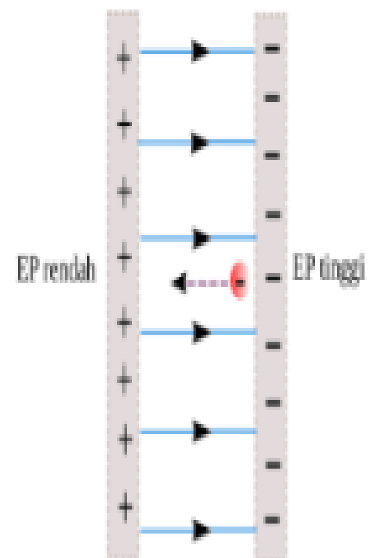
Problem 1

1. An electron is accelerated from rest through a potential difference 12 V. What is the change in electric potential energy of the electron?



Known :

The charge on an electron (e) = -1.60×10^{-19} Coulomb

Electric potential = voltage (V) = 12 Volt

Wanted: The change in electric potential energy of the electron (ΔPE)

Solution :

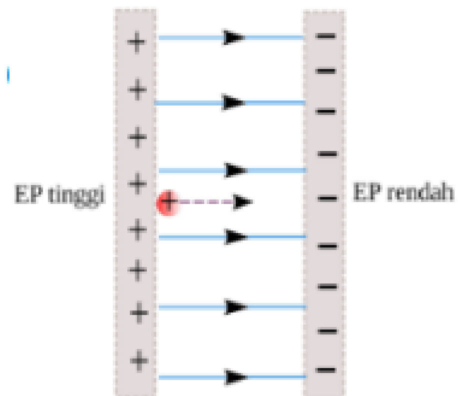
$\Delta PE = q\, V = (-1.60 \times 10^{-19}\ C)(12\ V) = -19.2 \times 10^{-19}$ Joule

The minus sign indicates that the potential energy decreases.

Problem 2

2. Two parallel plates are charged. The separation between the plates is 2 cm and the magnitude of the electric field between the plates is 500 Volt/meter. What is the change in potential energy of the proton when accelerated from the positively charged plate to the negatively charged plate.

Known :



The magnitude of the electric field between the plates (E) = 500 Volt/meter

The distance between the plates (s) = 2 cm = 0,02 m

The charge on an proton = +1.60 x 10^{-19} Coulomb

Wanted : The change in electric potential energy (ΔPE)

Solution :

Electric potential :

V = E s

V = (500 Volt/m)(0.02 m)

V = 10 Volt

The change in electric potential energy :

ΔPE = q V

ΔPE = (1,60 x 10^{-19} C)(10 V)

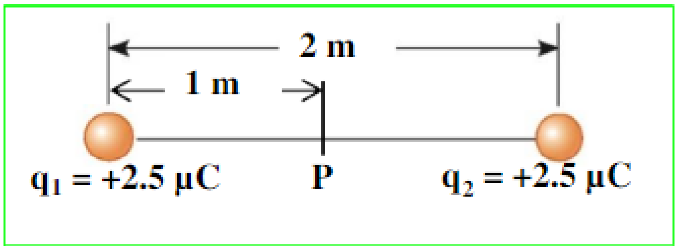
ΔPE = 16 x 10^{-19} Joule

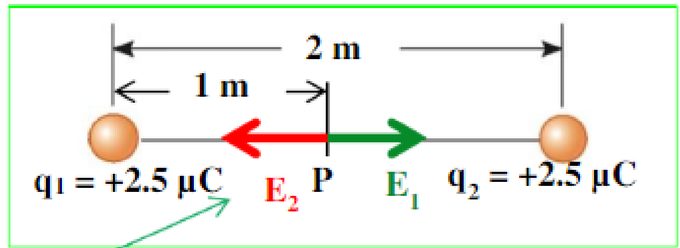
ΔPE = 1.6 x 10^{-1}

Problem 3

1. Find the electric field at a point located midway between the charges when both charges are positive as shown.

Solution





$$E = k\frac{|q|}{r^2} \qquad q_1 = q_2 \quad r_1 = r_2 = 1\,\mathrm{m}$$

$$|E_1| = |E_2| = k\frac{|q|}{r^2} \qquad E_{net} = 0$$

Find the electric potential at the same location.

Find the electric potential at the same location.

Solution

We express the electric potential of each charge at point P then add them algebraically, since electric potential is a scalar quantity.

Remember: r is the distance from the charge to the point where we want to determine the electric potential.

Therefore: r_1 is the distance from q_1 to point P and r_2 is the distance from q_2 to point P.

$$V = k\frac{q}{r} \qquad r_1 = r_2 = 1\,\mathrm{m}$$

$$V_{total} = k\frac{q_1}{r_1} + k\frac{q_2}{r_2} \qquad q_1 = q_1$$

$$V_{total} = 2k\frac{q}{r}$$

$$V_{total} = 2\left(9\times10^{9}\ \mathrm{N\cdot m^2/C^2}\right)\frac{2.5\times\times10^{-6}\,\mathrm{C}}{1\,\mathrm{m}} \qquad V_{total} = 4.5\times10^{4}\ \mathrm{V}$$

Problem 4

Electrical Potential in a Uniform Electric Field

2. Membrane walls of living cells have surprisingly large electric fields across them due to separation of ions. (Membranes are discussed in some detail in Nerve Conduction—Electrocardiograms.) What is the voltage across an 8.00 nm–thick membrane if the electric field strength across it is 5.50 MV/m? You may assume a uniform electric field.

Solution

There are 2 units in SI for the Electric Field: $[E]_{SI} = 1\frac{N}{C} = 1\frac{V}{m}$

$E = 5.50\times10^{6}\,V/m$

$d = 8\times10^{-9}\,m$

$V_{AB} = ?$

$V_{AB} = Ed \qquad V_{AB} = (5.50\times10^{6}\,V/m)(8\times10^{-9}\,m)$

$V_{AB} = 44\times10^{-3}\,V \qquad V_{AB} = 44\,mV$

---

3. An electron is to be accelerated in a uniform electric field having a strength of 2.00×10^{6} V/m.

a. What energy in keV is given to the electron if it is accelerated through 0.400 m?

b. Over what distance would it have to be accelerated to increase its energy by 50.0 GeV?

Solution

a. What energy in keV is given to the electron if it is accelerated through 0.400 m?

The potential energy of a particle accelerated through a potential difference V_{AB} in an uniform electric field (text book p. 740): $\Delta PE = q\,V_{AB}$

$V_{AB} = E\,d$

$\Delta PE = (1.6\times10^{-19}\,C)(2.00\times10^{6}\,V/m)(0.400\,m)$

$1\,eV = 1.6\times10^{-19}J \qquad 1\,keV = 10^{3}eV$

$\Delta PE = \frac{(1.6\times10^{-19})(8\times10^{5})\,J}{1.6\times10^{-19}J/eV} \qquad \Delta PE = 8\times10^{5}\,eV \qquad \Delta PE = 800\,keV$

b. Over what distance would it have to be accelerated to increase its energy by 50.0 GeV?

$$\Delta PE = q\,V_{AB} \Rightarrow \quad \Delta PE = q\,E\,d \;\Rightarrow d = \frac{\Delta PE}{q\,E} \qquad 1\,\text{GeV} = 10^9\,\text{eV}$$

$$\Delta PE = (1.6\times10^{-19}\,\text{C})(2.00\times10^6\ \text{V/m})(0.400\,\text{m})$$

$$d = \frac{50\times10^9\,\text{eV}\,(1.6\times10^{-19}\ \text{J/eV})}{(1.6\times10^{-19}\,\text{C})(2\times10^6\,\text{V/m})} \qquad d = 25\times10^3\,\text{m} \qquad d = 25\,\text{km}$$

Problem 5

Electric Potential and Electric Potential Energy

4. In nuclear fission, a nucleus splits roughly in half.

a. What is the potential 2.00×10^{-14} m from a fragment that has 46 protons in it?

b. What is the potential energy in MeV of a similarly charged fragment at this distance?

Solution

a. What is the potential 2.00×10^{-14} m from a fragment that has 46 protons in it?

We can use the formula for the potential of a point charge at a distance r from the charge:

$$V = k\frac{q}{r} \qquad r = 2\times10^{-14}\,\text{m}$$

$$q = 46\,e \quad q = 46\times1.6\times10^{-19}\,\text{C}$$

$$V = (9\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{46\times1.6\times10^{-19}\,\text{C}}{2\times10^{-14}\ \text{m}} \qquad V_{total} = 3.31\times10^6\ \text{V}$$

b. What is the potential energy in MeV of a similarly charged fragment at this distance?

The potential energy of a particle in an electric field:

$$PE_{pointP} = qV_{pointP}$$

$$PE_{pointP} = (46\times1.6\times10^{-19}\text{C})(3.31\times10^{6}\text{V})$$

$$1\,\text{eV} = 1.6\times10^{-19}\text{J} \qquad 1\,\text{MeV} = 10^6\,\text{eV}$$

$$PE_{pointP} = \frac{(46\times1.6\times10^{-19})(3.31\times10^6)\text{J}}{1.6\times10^{-19}\text{J/eV}} \qquad PE_{pointP} = 152\times10^6\ \text{eV} \qquad PE_{pointP} = 152\,\text{MeV}$$

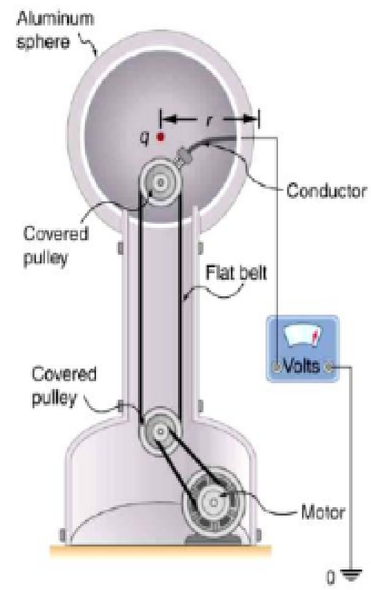
Problem 6

5. A research Van de Graaff generator has a 2.00 m diameter sphere with a charge of 5.00 mC on it.

a. What is the potential near its surface?

b. At what distance from its center is the potential 1.00 MV?

c. An oxygen atom with three missing electrons is released near the Van de Graaff generator. What is its energy in MeV at this distance?



Solution

a. What is the potential near its surface?

The potential on the surface will be the same as that of a point charge located at the center of the sphere at a distance of 1.00 m. (The radius of the sphere is 2.00 m.) We can thus use the equation:

$$V = k\frac{q}{r} \qquad r = 1\,\text{m}$$

$$V = \left(9\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\frac{5\times10^{-3}\,\text{C}}{1\,\text{m}} \qquad V_{\text{total}} = 4.5\times10^{7}\ \text{V} \quad V_{\text{total}} = 45\,\text{MeV}$$

b. At what distance from its center is the potential 1.00 MV?

$$V = k\frac{q}{r} \qquad r = \ ?$$

$$r = \frac{k\,q}{V} \qquad r = \frac{\left(9\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(5\times10^{-3}\,\text{C}\right)}{10^{6}\ \text{V}} \qquad r = 45\,\text{m}$$

c. An oxygen atom with three missing electrons is released near the Van de Graaff generator. What is its energy in MeV at this distance (at 1.00 m from the center?

The potential energy of a particle in an electric field:

$$\Delta PE = q\,\Delta V \quad q = 3\,e = 3\times1.6\times10^{-19}\,\text{C}$$

$$\Delta PE = \left(3\times1.6\times10^{-19}\ \text{C}\right)\left(45\times10^{6}\ \text{V} - 10^{6}\ \text{V}\right)$$

$$1\,\text{eV} = 1.6\times10^{-19}\text{J} \qquad 1\,\text{MeV} = 10^{6}\text{eV}$$

$$\Delta PE = \frac{\left(3\times1.6\times10^{-19}\right)\left(44\times10^{6}\right)\text{J}}{1.6\times10^{-19}\,\text{J/eV}} \qquad PE_{\text{pointP}} = 132\times10^{6}\ \text{eV}$$

$$\Delta PE = 132\,\text{MeV}$$

Problem 7

Electrostatic potential energy of a dipole in a uniform electric field

EXAMPLE 1.16

A water molecule has an electric dipole moment of 6.3×10^{-30} Cm. A sample contains 10^{22} water molecules, with all the dipole moments aligned parallel to the external electric field of magnitude 3×10^5 NC^{-1}. How much work is required to rotate all the water molecules from $\theta = 0^o$ to 90^o?

Solution

When the water molecules are aligned in the direction of the electric field, it has minimum potential energy. The work done to rotate the dipole from $\theta = 0^o$ to 90^o is equal to the potential energy difference between these two configurations.

$W = \Delta U = U(90^o) - U(0^o)$

From the equation (1.51), we write $U = -pE\cos\theta$, Next we calculate the work done to rotate one water molecule from $\theta = 0^o$ to 90^o.

For one water molecule

$W = -pE\cos 90^o + pE\cos 0^o = pE$

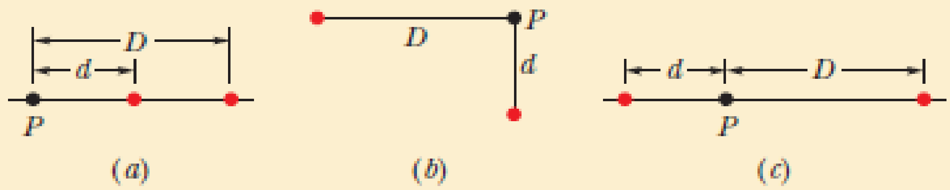
$W = 6.3 \times 10^{-30} \times 3 \times 10^5 = 18.9 \times 10^{-25}$ J

For 10^{22} water molecules, the total work done is

$W_{tot} = 18.9 \times 10^{-25} \times 10^{22} = 18.9 \times 10^{-3}$ J

Problem 8

The figure here shows three arrangements of two protons. Rank the arrangements according to the net electric potential produced at point P by the protons, greatest first.



What is the electric potential at point P, located at the center of the square of charged particles shown in Fig. 24-11a? The distance d is 1.3 m, and the charges are

$$q_1 = +12 \text{ nC}, \quad q_3 = +31 \text{ nC},$$
$$q_2 = -24 \text{ nC}, \quad q_4 = +17 \text{ nC}.$$

KEY IDEA

The electric potential V at point P is the algebraic sum of the electric potentials contributed by the four particles.

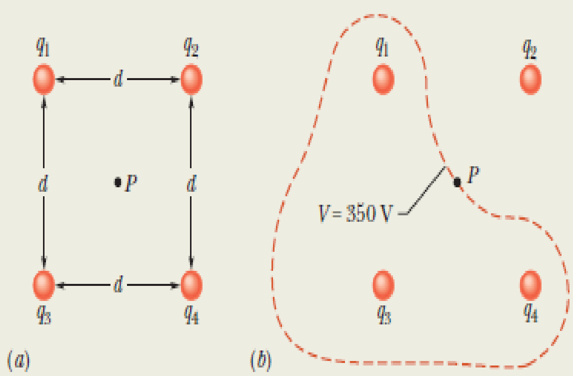


Figure 24-11 (a) Four charged particles. (b) The closed curve is a (roughly drawn) cross section of the equipotential surface that contains point P.

(Because electric potential is a scalar, the orientations of the particles do not matter.)

Calculations: From Eq. 24-27, we have

$$V = \sum_{i=1}^{4} V_i = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r} + \frac{q_2}{r} + \frac{q_3}{r} + \frac{q_4}{r}\right).$$

The distance r is $d/\sqrt{2}$, which is 0.919 m, and the sum of the charges is

$$q_1 + q_2 + q_3 + q_4 = (12 - 24 + 31 + 17) \times 10^{-9} \text{ C}$$
$$= 36 \times 10^{-9} \text{ C}.$$

Thus,
$$V = \frac{(8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(36 \times 10^{-9} \text{ C})}{0.919 \text{ m}}$$
$$\approx 350 \text{ V}. \qquad \text{(Answer)}$$

Close to any of the three positively charged particles in Fig. 24-11a, the potential has very large positive values. Close to the single negative charge, the potential has very large negative values. Therefore, there must be points within the square that have the same intermediate potential as that at point P. The curve in Fig. 24-11b shows the intersection of the plane of the figure with the equipotential surface that contains point P.