Chapter 20
Electric Potential and Electric potential Energy

Outline

20-1 Electric Potential Energy and the Electric Potential

20-2 Energy Conversation

20-3 The Electric Potential of Point Charges

20-4 Equipotential Surfaces and the Electric Field.

20-5 Capacitor and Dielectric

20-6 Electric Energy Storage

20-3 The electric potential of point charge

Deriving electric potential of point source

Consider a point charge, +q, at the originate of the coordinate system shown in the figure. Suppose a positive test charge, $+q_0$ is held rest at point A, a distance r_a from the origin.

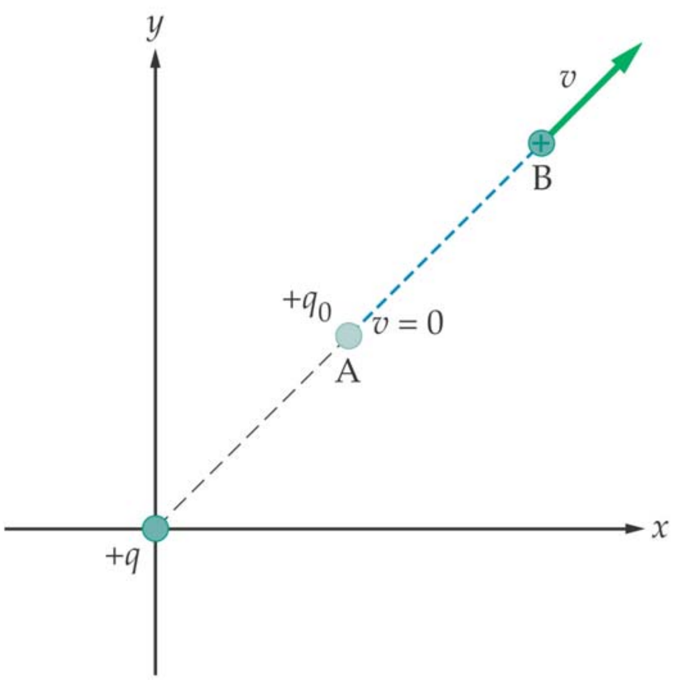


Figure 20-4. Energy Conservation in an Electrical System

After q_0 moves to point B, it can be derived by integral, that the difference in electric potential energy between points A and B is

$$U_A - U_B = \frac{kq_0 q}{r_A} - \frac{kq_0 q}{r_B}$$

The corresponding change in electric potential is

$$V_A - V_B = U_A / q_0 - U_B / q_0 = \frac{kq}{r_A} - \frac{kq}{r_B}$$

If the test charge is moved to infinite, $r_B \rightarrow \infty$, we have

$$V_A - V_B = \frac{kq}{r_A}$$

We define the potential to be zero at infinite from the given charge, and we have

$$V_B = 0.$$

Electric potential for a point charge

$$V = \frac{kq}{r} \qquad (20-7)$$

SI unit: Volt, V

Two Charges: Electric potential energy for point charge q and q_0 with r separated distance

$$U = q_0 V = \frac{kq_0 q}{r} \qquad (20-8)$$

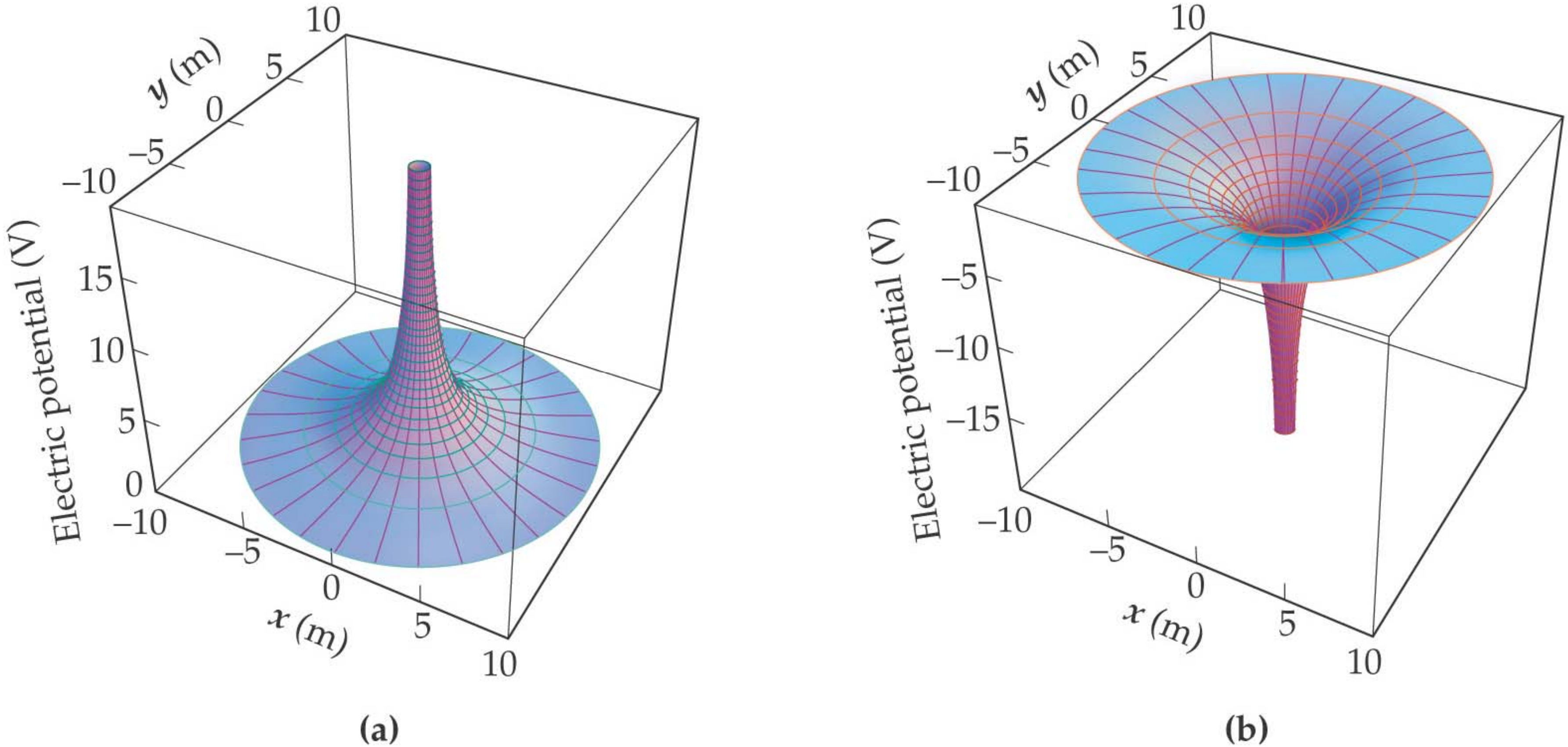
SI unit: Joule, J

Note: The electric potential / energy is zero at infinite distance. Negative charge has a minus V.

20-23 The potential of a Point charge

The hydrogen atom consists of one electron and one proton. The electron orbits the proton in a circular orbit of radius 0.529×10^{-10} m. (a) What is the electric potential due to the proton at the electron's orbit? (b) What is the potential energy of the atom at the orbit?

Figure 20-5
The Electric Potential of a Point Charge



Positive charge at origin

Negative charge at origin

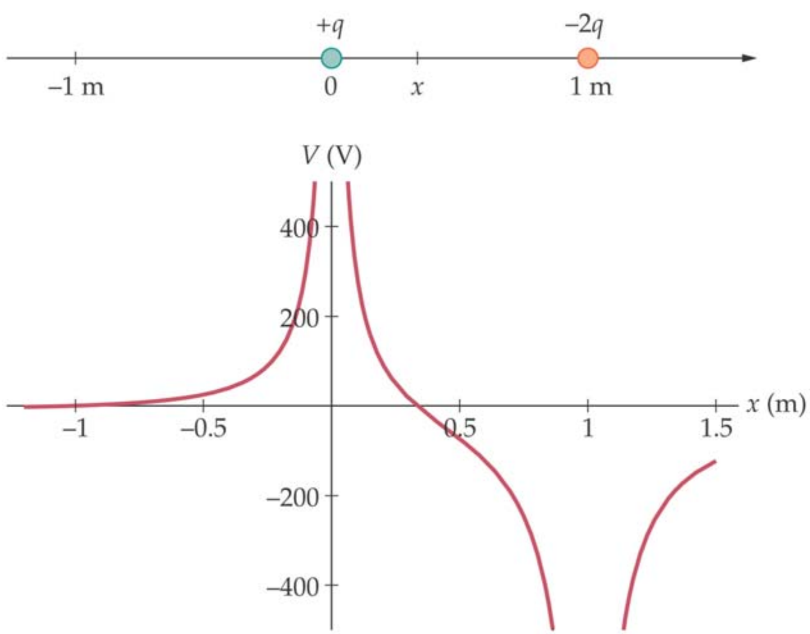
Superposition

The total electric potential due to two or more charges is equal to the algebraic sum of the potentials due to each charges.

The potential of positive and negative charges may be cancelled each other. Pay attention to the sign of the charge!

Example 20-3 Two point charges

A charge $q=4.11\text{x}10^{-9}$ C is placed at the origin, and a second charge of -2q is located on the x axis at the location x=1.00m. (a) Find the electric potential midway between the two charges. (b) The electric potential vanish at some distance between the two charges. Find the this value of x.



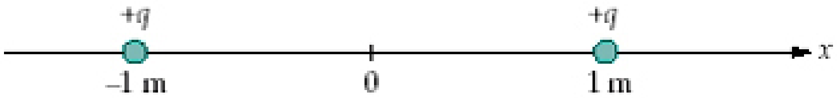
Picture the problem

Example 20-3

Two Point Charges

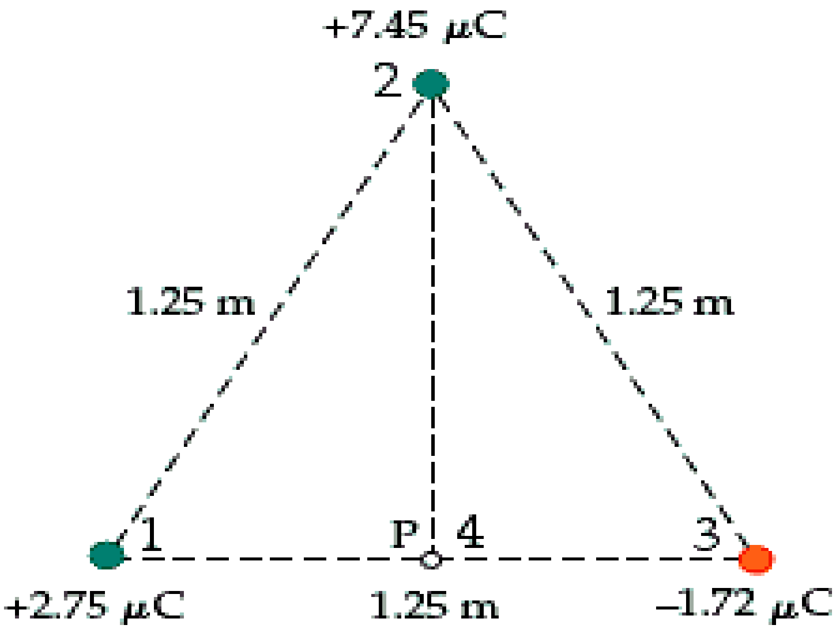
CONCEPTUAL CHECKPOINT 20–3

Two point charges, each equal to $+q$, are placed on the x axis at $x = -1$ m and $x = +1$ m. As one moves along the x axis, does the potential look like a peak or a valley near the origin?



20-33 Multiple Charges

(a) Find the electric potential at point P in the following figure. (b) A fourth charge, with charge of +6.11 uC and a mass 4.71 g, is released from rest at point P. What is the speed of the fourth charge when it has moved to infinite distance?



20-4 Equipotential surfaces and the electric field

Like the geometric contour map that is used to indicate the different altitudes, a equipotential plot/map, which consists of equipotential surface, could be used to indicate the difference of the potential.

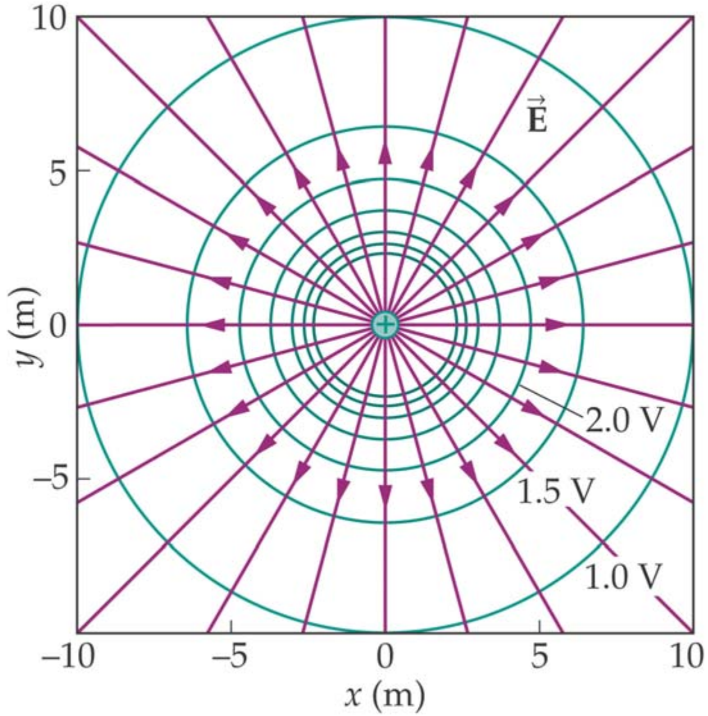


Figure 20-6
Equipotentials for a Point Charge

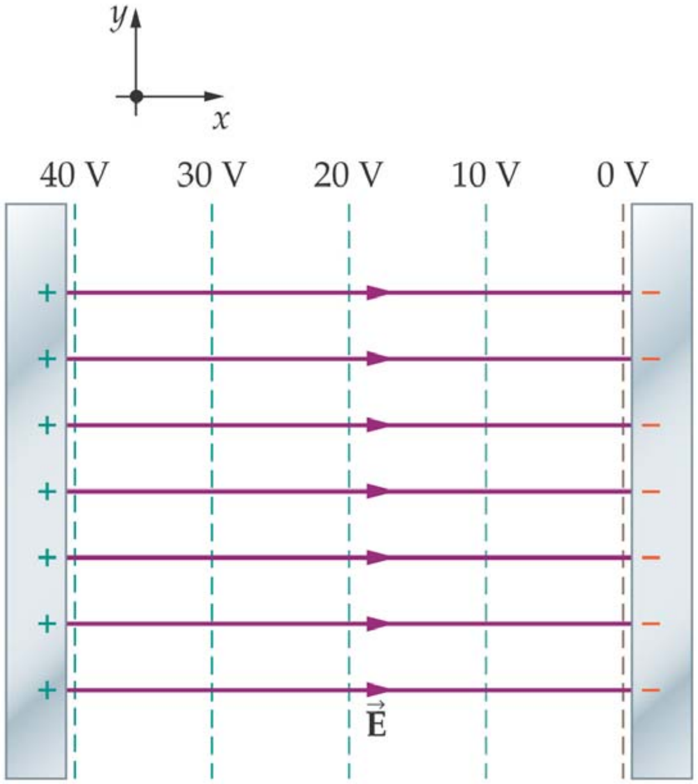
An equipotential plot must contain the following information

1) Relative magnitude and direction of the electric field.

- The $E = - \Delta V / \Delta S$, depend on the rate of the change of the potential.
- The electric field points in the direction of decreasing electric potential.

2) The electric field is always perpendicular to the equipotential surface.

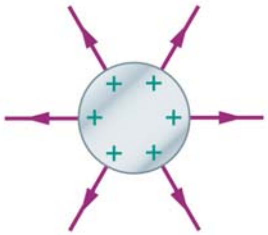
Figure 20-7
Equipotential Surfaces for a Uniform Electrical Field



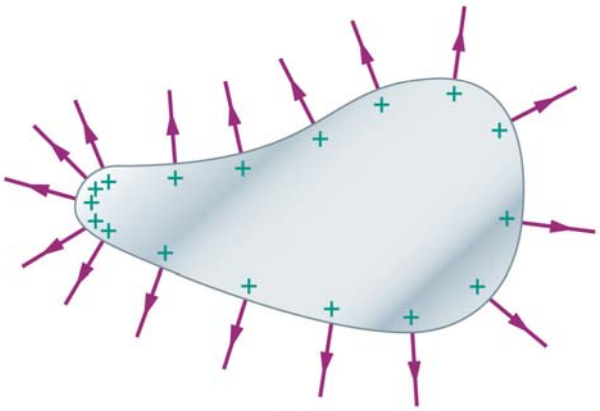
The electric field is perpendicular to the equipotentials and points in the dirtcion of decreasing potential.

Ideal Conductors

Charges on ideal conductor can move freely and with no work being done.



(a)



(b)

Figure 20-9
Electric Charges on the Surface of Ideal Conductors

Why the charges have high density (large electric field) at the sharp end?

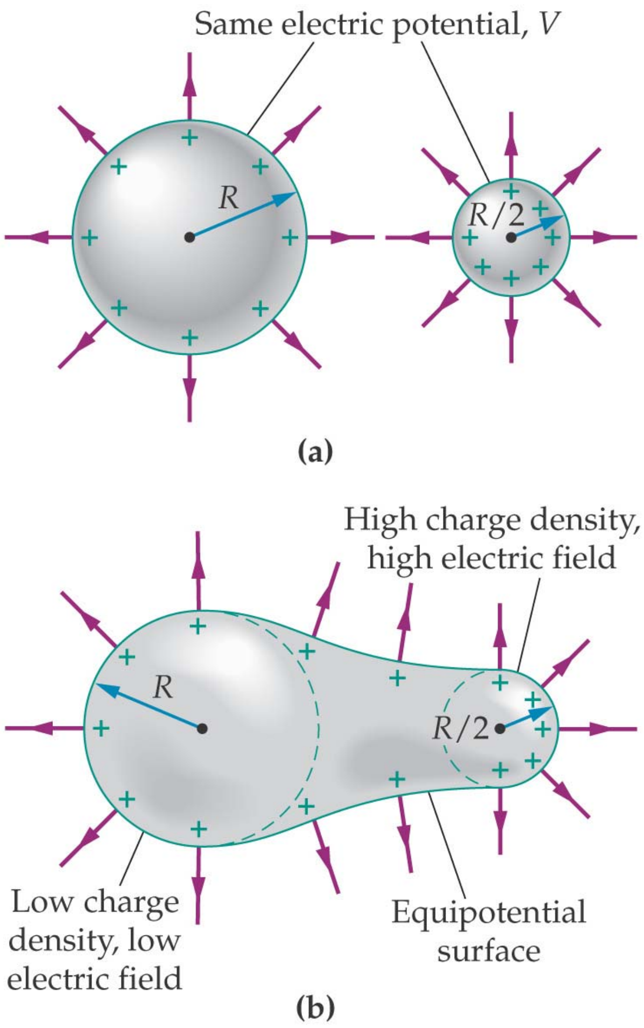


Figure 20-10
Charge Concentration Near Points

In figure (a), the potential at its surface is the same as for a point charge Q at the center of the sphere,

$$V = \frac{kQ}{R} = \frac{k\sigma(4\pi R^2)}{R} = 4\pi k\sigma R$$

Where σ is the charge density.

Consider (b) with a sphere of R/2, for the same potential with (a), we have

$$V = 4\pi k\sigma_b (R/2) = 4\pi k\sigma R$$

$$\sigma_b = 2\sigma$$

This prove that small radius surface has large charge density.

Summary

20-5 The Electric Potential of Point Charges

Electric potential for a point charge

$$V = \frac{kq}{r_A}$$

20-4 Equipotential Surfaces and the Electric Field.

1) Equipotential surfaces and its relationship with the electric field

2) For ideal conductor, charges have high density (large electric field) at the sharp end.

Addition Information for homework

The number of signification figures after *multiplication* or *division* is equal to the number of the signification figures in the *least* accurately known quantity.

For examples:

21.2 / 8.5 = 2.5

2.51 / 12.23 = 30.7

17 / 2.51 = 6.8

2.1×10^{-2} is two signification figures.

Exercise 20-2

Find the electric potential produced by a point charge of $6.80\text{x}10^{-7}$ C at a distance of 2.60 m.

Solution:

$$V = \frac{kq}{r} = \frac{(8.99\times 10^{9}\, N.m^{2})(6.80\times 10^{-7}\, C)}{2.60m}$$

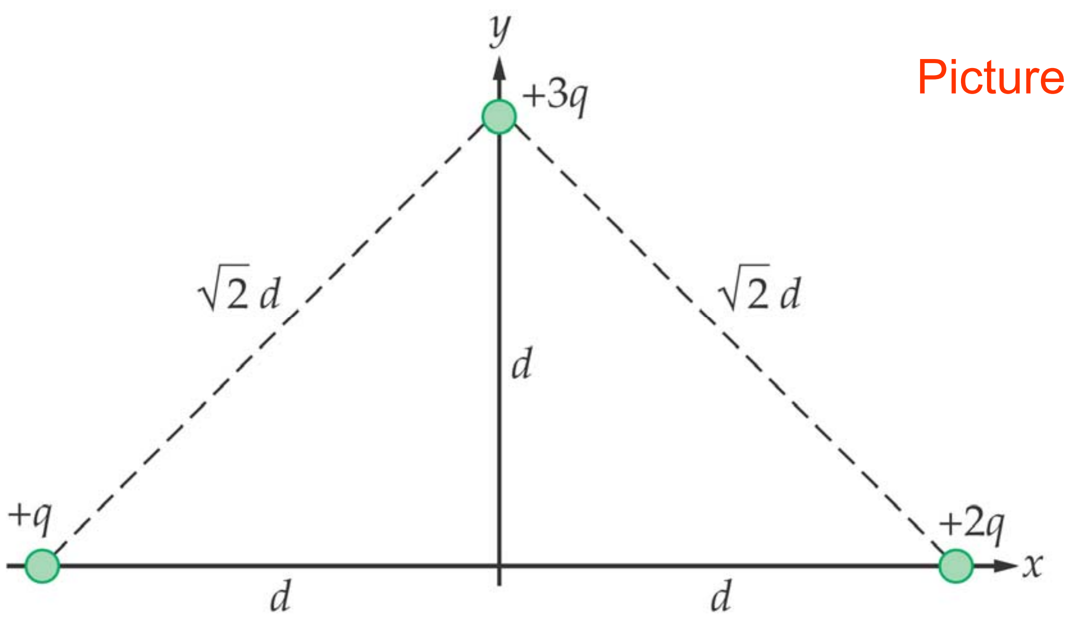
$$= 2350 \quad V$$

$$= 2.35\times 10^{3} \quad V$$

Example 20-4 **Fly Away**

Two charges, +q and +2q, are held on the x axis at the location x=-d and x=+d, respectively. A third charge +3q is released from rest on the y axis at y=d.

(a) Find the electric potential due to the first two charges at the initial location of the third charge. (b) Find the initial electric potential energy of the third charge. (c) What is the kinetic energy of the third charge when it has moved infinitely far away from the other two charges?



Picture the problem

Example 20-4
Fly Away

Solution

Part (a)

The electric potential at the initial position of the third charge is

$$V_i = \frac{k(+q)}{\sqrt{2}d} + \frac{k(+2q)}{\sqrt{2}d} = \frac{3kq}{\sqrt{2}d}$$

Part (b)

Multiply V_i by (3q) to find the U:

$$U_i = (+3q)V_i = (+3q)\frac{3kq}{\sqrt{2}d} = \frac{9kq^2}{\sqrt{2}d}$$

Part (c)

Since energy conservation:

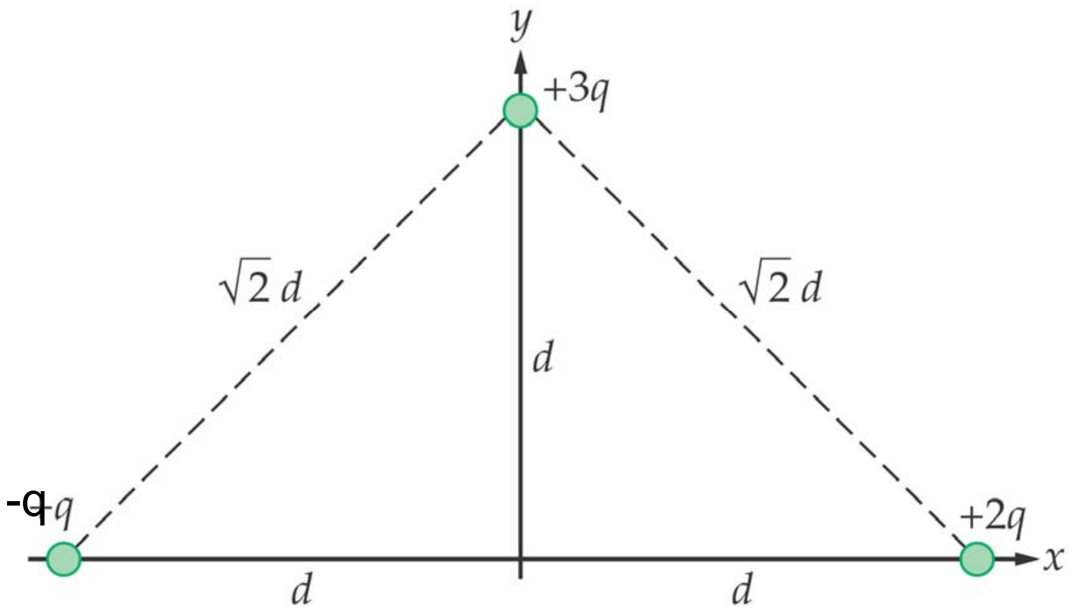
$$U_i + K_i = U_f + K_f$$

$$\frac{9kq^2}{\sqrt{2}d} + 0 = 0 + K_f$$

$$K_f = \frac{9kq^2}{\sqrt{2}d}$$

Example 20-4 **Find the electric potential energy**

A system consists of three charges –q at (-d,0), +2q at (d,0) and +3q at (0,d). What is total electric potential energy of the system?



Picture the problem

Solution

1) **The electric potential energy between –q and +2q**

$$U_{12} = \frac{k(-q)(2q)}{2d}$$

2) **The electric potential energy between –q and +3q**

$$U_{13} = \frac{k(-q)(3q)}{\sqrt{2}d}$$

3) **The electric potential energy between 2q and +3q**

$$U_{23} = \frac{k(2q)(3q)}{\sqrt{2}d}$$

4) **The total electric potential energy of the system**

$$U = U_{12} + U_{13} + U_{23} = \frac{k3q^2}{\sqrt{2}d} - \frac{kq^2}{d}$$