

Chapter 25

1

Electric Potential

Mustafa Al-Zyout - Philadelphia University

10/5/2025

1

Lecture 03

2

Electric Potential Due To A Point Charges

Mustafa Al-Zyout - Philadelphia University

10/5/2025

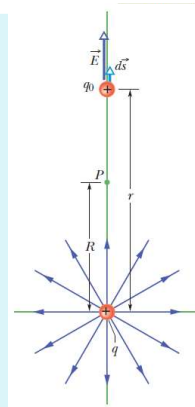
2

Electric Potential due to a Point Charges

3

The electric potential at (P) measured with respect to zero potential at infinity will be

$$V_P = \frac{k_e q}{R}$$



Mustafa Al-Zyout - Philadelphia University

10/5/2025

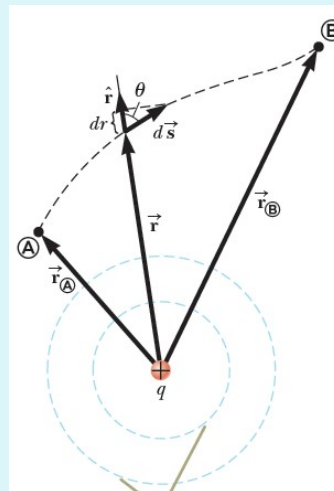
3

Electric Potential due to a Point Charges , cont.

4

- The potential difference between points A and B will be

$$V_B - V_A = k_e q \left(\frac{1}{r_B} - \frac{1}{r_A} \right)$$



Mustafa Al-Zyout - Philadelphia University

10/5/2025

4

Electric Potential due to a Point Charges, final

5

- The electric potential is independent of the path between points A and B .
- It is customary to choose a reference potential of $V = 0$ at $r_A = \infty$.
- The potential due to a point charge at some point r is

$$V_P = \frac{k_e q}{r}$$

- The potential due to a group of point charges is:

$$V_P = k_e \sum_i \frac{q_i}{r_i}$$

Mustafa Al-Zyout - Philadelphia University

10/5/2025

5

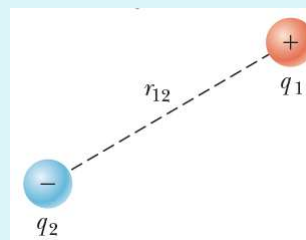
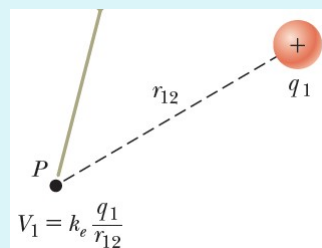
Potential Energy of Multiple Charges

6

- The potential energy of a system of two charges is:

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

- If the two charges are of the same sign, U is positive and work must be done to bring the charges together.
- If the two charges have opposite signs, U is negative and work is done to keep the charges apart.



Mustafa Al-Zyout - Philadelphia University

10/5/2025

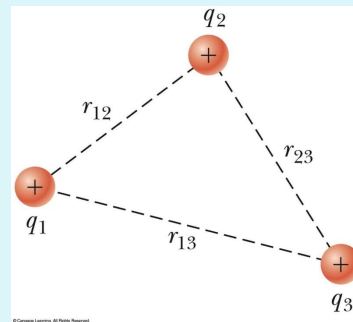
6

Potential Energy of Multiple Charges, cont.

7

- If there are more than two charges, then find U for each pair of charges and add them.
- For three charges:

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



Net potential of several charged particles

Friday, 29 January, 2021 20:53

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.



R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.



J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY, 2014.



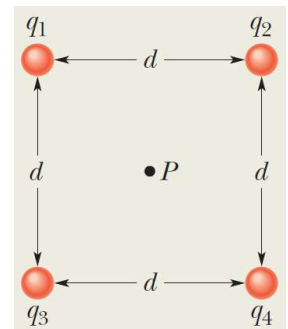
H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.



H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

What is the electric potential at point P, located at the center of the square of point charges shown? The distance is 1.3 m, and the charges are:

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



Solution

The electric potential V at point P is the algebraic sum of the electric potentials contributed by the four point charges, (Because electric potential is a scalar).

The distance r is:

$$r = \frac{d}{\sqrt{2}} = \frac{1.3}{\sqrt{2}} = 0.919m$$

And is equal for all charges. The sum of the charges is:

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

Then we have:

$$V = \sum_{i=1}^4 V_i = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1}{r} + \frac{q_2}{r} + \frac{q_3}{r} + \frac{q_4}{r} \right)$$

Thus:

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

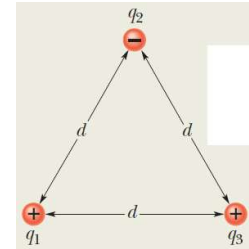
Potential energy of a system of three charged particles

Friday, 29 January, 2021 20:54

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

-  R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
-  J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY, 2014.
-  H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
-  H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

The figure shows three point charges held in fixed positions. What is the electric potential energy of this system of charges? Assume that: $d = 12\text{ cm}$, $q_1 = +q$, $q_2 = -4q$ and $q_3 = +2q$ in which $q = 150\text{ nC}$.



Solution

The potential energy U of the system is equal to the work we must do to assemble the system, bringing in each charge from an infinite distance.

Let's mentally build the system, starting with one of the point charges, say q_1 , in place and the others at infinity. Then we bring another one, say q_2 , in from infinity and put it in place. The potential energy U_{12} associated with the pair of point charges q_1 and q_2 is:

$$U_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{d}$$

We then bring the last point charge q_3 in from infinity and put it in place. The work that we must do in this last step is equal to the sum of the work we must do to bring q_3 near q_1 and the work we must do to bring it near q_2 . That sum is:

$$W_{13} + W_{23} = U_{13} + U_{23} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_3}{d} + \frac{1}{4\pi\epsilon_0} \frac{q_2 q_3}{d}$$

The total potential energy U of the three-charge system is the sum of the potential energies associated with the three pairs of charges. This sum (which is actually independent of the order in which the charges are brought together) is:

$$\begin{aligned} U &= U_{12} + U_{13} + U_{23} \\ &= \frac{1}{4\pi\epsilon_0} \left(\frac{(+q)(-4q)}{d} + \frac{(+q)(+2q)}{d} + \frac{(-4q)(+2q)}{d} \right) \\ &= -\frac{10q^2}{4\pi\epsilon_0 d} \\ &= -\frac{(8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2)(10)(150 \times 10^{-9} \text{ C})^2}{0.12 \text{ m}} \\ &= -1.7 \times 10^{-2} \text{ J} = -17 \text{ mJ} \end{aligned}$$

The negative potential energy means that negative work would have to be done to assemble this structure, starting with the three charges infinitely separated and at rest. Put another way, an external agent would have to do 17 mJ of

work to disassemble the structure completely, ending with the three charges infinitely far apart.

The change in potential energy

Friday, 29 January, 2021 20:54

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

-  R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
-  J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY, 2014.
-  H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
-  H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

As shown in the figure, a charge $q_1 = 2 \mu\text{C}$ is located at the origin and a charge $q_2 = -6 \mu\text{C}$ is located at $(0, 3)$ m. Find the change in potential energy of the system of two charges plus a third charge $q_3 = 3 \mu\text{C}$ as the latter charge moves from infinity to point P.

Solution

Assign $U_i = 0$ for the system to the configuration in which the charge q_3 is at infinity.

To evaluate the potential energy for the configuration in which the charge is at P we use:

$$\Delta U = U_f - U_i$$

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

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

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

$$\Delta U = q_3 V_P$$

Substitute numerical values to evaluate ΔU :

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

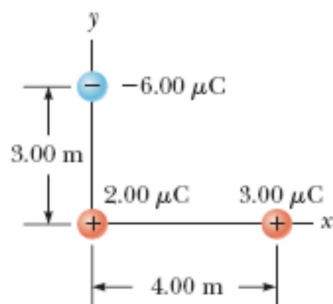
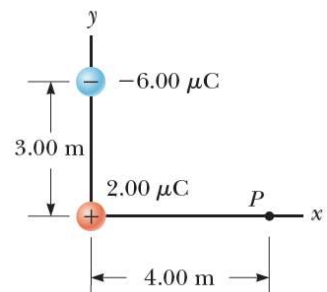
$$\Delta U = (9 \times 10^9)(3 \times 10^{-6}) \left(\frac{2 \times 10^{-6}}{4} + \frac{-6 \times 10^{-6}}{5} \right)$$

$$\Delta U = -1.86 \times 10^{-2} \text{ J}$$

Because the potential energy of the system has decreased, an external agent has to do positive work to remove the charge q_3 from point P back to infinity.

We ignored the potential energy associated with the pair of charges q_1 and q_2 ! How would you respond?

Given the statement of the problem, it is not necessary to include this potential energy because part (B) asks for the change in potential energy of the system as q_3 is brought in from infinity. Because the configuration of charges q_1 and q_2 does not change in the process, there is no ΔU associated with these charges.



The Electric Potential Due to a Dipole

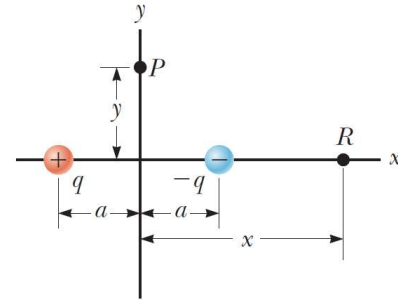
Friday, 29 January, 2021 20:55

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

-  R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
-  J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY, 2014.
-  H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
-  H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

An electric dipole consists of two charges of equal magnitude and opposite sign separated by $2a$. The dipole is along the x axis and is centered at the origin.

- Calculate the electric potential at point P on the y -axis.
- Calculate the electric potential at point R on the positive x -axis.
- Calculate V and E_x at a point on the x -axis far from the dipole.



Solution

$$V_P = k_e \sum_i \frac{q_i}{r_i} = k_e \left(\frac{q}{\sqrt{a^2 + y^2}} + \frac{-q}{\sqrt{a^2 + y^2}} \right) = 0$$

Solution

$$V_R = k_e \sum_i \frac{q_i}{r_i} = k_e \left(\frac{-q}{x - a} + \frac{q}{x + a} \right) = -\frac{2k_e qa}{x^2 - a^2}$$

Solution

For point R far from the dipole such that $(x \gg a)$, neglect a^2 in the denominator of the answer to part (B) and write V in this limit:

$$V_R = \lim_{x \gg a} \left(-\frac{2k_e qa}{x^2 - a^2} \right) \approx -\frac{2k_e qa}{x^2}$$