# Chapter 25

# Electric Potential

CHAPTER OUTLINE

25.1 Potential Difference and Electric Potential

25.3 Electric Potential and Potential Energy Due to Point Charges

25.4 Obtaining the Value of the Electric Field from the Electric Potential

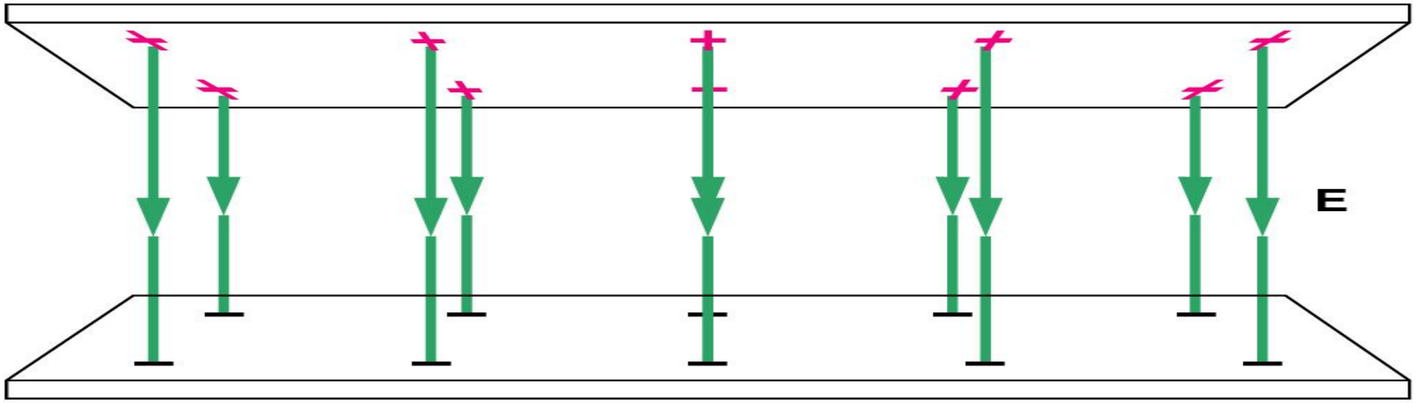
# 25.1 Potential Difference and Electric Potential

## The Electric Potential

Moving an electric charge through space where electric fields are present can require work, since forces associated with the fields act on the charge.

This work can be described as a change in potential energy. We introduce the new concept of "**electric potential**" to describe the amount of work needed to move a charge through a region with electric fields.

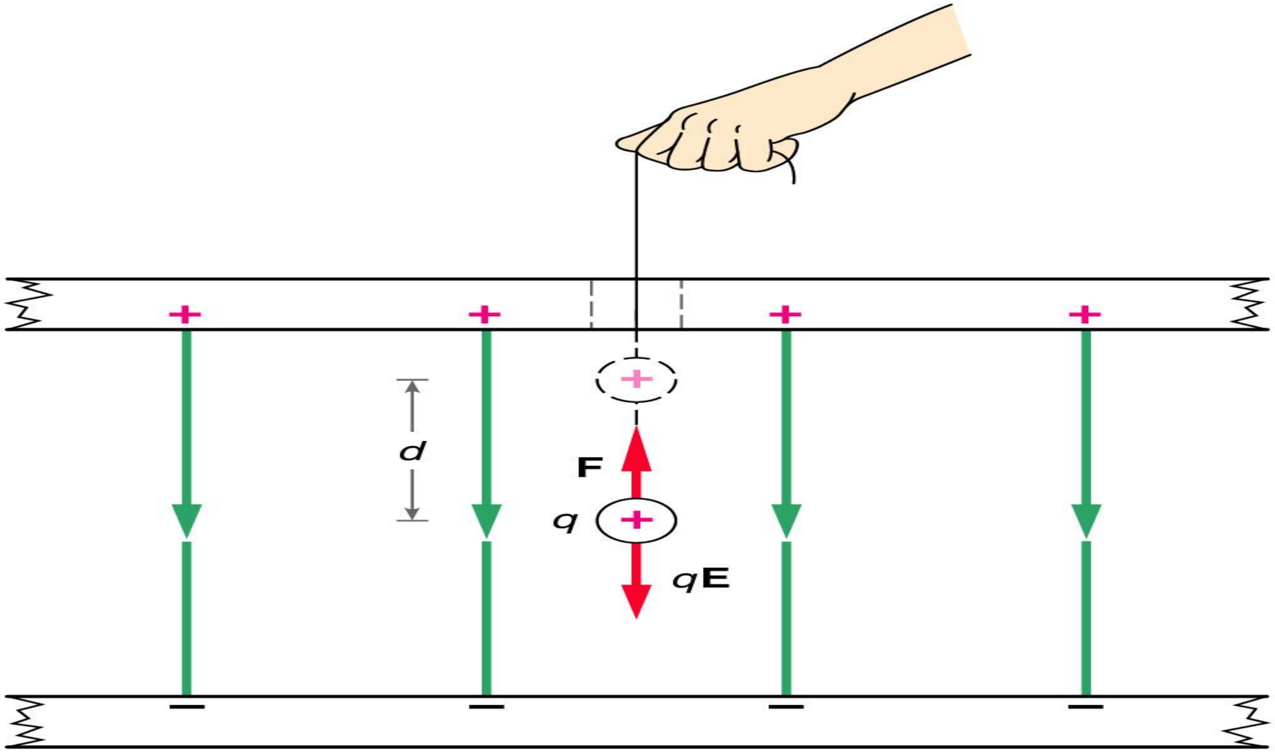
**Two parallel metal plates containing equal but opposite-sign charges produce a uniform electric field in the region between the plates.**



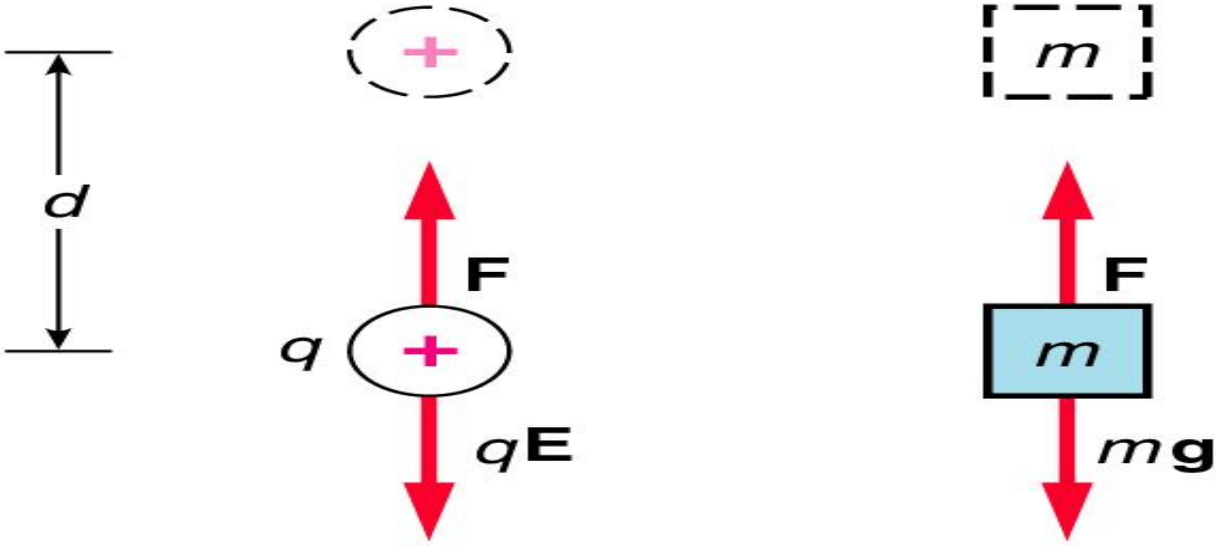

“CAPACITOR”

(This is a convenient device that allows us to talk about a region where the electric field does not change. This makes the calculations much easier.)

**An external force F, equal in magnitude to the electrostatic force *q*E, is used to move the charge *q* a distance *d* in a uniform field.**



**The increase in potential energy when a charge *q* is moved against the electrostatic force is analogous to what happens when a mass *m* is lifted against the gravitational force.**



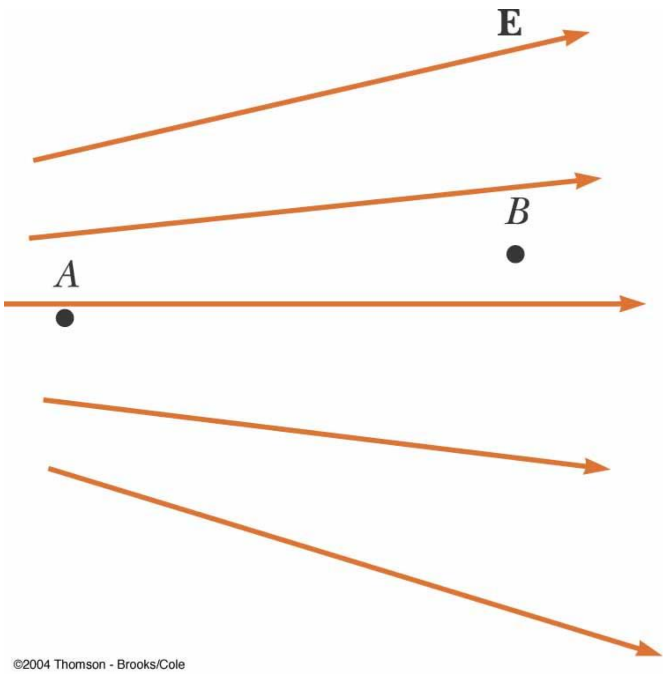

$$\Delta PE = W = Fd$$

We call this the <u>electrostatic</u> potential energy (instead of the gravitational potential energy).

# The Electric Potential

The work done by the electric field on the charge is

$$\mathbf{F} \cdot d\mathbf{s} = q_0 \mathbf{E} \cdot d\mathbf{s}$$




The potential energy of the charge–field system is changed by an amount

$$dU = -q_0 \mathbf{E} \cdot d\mathbf{s}.$$

$$\Delta U = -q_0 \int_A^B \mathbf{E} \cdot d\mathbf{s}$$

this line integral does not depend on the path taken from ***A*** to ***B***.

## The potential difference

The change in electric potential is equal to the change in electrostatic potential energy per unit of positive test charge:

$$\Delta V = \frac{\Delta U}{q}$$

This is the definition of potential. It is measured in volts.

The potential difference $\Delta V = V_B - V_A$ between two points $A$ and $B$ in an electric field is defined as the change in potential energy of the system when a test charge is moved between the points divided by the test charge $q_0$:

$$\Delta V \equiv \frac{\Delta U}{q_0} = -\int_A^B \mathbf{E} \cdot d\mathbf{s}$$

Electric potential is a scalar characteristic of an electric field, independent of any charges that may be placed in the field.

The work done by an external agent in moving a charge $q$ through an electric field at constant velocity is

$$W = \Delta U$$

$$W = q\Delta V$$

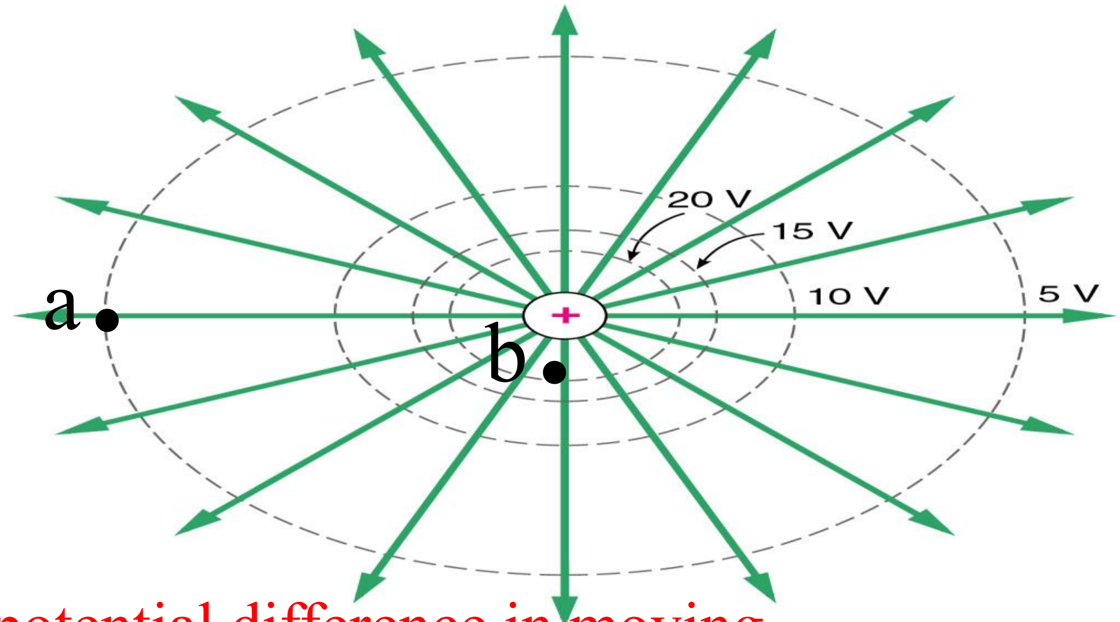
The SI unit of the electric potential is energy per unit charge and potential difference is joules per coulomb, which is defined as a volt (V):

$$1\ \mathrm{V} \equiv 1\ \frac{\mathrm{J}}{\mathrm{C}}$$

The electron volt is related to the joule as follows:

$$1\ \mathrm{eV} = 1.60 \times 10^{-19}\ \mathrm{C \cdot V} = 1.60 \times 10^{-19}\ \mathrm{J}$$

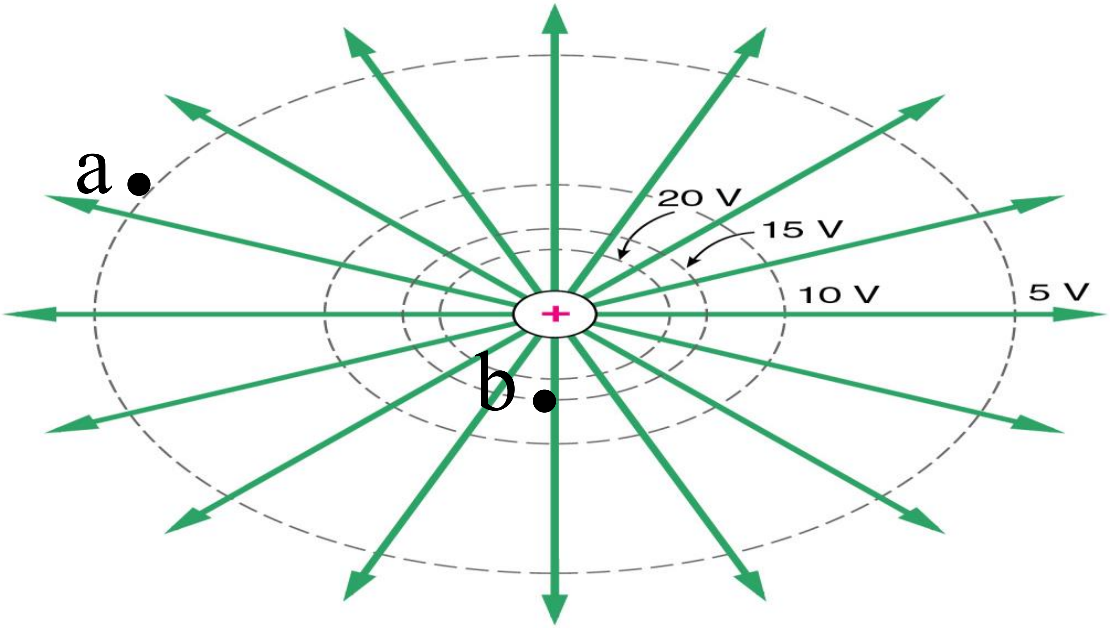
**Example: The electric potential (represented by the dashed lines of constant potential) increases as we move closer to a positive charge.**




What is the potential difference in moving From a to b.

1. 15 V
2. -15V
3. 25 V
4. -25V
5. Can tell not in a straight line

# Example:




What is the work done in moving a +2 coulomb charge from a to b?

1. 50 J
2. 30 J
3. 25 J
4. 20 J
5. 15 J

If 500 J of work is required to carry a 40 C charge from one point to another, the potential difference between the two points is

1. 12.5 V
2. 20,000 V
3. 0.08 V
4. depends upon the path
5. none of these

# 25.3 Electric Potential and Potential Energy Due to Point Charges

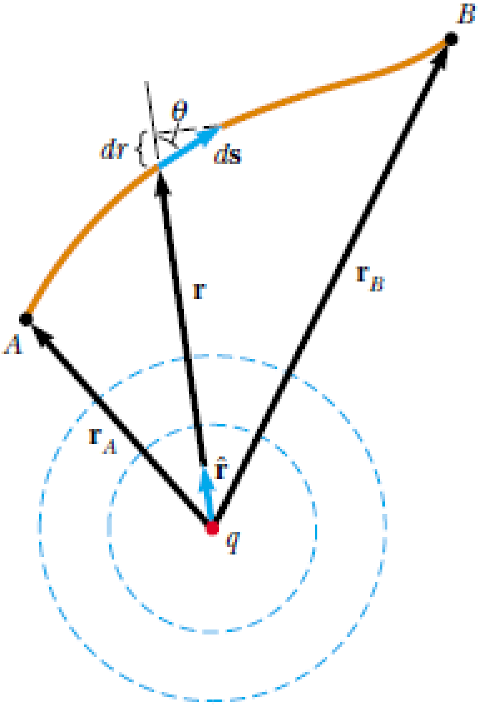
## Electric Potential due to point charges

$$V_B - V_A = -\int_A^B \mathbf{E} \cdot d\mathbf{s}$$

$$\mathbf{E} \cdot d\mathbf{s} = k_e \frac{q}{r^2} \hat{\mathbf{r}} \cdot d\mathbf{s}$$

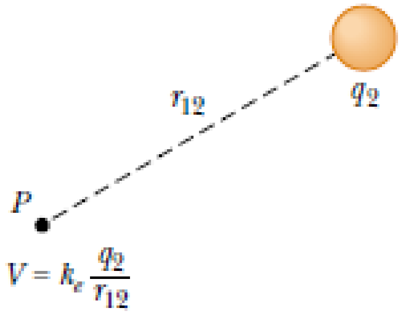
$$V_B - V_A = -k_e q \int_{r_A}^{r_B} \frac{dr}{r^2} = \frac{k_e q}{r}\Bigg]_{r_A}^{r_B}$$

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



The electric potential created by a point charge at any distance *r* from the charge is

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

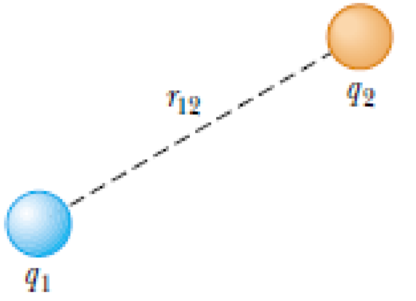


The total electric potential at some point *P* due to several point charges is the sum of the potentials due to the individual charges

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

## Potential Electric due to point charges

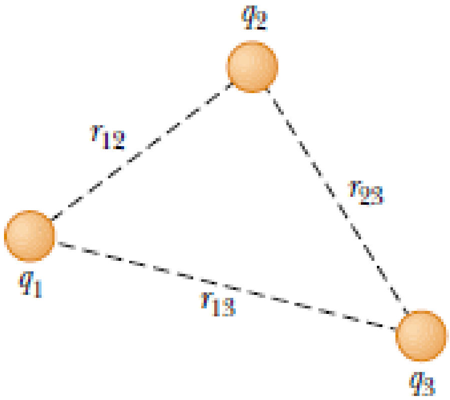
$$U = k_e \frac{q_1 q_2}{r_{12}}$$




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 (because charges of the same sign repel). If the charges are of opposite sign, *U* is negative; this means that negative work is done by an external agent against the attractive force between the charges of opposite sign as they are brought near each other—a force must be applied opposite to the displacement to prevent *q*1 from accelerating toward *q*2.

The total potential energy of the system of three charges is:

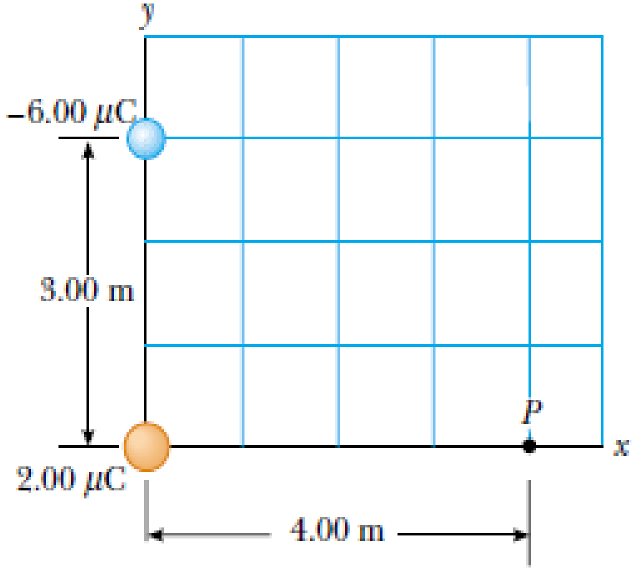
$$U = k_e\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right)$$



Example 25.3 **The Electric Potential Due to Two Point Charges**

A charge $q_1 = 2.00\ \mu C$ is located at the origin, and a charge $q_2 = -6.00\ \mu C$ is located at (0, 3.00) m, as shown in Figure 25.12a.

**(A)** Find the total electric potential due to these charges at the point *P*, whose coordinates are (4.00, 0) m.




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

$$V_P = (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2})$$

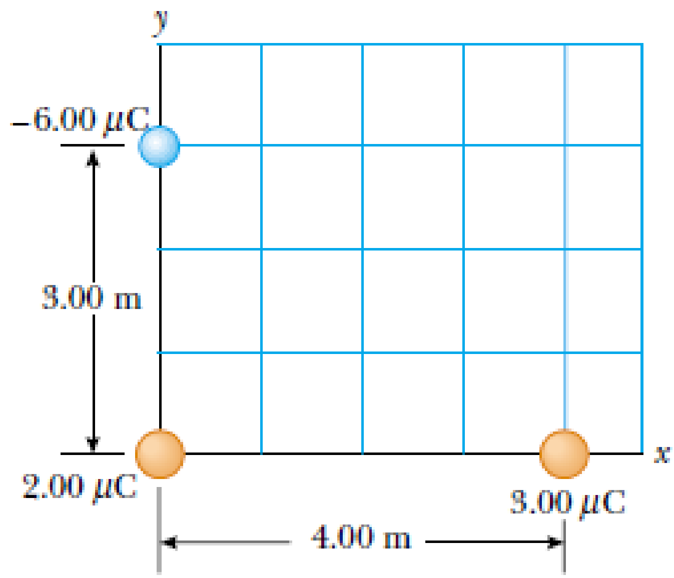
$$\times\left(\frac{2.00 \times 10^{-6}\ \mathrm{C}}{4.00\ \mathrm{m}} - \frac{6.00 \times 10^{-6}\ \mathrm{C}}{5.00\ \mathrm{m}}\right)$$

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

**(B)** Find the change in potential energy of the system of two charges plus a charge $q_3 = 3.00\ \mu\text{C}$ as the latter charge moves from infinity to point $P$ (Fig. 25.12b).

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

$$= \boxed{-1.89 \times 10^{-2}\ \text{J}}$$



## 25.4 Obtaining the Value of the Electric

If the electric field has only one component

Field from the Electric Potential

$E_x = - dV / dx$

Two things about E and V:

• The electric field points in the direction of decreasing electric potential.

• The electric field is always perpendicular to the equipotential surface

If the charge distribution creating an electric field has spherical symmetry such that the volume charge density depends only on the radial distance r, the electric field is radial.

$$E_r = -\frac{dV}{dr}$$

(A) Calculate the electric potential at points a and b on the x axis.
(B) Calculate the work to remove the charge $q_o$ from point a to b.

- $r_a = 1$ m , $r_b = 0.1$ m , $q = 1\text{x}10^{-6}$ C

$$V_a = K_e \frac{q}{r_a} = 9000 \ Volt$$

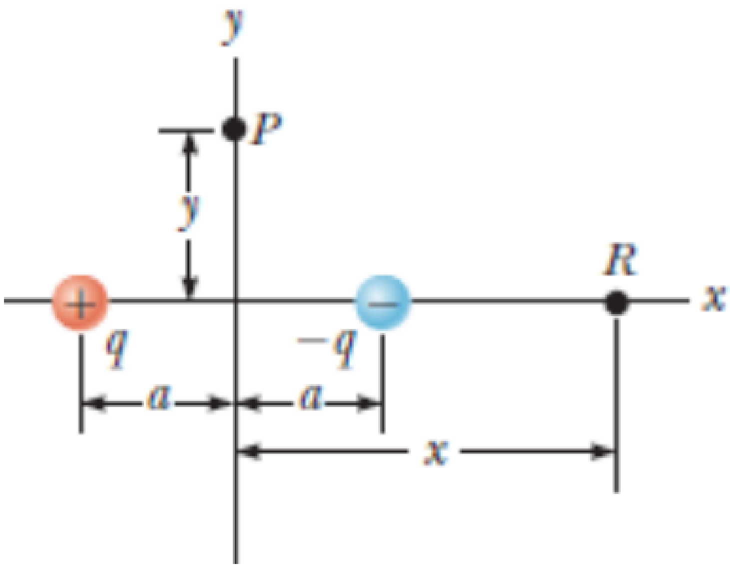
$$V_b = K_e \frac{q}{r_b} = 90000 \ Volt$$

$$V_{ab} = V_b - V_a = 90000 - 9000 = 81000 \ \ Volt$$

$$\mathrm{U_{ab}} = q_o V_{ab} = 2.5 \times 10^{-7} \times 81000 = 0.02 \ \ Joule$$

# EX: The Electric Potential Due to a Dipole

An electric dipole consists of two charges of equal magnitude and opposite sign separated by a distance 2*a* as shown in Figure. The dipole is along the *x* axis and is centered at the origin.




(A) Calculate the electric potential at point *P* on the *y* axis.

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

(B) Calculate the electric potential at point *R* on the positive *x* axis.

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