrange the equation so that the right side equals the equation for voltage:

$$E = \frac{kQ_{source}}{r^2}$$

$$Er = \frac{kQ_{source}}{r}$$

$$Er = V$$

$V = 4V$

$r = 0.25\,mm = 2.5 \times 10^{-4}\,m$

Rearrange to solve for the electric field E:

$$E = \frac{V}{r}$$

$$E = \frac{4\,V}{2.5 \times 10^{-4}\,m}$$

$$E = 1.6 \times 10^{4}\,V/m$$

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4. A proton starts moving from rest in an electric field of magnitude 6.5×10^5 V/m. The field points in the positive x-direction, and under the influence of the field, the proton moves 0.25 m in that direction.

a. What is the change in the proton's electric potential as a result of the displacement?

The electric potential of a charge equals the product of the electric field experienced by the charge times the resulting distance moved by the charge. Because the proton moves with the field rather than against it, the proton loses electric potential. The change in potential is:

$$\Delta V = -Ed$$
$$\Delta V = -(6.5 \times 10^5\ V/m)(0.25\ m)$$
$$\Delta V = -1.6 \times 10^5\ V$$

b. What is the change in the proton's electric potential energy due to the displacement?

The proton's electric potential energy equals its electric potential times its charge.

$$\Delta PE_{electric} = \Delta V q_{proton}$$
$$\Delta PE_{electric} = (-1.6 \times 10^5\ V)(1.6 \times 10^{-19}\ C)$$
$$\Delta PE_{electric} = -2.6 \times 10^{-14}\ VC$$
$$\Delta PE_{electric} = -2.6 \times 10^{-14}\ J$$

c. What is the speed of the proton after it has moved 0.25 m, beginning from rest?

Because the proton's energy is conserved, its loss in electric potential energy is balanced by a gain in kinetic energy:

$$|\Delta PE_{electric}| = |\Delta KE|$$
$$m = 1.7 \times 10^{-27}\ kg$$
$$\Delta PE_{electric} = -2.6 \times 10^{-14}\ J$$

$$|-2.6 \times 10^{-14}\ J| = \tfrac{1}{2} mv^2$$
$$2.6 \times 10^{-14}\ J = \tfrac{1}{2}(1.7 \times 10^{-27}\ kg)v^2$$
$$v = \sqrt{\frac{(2)\,2.6 \times 10^{-14}\ J}{1.7 \times 10^{-27}\ kg}}$$
$$v = 5.5 \times 10^6\ \text{m/s}$$

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5. If 3 C of charge moves through a 12 V potential difference, what is the change in electric potential energy?

$$PE_{electric} = Vq$$
$$PE_{electric} = (12\,V)(3\,C)$$
$$PE_{electric} = 36\,J$$

6. An electric field of constant strength 6 N/C points in the positive y direction. A proton moves from the origin to the point (0, 2) m. What is the change in the proton's electric potential? What would be the change in electric potential if an electron moved the same way?

Because the electric field is constant and the proton moves in the direction of the field, it loses electric potential as it travels.

$$E = 6\,N/C$$
$$d = 2\,m$$

$$\Delta V = -|Ed|$$
$$\Delta V = -|(6\,N/C)(2\,m)|$$
$$\Delta V = -12\,V$$

If an electron traveled this path instead of a proton, the charge would be moving against the electric field. Therefore, it would gain 12 V of electric potential.

7. A particle with charge 1.7 μC moves along an electric field line in a field of strength 35 N/m. If the particle moves 19 m along the line, what is the change in its electric potential and electric potential energy?

Electric potential is the same as voltage, which equals electric field strength times distance. Since the positively charged particle moves with the electric field (from positive to negative), it loses electric potential:

$$\Delta V = -|Ed|$$
$$\Delta V = -|(35\,N/m)(19\,m)|$$
$$\Delta V = -665\,V$$
$$\Delta PE_{electric} = \Delta Vq$$
$$\Delta PE_{electric} = (-665V)(1.7 \times 10^{-6}\,C)$$
$$\Delta PE_{electric} = -1.1 \times 10^{-3}\,J$$

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8. A -3 C charge moves through a 2000 V loss of electric potential. Will the charge gain or lose electric potential energy? Will the charge gain or lose kinetic energy?

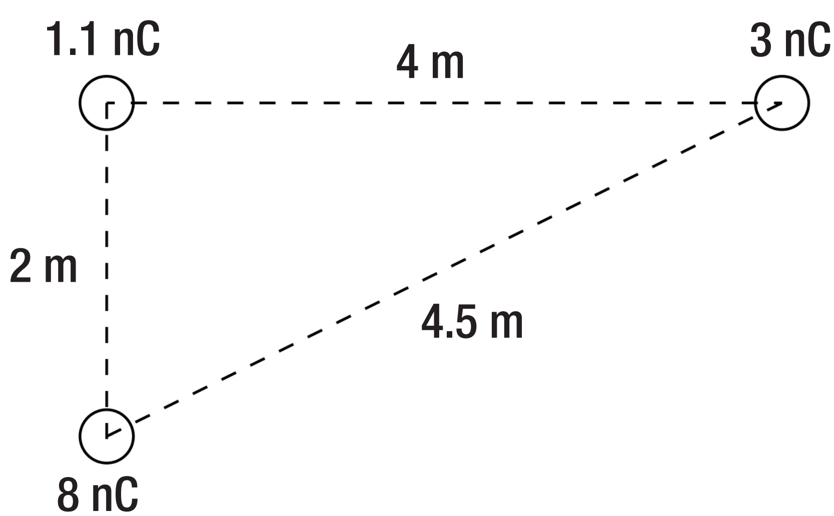
Because the charge is negative and it moves from higher to lower electric potential, it gains electric potential energy; i.e., it climbs an "uphill" potential difference, so it has more potential after the move. A negative charge would have lost electric potential energy. Calculate the change:

$$\Delta V = -2000\,V$$
$$q = -3\,C$$

$$\Delta PE_{electric} = \Delta V q$$
$$\Delta PE_{electric} = (-2000\,V)(-3\,C)$$
$$\Delta PE_{electric} = 6000\,J$$

Energy is conserved in this system, so the gain in electric potential energy is balanced by a 6000 J loss in kinetic energy.

9. Find the total electric potential energy of the system of charges shown below:



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There are three pairs of charges in this scenario, each possessing its own electric potential energy. Since electric potential energy is a scalar quantity, the total electric potential energy of the system is the sum of the electric potential energy in each pair. Let pair one be the charges separated by 2 m, pair two the charges separated by 4 m, and pair three the charges separated by 4.5 m.

$$\Delta PE_{electric} = \frac{kq_1 q_2}{r}$$
$$k = 9 \times 10^{9}\ Nm^2/C^2$$
$$q_1 = 1.1 \times 10^{-9}\ C$$
$$q_2 = 8 \times 10^{-9}\ C$$
$$q_3 = 3 \times 10^{-9}\ C$$
$$r_1 = 2\ m$$
$$r_2 = 4\ m$$
$$r_3 = 4.5\ m$$
$$\Delta PE_{electric} = ?$$

$$PE_{pair1} = \frac{kq_1 q_2}{r_1}$$
$$PE_{pair1} = \frac{(9 \times 10^{9}\ Nm^2/C^2)(1.1 \times 10^{-9}\ C)(8 \times 10^{-9}\ C)}{2\ m}$$
$$PE_{pair1} = 4.0 \times 10^{-8}\ J$$

$$PE_{pair2} = \frac{kq_1 q_3}{r_2}$$
$$PE_{pair2} = \frac{(9 \times 10^{9}\ Nm^2/C^2)(1.1 \times 10^{-9}\ C)(3 \times 10^{-9}\ C)}{4\ m}$$
$$PE_{pair2} = 7.4 \times 10^{-9}\ J$$

$$PE_{pair3} = \frac{kq_2 q_3}{r_3}$$
$$PE_{pair3} = \frac{(9 \times 10^{9}\ Nm^2/C^2)(8 \times 10^{-9}\ C)(3 \times 10^{-9}\ C)}{4.5\ m}$$
$$PE_{pair3} = 4.8 \times 10^{-8}\ J$$

$$PE_{total} = PE_{pair1} + PE_{pair2} + PE_{pair3}$$
$$PE_{total} = 4.0 \times 10^{-8}\ J + 7.4 \times 10^{-9}\ J + 4.8 \times 10^{-8}\ J$$
$$PE_{total} = 9.5 \times 10^{-8}\ J$$