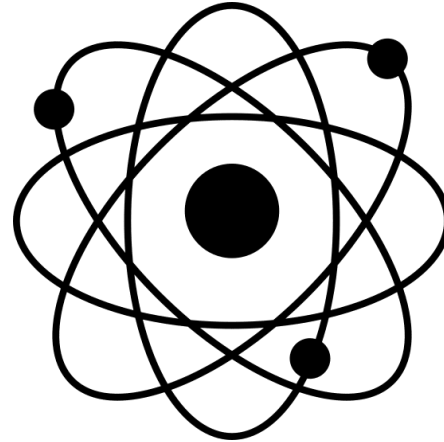


Chapter 3

Electric Potential



Revision Paper

Electric Potential Energy

Chapter 3 Lesson 1 – Revision Paper

3.1 – Electric Potential Energy

$$\Delta U = -W_e$$

$$W = q\vec{E} \cdot \vec{d} = qEd \cos \theta$$

Multiple Choice Question 3.1

A positive charge is released and moves along an electric field line. This charge moves to a position of

- a) lower potential and lower potential energy.
- b) lower potential and higher potential energy.
- c) higher potential and lower potential energy.
- d) higher potential and higher potential energy

Multiple Choice Question 3.1

A positive charge is released and moves along an electric field line. This charge moves to a position of

- a) **lower potential and lower potential energy.**
- b) lower potential and higher potential energy.
- c) higher potential and lower potential energy.
- d) higher potential and higher potential energy

Multiple Choice Question 3.2

A **proton** is placed midway between points **A** and **B**. The potential at point **A** is **-20 V**, and the potential at point **B** **+20 V**. The potential at the midpoint is **zero**. The proton will

- a) remain at rest.
- b) move toward point B with constant velocity.
- c) accelerate toward point A.
- d) accelerate toward point B.
- e) move toward point A with constant velocity.

Multiple Choice Question 3.2

A **proton** is placed midway between points **A** and **B**. The potential at point **A** is **-20 V**, and the potential at point **B** **+20 V**. The potential at the midpoint is **zero**. The proton will

- a) remain at rest.
- b) move toward point B with constant velocity.
- c) **accelerate toward point A.**
- d) accelerate toward point B.
- e) move toward point A with constant velocity.

Multiple Choice Question 3.3

What would be the consequence of setting the potential at **+100 V** at infinity, rather than taking it to be zero there?

- a) Nothing; the field and the potential would have the same values at every finite point.
- b) The electric potential would become infinite at every finite point, and the electric field could not be defined.
- c) The electric potential everywhere would be 100 V higher, and the electric field would be the same.
- d) It would depend on the situation. For example, the potential due to a positive point charge would drop off more slowly with distance, so the magnitude of the electric field would be less.

Multiple Choice Question 3.3

What would be the consequence of setting the potential at **+100 V** at infinity, rather than taking it to be zero there?

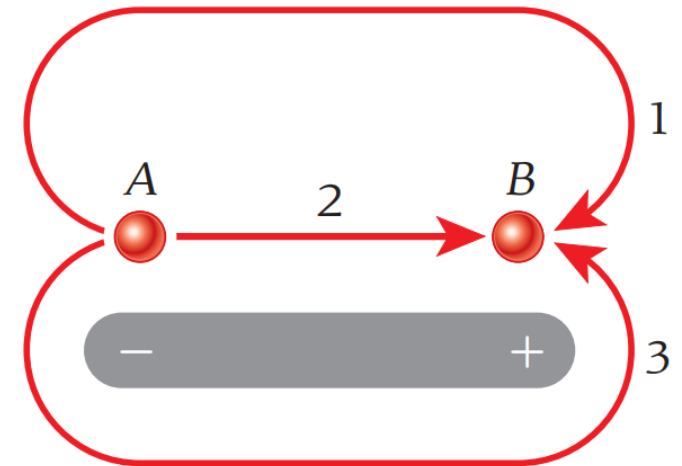
- a) Nothing; the field and the potential would have the same values at every finite point.
- b) The electric potential would become infinite at every finite point, and the electric field could not be defined.
- c) **The electric potential everywhere would be 100 V higher, and the electric field would be the same.**
- d) It would depend on the situation. For example, the potential due to a positive point charge would drop off more slowly with distance, so the magnitude of the electric field would be less.

Multiple Choice Question 3.8

04

A **positive** point charge is to be moved from point **A** to point **B** in the vicinity of an electric dipole. Which of the three paths shown in the figure will result in the most work being done by the dipole's electric field on the point charge?

- a) path 1
- b) path 2
- c) path 3
- d) The work is the same on all three paths.

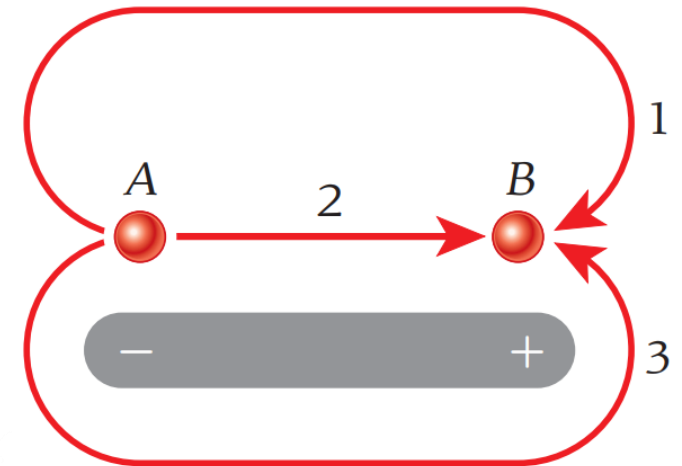


Multiple Choice Question 3.8

04

A **positive** point charge is to be moved from point **A** to point **B** in the vicinity of an electric dipole. Which of the three paths shown in the figure will result in the most work being done by the dipole's electric field on the point charge?

- a) path 1
- b) path 2
- c) path 3
- d) The work is the same on all three paths.



Exercise 3.24

In molecules of gaseous sodium chloride, the chloride ion has one more electron than proton, and the sodium ion has one more proton than electron. These ions are separated by about **0.236 nm**. How much work would be required to increase the distance between these ions to **1.00 cm**?

Exercise 3.24

05

In molecules of gaseous sodium chloride, the chloride ion has one more electron than proton, and the sodium ion has one more proton than electron. These ions are separated by about **0.236 nm**. How much work would be required to increase the distance between these ions to **1.00 cm**?

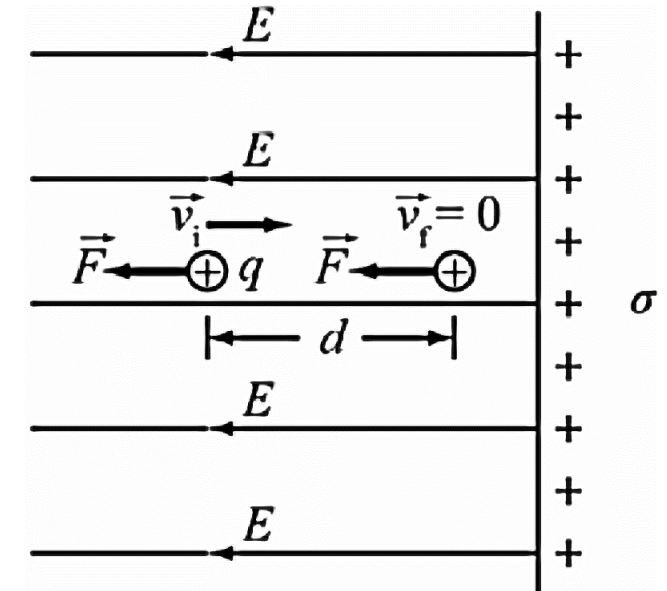
$$W = -\Delta U = -kq_1q_2 \left(\frac{1}{r_f} - \frac{1}{r_i} \right)$$
$$= (8.99 \cdot 10^9 \text{ N m}^2/\text{C}^2) \cdot \left| (-1.602 \cdot 10^{-19} \text{ C})(1.602 \cdot 10^{-19} \text{ C}) \right| \cdot \left(\frac{1}{1.0 \cdot 10^{-2} \text{ m}} - \frac{1}{0.24 \cdot 10^{-9} \text{ m}} \right)$$

$$W = 9.6 \cdot 10^{-19} \text{ J}.$$

Exercise 3.25

o6

A metal ball with a mass of $3.00 \times 10^{-6} \text{ kg}$ and a charge of $+5.00 \text{ mC}$ has a kinetic energy of $6.00 \times 10^8 \text{ J}$. It is traveling directly at an infinite plane of charge with a charge distribution of $+4.00 \text{ C/m}^2$. If it is currently 1.00 m away from the plane of charge, how close will it come to the plane before stopping?



Exercise 3.25

A metal ball with a mass of $3.00 \times 10^{-6} \text{ kg}$ and a charge of $+5.00 \text{ mC}$ has a kinetic energy of $6.00 \times 10^8 \text{ J}$. It is traveling directly at an infinite plane of charge with a charge distribution of $+4.00 \text{ C/m}^2$. If it is currently 1.00 m away from the plane of charge, how close will it come to the plane before stopping?

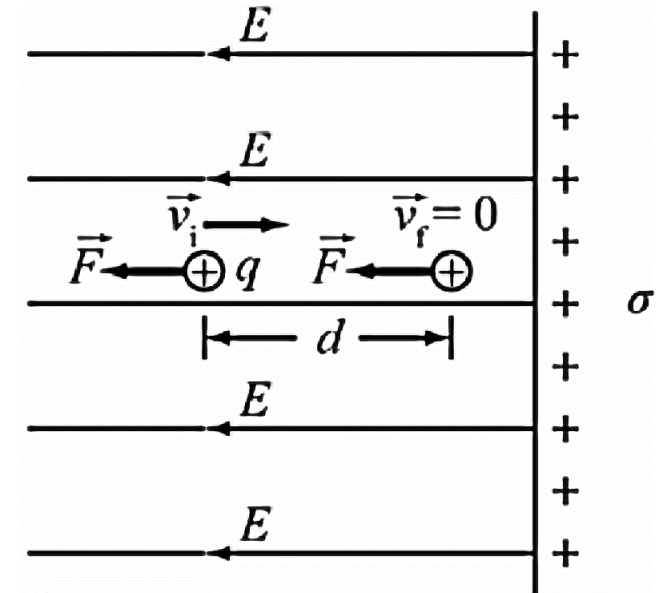
$$W = \Delta K$$

$$qEd = K - K_0$$

$$E = \frac{\sigma}{\epsilon_0} = \frac{4}{\epsilon_0} = 4.5 \times 10^{11} \text{ N/C}$$

$$d = \frac{0 - K_0}{qE} = \frac{-(6 \times 10^8)}{(5 \times 10^{-3})(4.5 \times 10^{11})} = -0.266 \text{ m}$$

The final distance from the plane is $x = -1 - 0.266 = 0.734 \text{ m}$.



Definition of Electric Potential

Chapter 3
Lesson 2 – Revision Paper

3.2 – Definition of Electric Potential

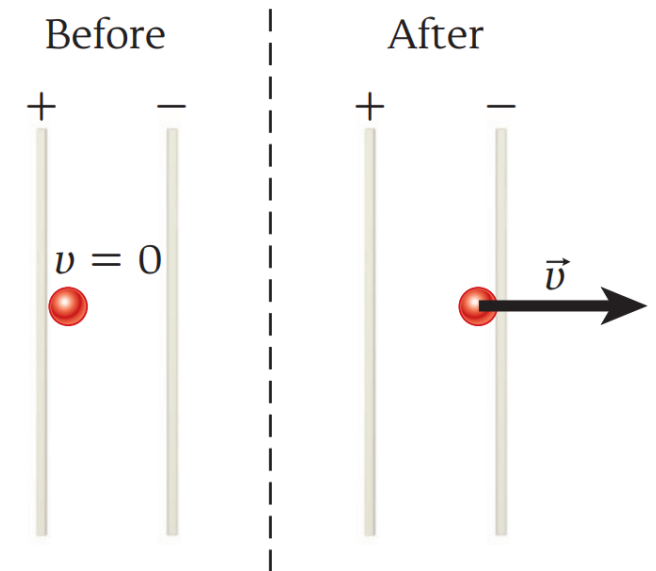
$$V = \frac{U}{q}$$

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

$$V = -\frac{W_{e,\infty}}{q}$$

Example 3.1

A **proton** is placed between two parallel conducting plates in a vacuum. The difference in electric potential between the two plates is **450 V**. The proton is released from rest close to the positive plate. What is the kinetic energy of the proton when it reaches the negative plate?



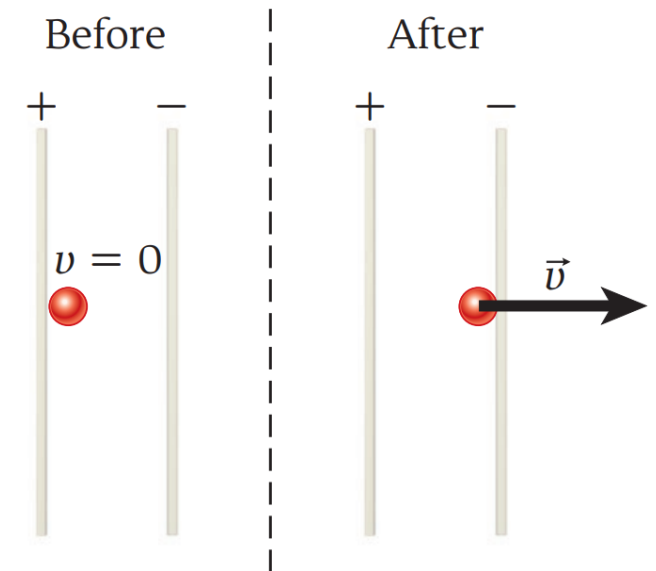
Example 3.1

A **proton** is placed between two parallel conducting plates in a vacuum. The difference in electric potential between the two plates is **450 V**. The proton is released from rest close to the positive plate. What is the kinetic energy of the proton when it reaches the negative plate?

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

$$\Delta K = -\Delta U = -q\Delta V$$

$$K = - (1.602 \times 10^{-19} \text{ C})(-450 \text{ V}) = 7.21 \times 10^{-17} \text{ J}$$



Concept Check 3.1

An **electron** is positioned and then released on the x-axis, where the electric potential has the value **-20 V**. Which of the following statements describes the subsequent motion of the electron?

- a) The electron will move to the left (negative x-direction) because it is negatively charged.
- b) The electron will move to the right (positive x-direction) because it is negatively charged.
- c) The electron will move to the left (negative x-direction) because the electric potential is negative.
- d) The electron will move to the right (positive x-direction) because the electric potential is negative.
- e) Not enough information is given to predict the motion of the electron.

Concept Check 3.1

An **electron** is positioned and then released on the x-axis, where the electric potential has the value **-20 V**. Which of the following statements describes the subsequent motion of the electron?

- a) The electron will move to the left (negative x-direction) because it is negatively charged.
- b) The electron will move to the right (positive x-direction) because it is negatively charged.
- c) The electron will move to the left (negative x-direction) because the electric potential is negative.
- d) The electron will move to the right (positive x-direction) because the electric potential is negative.
- e) **Not enough information is given to predict the motion of the electron.**

Concept Check 3.2

A cathode ray tube uses a potential difference of 5.0 kV to accelerate electrons and produce an electron beam that makes images on a phosphor screen. What is the speed of these electrons as a percentage of the speed of light?

- a) 0.025%
- b) 0.22%
- c) 1.3%
- d) 4.5%
- e) 14%

Concept Check 3.2

A cathode ray tube uses a potential difference of 5.0 kV to accelerate electrons and produce an electron beam that makes images on a phosphor screen. What is the speed of these electrons as a percentage of the speed of light?

- a) 0.025%
- b) 0.22%
- c) 1.3%
- d) 4.5%
- e) 14%**

Multiple Choice Question 3.4

In which situation is the electric potential the highest?

- a) at a point 1 m from a point charge of 1 C
- b) at a point 1 m from the center of a uniformly charged spherical shell with a radius of 0.5 m and a total charge of 1 C
- c) at a point 2 m from a point charge of 2 C
- d) at a point 0.5 m from a point charge of 0.5 C

Multiple Choice Question 3.4

In which situation is the electric potential the highest?

- a) at a point 1 m from a point charge of 1 C
- b) at a point 1 m from the center of a uniformly charged spherical shell with a radius of 0.5 m and a total charge of 1 C**
- c) at a point 2 m from a point charge of 2 C
- d) at a point 0.5 m from a point charge of 0.5 C

Multiple Choice Question 3.14

If a **proton** and an **alpha** particle (composed of **two protons** and **two neutrons**) are each accelerated from rest through the same potential difference, how do their resulting speeds compare?

- a) The proton has twice the speed of the alpha particle.
- b) The proton has the same speed as the alpha particle.
- c) The proton has half the speed of the alpha particle.
- d) The speed of the proton is $\sqrt{2}$ times the speed of the alpha particle.
- e) The speed of the alpha particle is $\sqrt{2}$ times the speed of the proton.

Multiple Choice Question 3.14

If a **proton** and an **alpha** particle (composed of **two protons** and **two neutrons**) are each accelerated from rest through the same potential difference, how do their resulting speeds compare?

- a) The proton has twice the speed of the alpha particle.
- b) The proton has the same speed as the alpha particle.
- c) The proton has half the speed of the alpha particle.
- d) The speed of the proton is $\sqrt{2}$ times the speed of the alpha particle.**
- e) The speed of the alpha particle is $\sqrt{2}$ times the speed of the proton.

$$\frac{\Delta K_p}{\Delta K_a} = \frac{-q_p \Delta V}{-q_a \Delta V}$$

$$\frac{\frac{1}{2} m_p v_p^2}{\frac{1}{2} m_a v_a^2} = \frac{-q_p}{-q_a}$$

$$\frac{m_p v_p^2}{m_a v_a^2} = \frac{-q_p}{-q_a}$$

$$\frac{v_p}{v_a} = \sqrt{\frac{-q_p m_a}{-q_a m_p}}$$

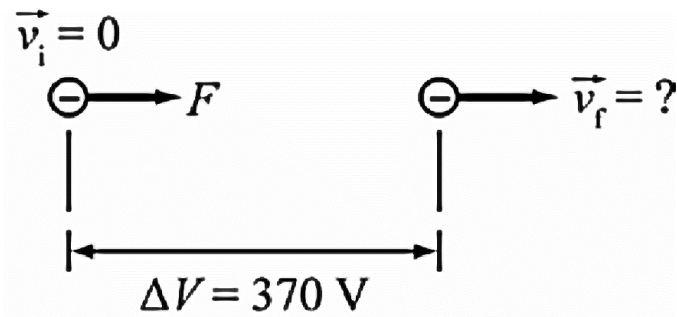
$$\frac{v_p}{v_a} = \sqrt{\frac{-(e)(4m_p)}{-(2e)m_p}} = \sqrt{2}$$

Exercise 3.26

An **electron** is accelerated from rest through a potential difference of **370. V**. What is its final speed?

Exercise 3.26

An **electron** is accelerated from rest through a potential difference of **370. V**. What is its final speed?



$$\Delta K = -\Delta U$$

$$\Delta U = q\Delta V$$

$$\Delta K = -q\Delta V$$

$$= -(-1.602 \times 10^{-19} \times 370)$$

$$= 1.14 \times 10^7 \text{ m/s}$$

Exercise 3.27

How much work would be done by an electric field in moving a **proton** from a point at a potential of **+180. V** to a point at a potential of **-60.0 V**?

Exercise 3.27

How much work would be done by an electric field in moving a **proton** from a point at a potential of **+180. V** to a point at a potential of **-60.0 V**?

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

$$W_e = -q\Delta V$$

$$= -(1.602 \times 10^{-19} \times (-60 - 180))$$

$$= 3.84 \times 10^{-17} \text{ J}$$

Exercise 3.28

What potential difference is needed to give an alpha particle (composed of **2 protons** and **2 neutrons**) **200. keV** of kinetic energy?

Exercise 3.28

What potential difference is needed to give an alpha particle (composed of **2 protons** and **2 neutrons**) **200. keV** of kinetic energy?

$$\begin{aligned}\Delta V &= \frac{\Delta U}{q} = -\frac{\Delta K}{q} \\ &= -\frac{(200 \times 10^3 \times 1.602 \times 10^{-19})}{2(1.602 \times 10^{-19})} \\ &= -100 \text{ kV}\end{aligned}$$

Exercise 3.29

A **proton**, initially at rest, is accelerated through a potential difference of **500. V**. What is its final velocity?

Exercise 3.29

A **proton**, initially at rest, is accelerated through a potential difference of **500. V**. What is its final velocity?

$$\Delta K = -\Delta U$$

$$\Delta U = q\Delta V$$

$$\Delta K = -q\Delta V$$

$$\frac{1}{2}m_p v^2 = -(1.602 \times 10^{-19} \times -500)$$

$$v = 3.1 \times 10^5 \text{ m/s}$$

$$W = -q\Delta V,$$

$$W = \Delta K = -q\Delta V$$

$$\frac{1}{2}mv_f^2 = -q\Delta V \Rightarrow v_f = \sqrt{\frac{-2q\Delta V}{m}}.$$

$$v_f = \sqrt{\frac{-2(1.602 \cdot 10^{-19} \text{ C})(-500. \text{ V})}{(1.67 \cdot 10^{-27} \text{ kg})}} = 3.10 \cdot 10^5 \text{ m/s}.$$

Exercise 3.30

10

A **10.0V** battery is connected to two parallel metal plates placed in a vacuum. An **electron** is accelerated from rest from the negative plate toward the positive plate.

- a) What **kinetic energy** does the electron have just as it reaches the positive plate?
- b) What is the **speed** of the electron just as it reaches the positive plate?

Exercise 3.30

A **10.0V** battery is connected to two parallel metal plates placed in a vacuum. An **electron** is accelerated from rest from the negative plate toward the positive plate.

- What **kinetic energy** does the electron have just as it reaches the positive plate?
- What is the **speed** of the electron just as it reaches the positive plate?

$$\Delta K = -\Delta U$$

$$\Delta U = q\Delta V$$

$$\Delta K = -q\Delta V$$

$$= -(-1.602 \times 10^{-19} \times 10) = 1.6 \times 10^{-18} \text{ J}$$

$$\Delta K = \frac{1}{2} m_e v^2 = 1.6 \times 10^{-18} \rightarrow v = 1.88 \times 10^6 \text{ m/s}$$

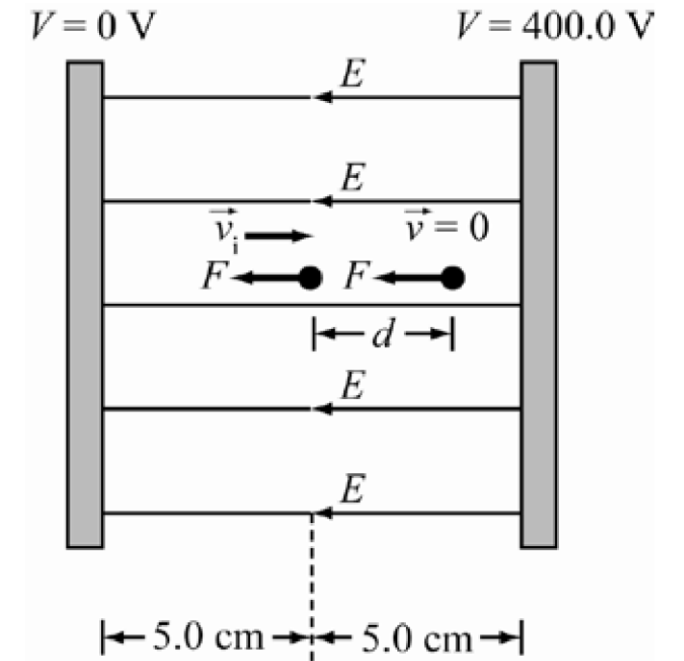
$$W = -q\Delta V,$$

$$W = \Delta K = -q\Delta V$$

Exercise 3.31

A proton gun fires a **proton** from midway between two plates, A and B, which are separated by a distance of **10.0 cm**; the proton initially moves at a speed of **150.0 km/s** toward plate B. Plate A is kept at **zero** potential, and plate B at a potential of **400.0 V**.

a) Will the proton reach plate B?



11



Exercise 3.31

A proton gun fires a **proton** from midway between two plates, A and B, which are separated by a distance of **10.0 cm**; the proton initially moves at a speed of **150.0 km/s** toward plate B. Plate A is kept at **zero** potential, and plate B at a potential of **400.0 V**.

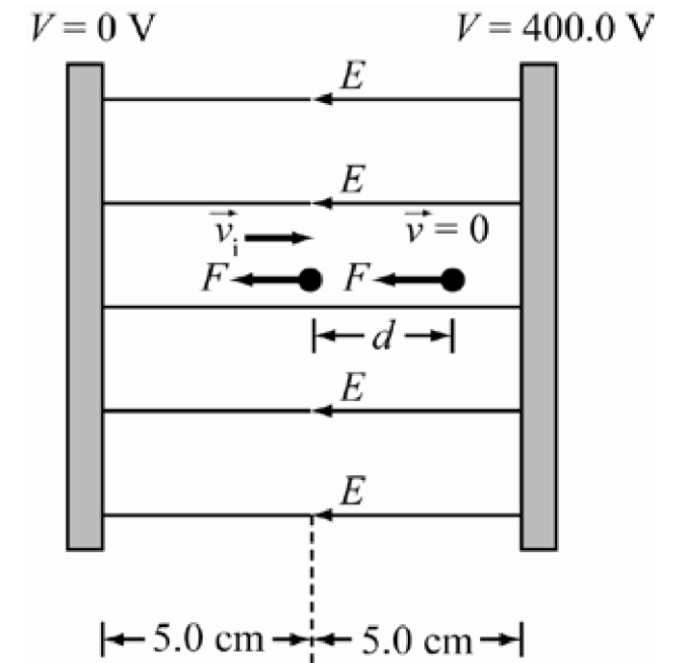
a) Will the proton reach plate B?

$$\Delta K = -\Delta U$$

$$E = \frac{\Delta V}{d} = \frac{400}{0.1} = 4000 \text{ V/m}$$

$$\frac{1}{2} m_p v^2 = -qE(-d)$$

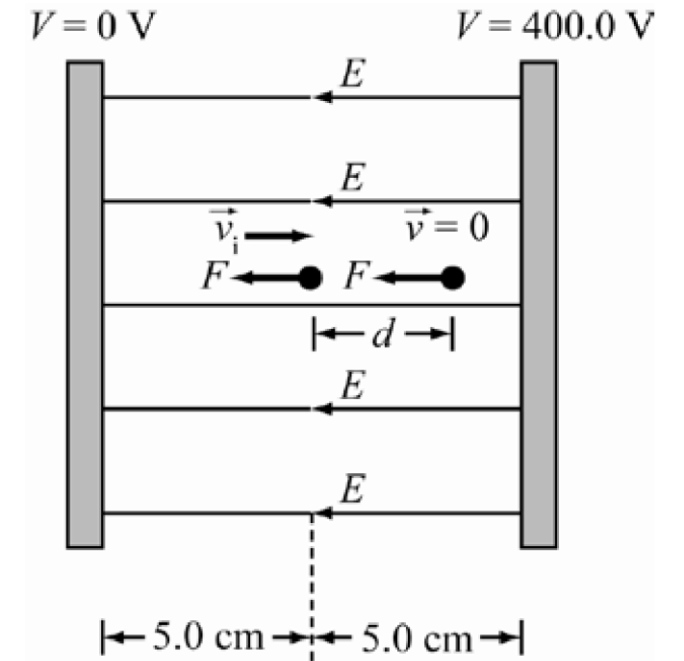
$$d = \frac{m_p v^2}{2qE} = 0.029 \text{ m} \quad \text{The proton will not reach plate A}$$



Exercise 3.31

A proton gun fires a **proton** from midway between two plates, A and B, which are separated by a distance of **10.0 cm**; the proton initially moves at a speed of **150.0 km/s** toward plate B. Plate A is kept at **zero** potential, and plate B at a potential of **400.0 V**.

b) If not, where will it turn around?

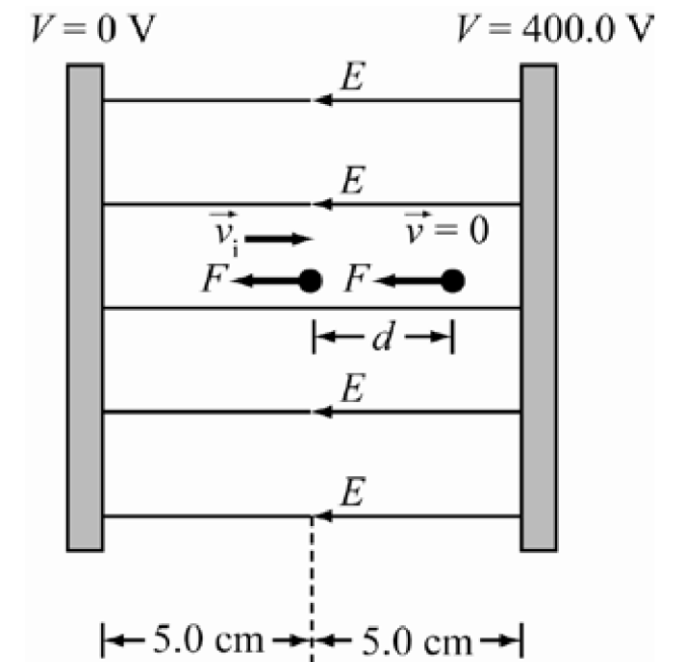


Exercise 3.31

A proton gun fires a **proton** from midway between two plates, A and B, which are separated by a distance of **10.0 cm**; the proton initially moves at a speed of **150.0 km/s** toward plate B. Plate A is kept at **zero** potential, and plate B at a potential of **400.0 V**.

b) If not, where will it turn around?

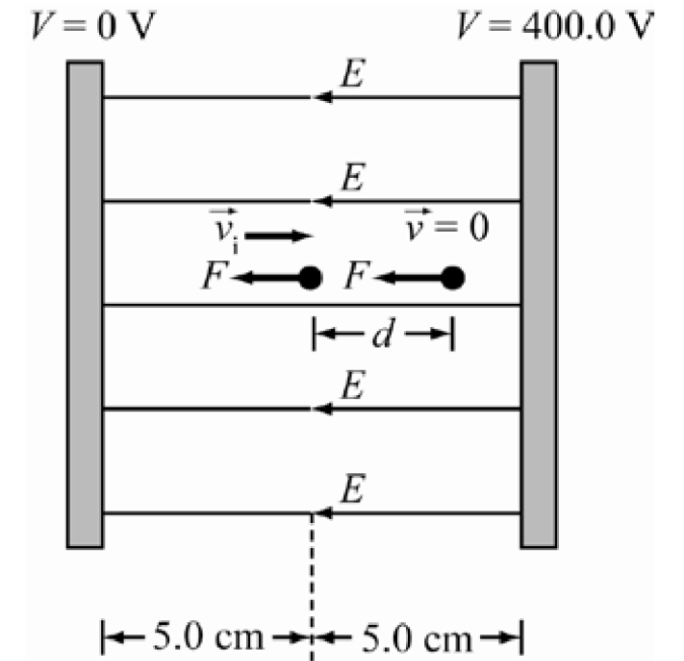
The proton will turn around at a distance $x = (10.0/2) \text{ cm} + 2.93 \text{ cm} = 7.93 \text{ cm}$ from the plate A.



Exercise 3.31

A proton gun fires a **proton** from midway between two plates, A and B, which are separated by a distance of **10.0 cm**; the proton initially moves at a speed of **150.0 km/s** toward plate B. Plate A is kept at **zero** potential, and plate B at a potential of **400.0 V**.

c) With what speed will it hit plate A?



11



Exercise 3.31

A proton gun fires a **proton** from midway between two plates, A and B, which are separated by a distance of **10.0 cm**; the proton initially moves at a speed of **150.0 km/s** toward plate B. Plate A is kept at **zero** potential, and plate B at a potential of **400.0 V**.

c) With what speed will it hit plate A?

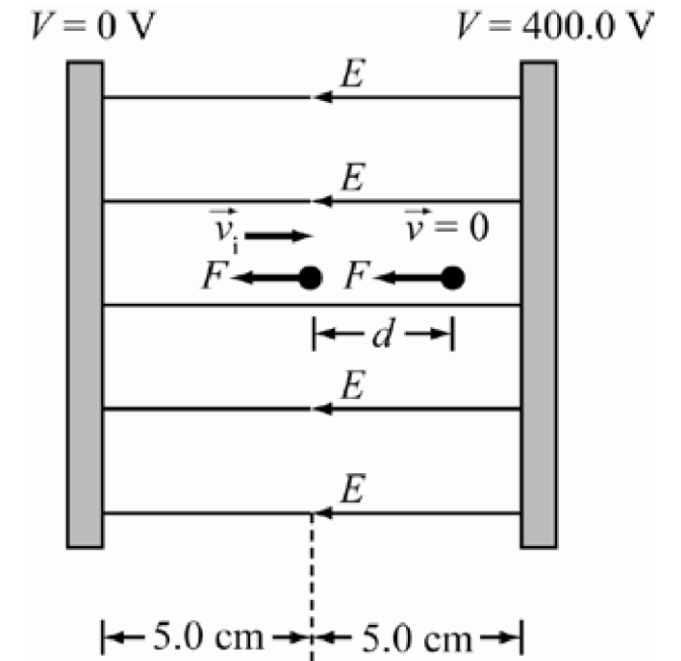
$$\Delta K = W_e$$

$$d = 0.0793 \text{ m}$$

$$\frac{1}{2} m_p v^2 = qEd$$

$$E = 4000 \text{ V/m}$$

$$v = \sqrt{\frac{2qEd}{m_p}} = 2.46 \times 10^5 \text{ m/s}$$



Equipotential Surfaces and Lines

Chapter 3
Lesson 3 – Revision Paper

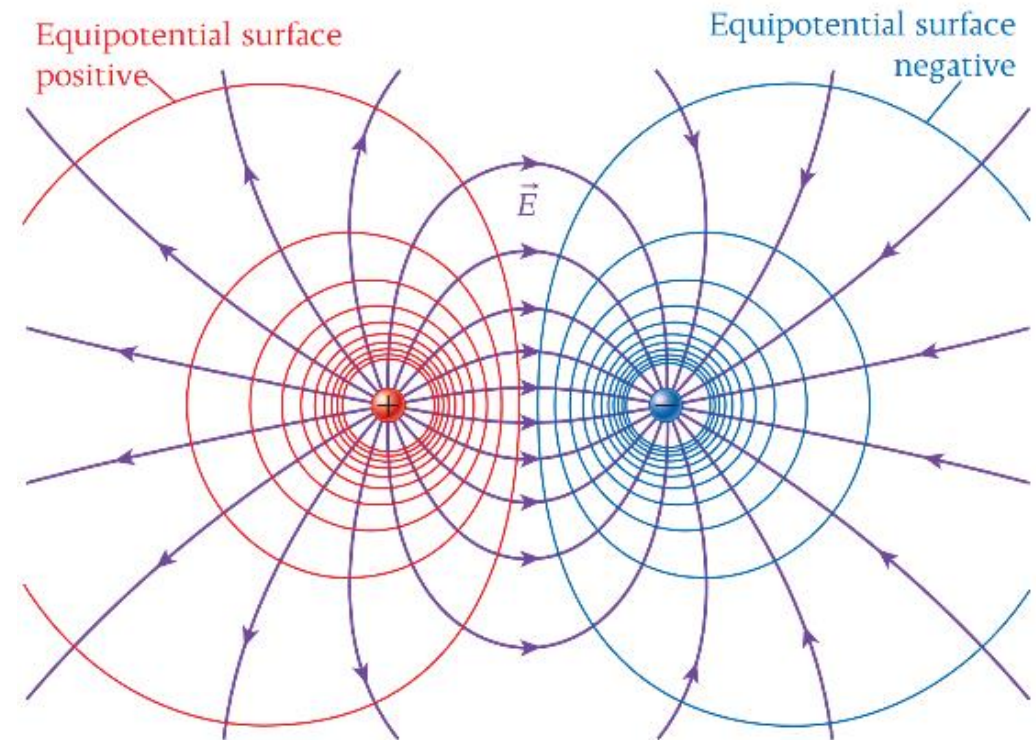
3.3 – Equipotential Surfaces and Lines

- The surface of any conductor forms an equipotential surface.
- Equipotential surfaces are always perpendicular to the electric field lines at any point in space.

Self-Test Opportunity 3.1

01

Suppose the charges in the figure were located at $(x,y) = (-10 \text{ cm}, 0)$ and $(x,y) = (+10 \text{ cm}, 0)$. What would the electric potential be along the y -axis ($x = 0$)?



Self-Test Opportunity 3.1 – Page 69

3.3 Equipotential Surfaces and Lines

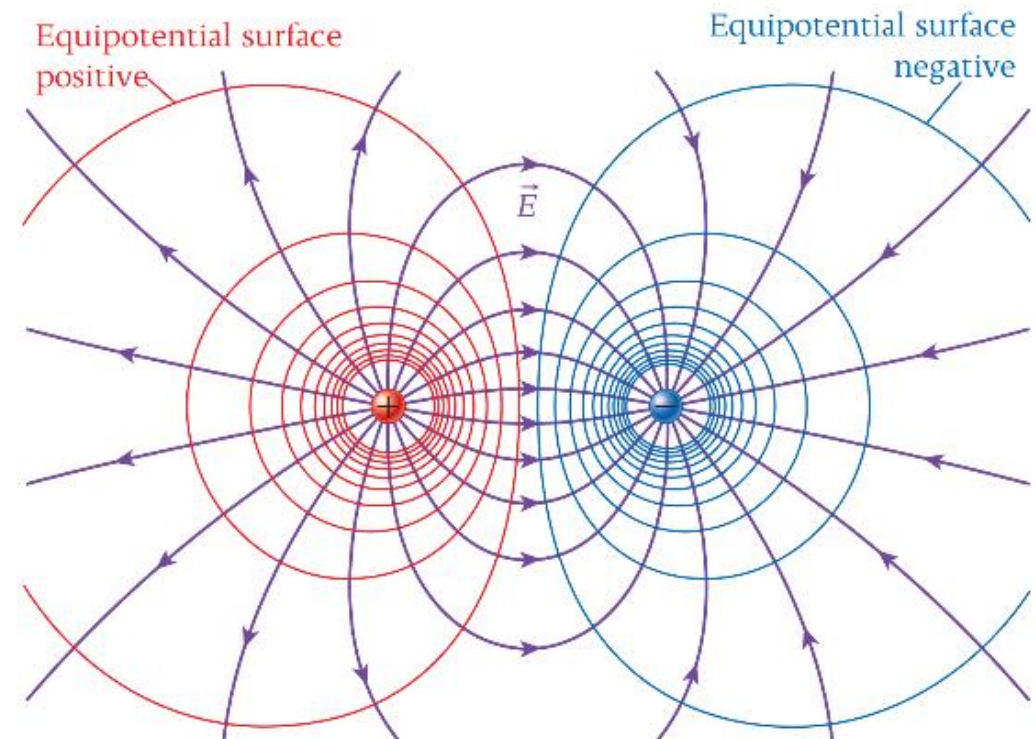


Self-Test Opportunity 3.1

01

Suppose the charges in the figure were located at $(x,y) = (-10 \text{ cm}, 0)$ and $(x,y) = (+10 \text{ cm}, 0)$. What would the electric potential be along the y -axis ($x = 0$)?

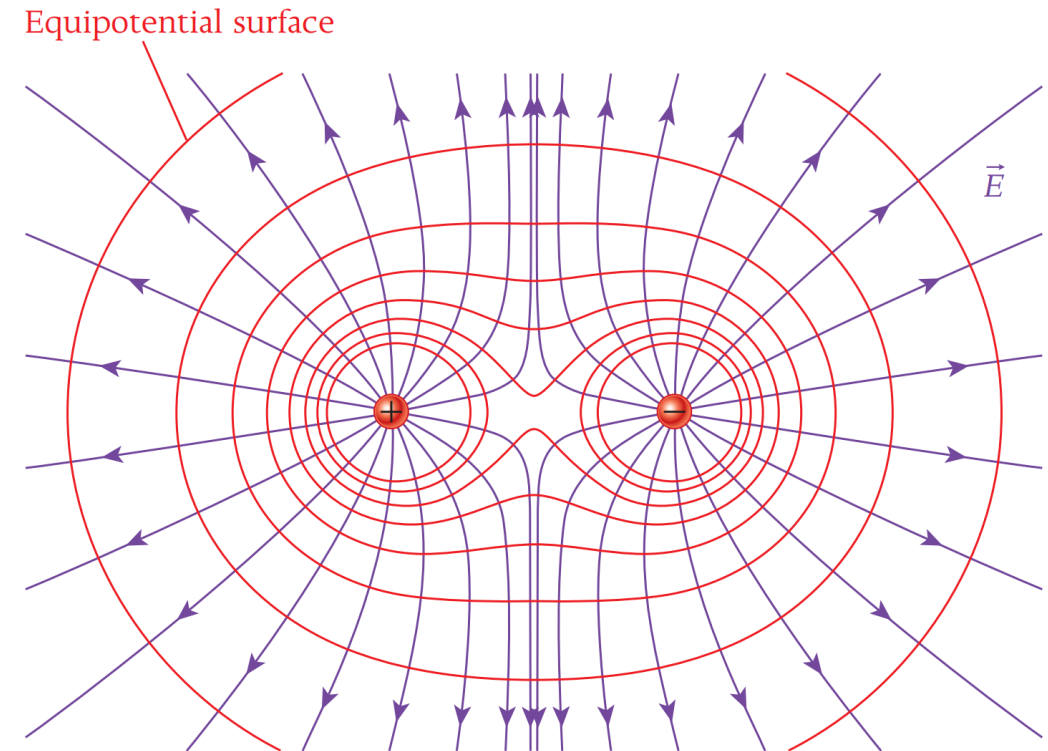
The electric potential along the y -axis is zero.



Self-Test Opportunity 3.2

02

Suppose the charges in the figure were located at $(x,y) = (-10 \text{ cm}, 0)$ and $(x,y) = (+10 \text{ cm}, 0)$. Would $(x,y) = (0,0)$ correspond to a maximum, a minimum, or a saddle point in the electric potential?



Self-Test Opportunity 3.2 – Page 69

3.3 Equipotential Surfaces and Lines

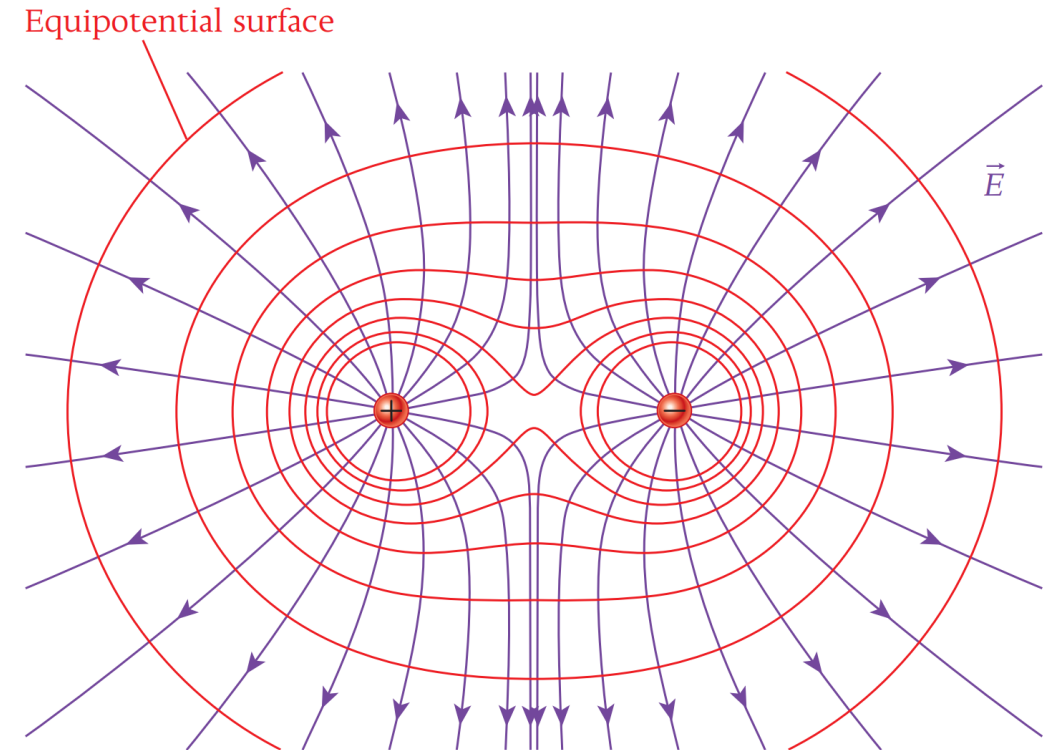


Self-Test Opportunity 3.2

02

Suppose the charges in the figure were located at $(x,y) = (-10 \text{ cm}, 0)$ and $(x,y) = (+10 \text{ cm}, 0)$. Would $(x,y) = (0,0)$ correspond to a maximum, a minimum, or a saddle point in the electric potential?

$(x,y) = (0,0)$ corresponds to a saddle point.



Multiple Choice Question 3.5

The amount of work done to move a **positive** point charge q on an equipotential surface of **1000 V** relative to that done to move the charge on an equipotential surface of **10 V** is

- a) the same.
- b) less.
- c) more.
- d) dependent on the distance the charge moves.

Multiple Choice Question 3.5

The amount of work done to move a **positive** point charge q on an equipotential surface of **1000 V** relative to that done to move the charge on an equipotential surface of **10 V** is

- a) the same.
- b) less.
- c) more.
- d) dependent on the distance the charge moves.

Multiple Choice Question 3.6

A solid conducting sphere of radius R is centered about the origin of an xyz-coordinate system. A total charge Q is distributed uniformly on the surface of the sphere. Assuming, as usual, that the electric potential is zero at an infinite distance, what is the electric potential at the center of the conducting sphere?

- a) zero
- b) $Q/\epsilon_0 R$
- c) $Q/2\pi\epsilon_0 R$
- d) $Q/4\pi\epsilon_0 R$

Multiple Choice Question 3.6

A solid conducting sphere of radius R is centered about the origin of an xyz-coordinate system. A total charge Q is distributed uniformly on the surface of the sphere. Assuming, as usual, that the electric potential is zero at an infinite distance, what is the electric potential at the center of the conducting sphere?

- a) zero
- b) $Q/\epsilon_0 R$
- c) $Q/2\pi\epsilon_0 R$
- d) $Q/4\pi\epsilon_0 R$

Multiple Choice Question 3.10

A negatively charged particle revolves in a **clockwise** direction around a positively charged sphere. The work done on the negatively charged particle by the electric field of the sphere is

- a) positive.
- b) negative.
- c) zero.

Multiple Choice Question 3.10

A negatively charged particle revolves in a **clockwise** direction around a positively charged sphere. The work done on the negatively charged particle by the electric field of the sphere is

- a) positive.
- b) negative.
- c) zero.

Multiple Choice Question 3.11

A hollow conducting sphere of radius R is centered about the origin of an xyz-coordinate system. A total charge Q is distributed uniformly over the surface of the sphere. Assuming, as usual, that the electric potential is **zero** at an infinite distance, what is the electric potential at the center of the sphere?

- a) zero
- b) $2kQ/R$
- c) kQ/R
- d) $kQ/2R$
- e) $kQ/4R$

Multiple Choice Question 3.11

A hollow conducting sphere of radius R is centered about the origin of an xyz-coordinate system. A total charge Q is distributed uniformly over the surface of the sphere. Assuming, as usual, that the electric potential is **zero** at an infinite distance, what is the electric potential at the center of the sphere?

- a) zero
- b) $2kQ/R$
- c) kQ/R
- d) $kQ/2R$
- e) $kQ/4R$

Multiple Choice Question 3.12

A solid conducting sphere of radius R has a charge Q evenly distributed over its surface, producing an electric potential V_o at the surface. How much charge must be added to the sphere to increase the potential at the surface to $2V_o$?

- a) $Q/2$
- b) Q
- c) $2Q$
- d) Q^2
- e) $2Q^2$

Multiple Choice Question 3.12

A solid conducting sphere of radius R has a charge Q evenly distributed over its surface, producing an electric potential V_o at the surface. How much charge must be added to the sphere to increase the potential at the surface to $2V_o$?

- a) $Q/2$
- b) Q
- c) $2Q$
- d) Q^2
- e) $2Q^2$

Multiple Choice Question 3.13

Which one of the following statements is not true?

- a) Equipotential lines for a point charge are circular.
- b) Equipotential surfaces exist for any charge distribution.
- c) Equipotential lines are parallel to the electric field lines.
- d) When a charge moves on an equipotential surface, the work done on the charge is zero

Multiple Choice Question 3.13

Which one of the following statements is not true?

- a) Equipotential lines for a point charge are circular.
- b) Equipotential surfaces exist for any charge distribution.
- c) Equipotential lines are parallel to the electric field lines.**
- d) When a charge moves on an equipotential surface, the work done on the charge is zero

Electric Potential of Various Charge Distributions

Chapter 3
Lesson 4 – Revision Paper

3.4 – Electric Potential of Various Charge Distributions

$$\Delta V = -\frac{W}{q}$$

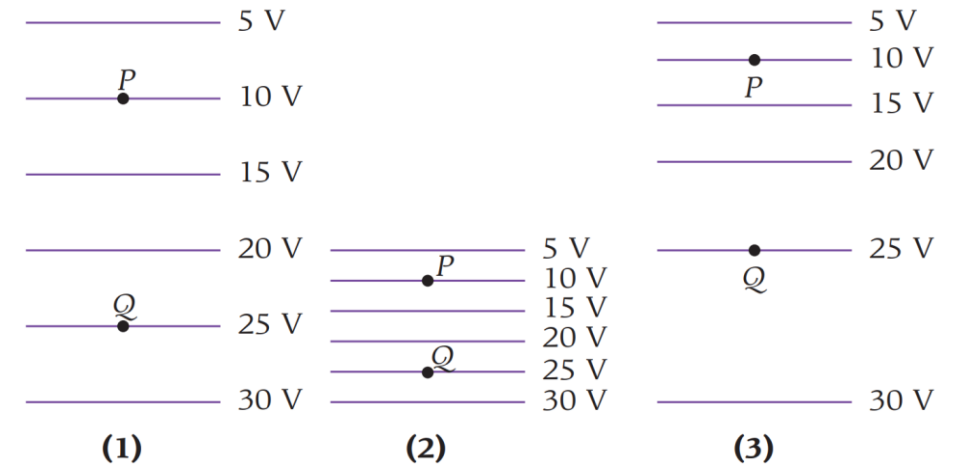
$$V = k \left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \dots + \frac{q_i}{r_i} \right)$$

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

Concept Check 3.3

In the figure, the lines represent equipotential lines. A charged object is moved from point **P** to point **Q**. How does the amount of work done on the object compare for these three cases?

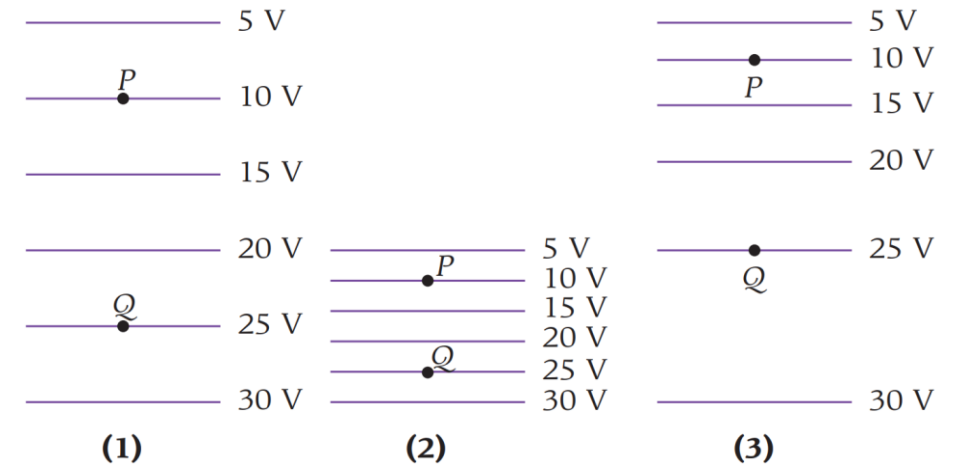
- a) All three cases involve the same work.
- b) The most work is done in case 1.
- c) The most work is done in case 2.
- d) The most work is done in case 3.
- e) Cases 1 and 3 involve the same amount of work, which is more than is involved in case 2.



Concept Check 3.3

In the figure, the lines represent equipotential lines. A charged object is moved from point **P** to point **Q**. How does the amount of work done on the object compare for these three cases?

- a) **All three cases involve the same work.**
- b) The most work is done in case 1.
- c) The most work is done in case 2.
- d) The most work is done in case 3.
- e) Cases 1 and 3 involve the same amount of work, which is more than is involved in case 2.



Self-Test Opportunity 3.3

02

Obtaining equation **3.12** for the electric potential from a point charge involved integrating along a radial line from infinity to a point at a distance R from the point charge. How would the result change if the integration were carried out over a different path?

$$V(R) = - \int_{\infty}^R \vec{E} \cdot d\vec{s} = - \int_{\infty}^R \frac{kq}{r^2} dr = \left[\frac{kq}{r} \right]_{\infty}^R = \frac{kq}{R}$$

Self-Test Opportunity 3.3

02

Obtaining equation 3.12 for the electric potential from a point charge involved integrating along a radial line from infinity to a point at a distance R from the point charge. How would the result change if the integration were carried out over a different path?

Nothing would change. The electrostatic force is conservative, and for a conservative force, the work is path-independent.

$$V(R) = - \int_{\infty}^R \vec{E} \cdot d\vec{s} = - \int_{\infty}^R \frac{kq}{r^2} dr = \left[\frac{kq}{r} \right]_{\infty}^R = \frac{kq}{R}$$

Concept Check 3.4

What is the electric potential **45.5 cm** away from a point charge of **12.5 pC**?

- a) 0.247 V
- b) 1.45 V
- c) 4.22 V
- d) 10.2 V
- e) 25.7 V

Concept Check 3.4

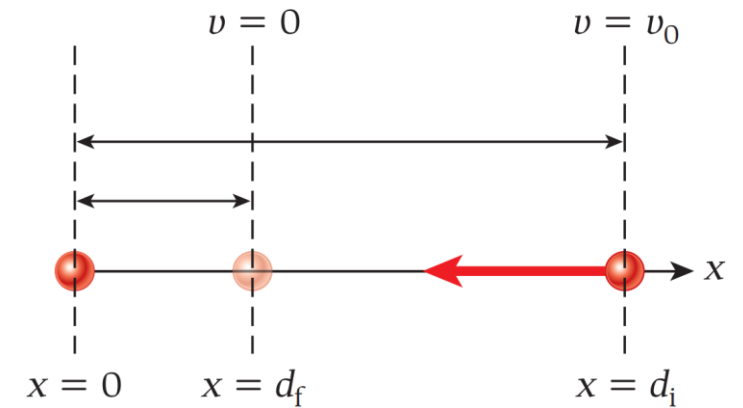
What is the electric potential **45.5 cm** away from a point charge of **12.5 pC**?

- a) **0.247 V**
- b) 1.45 V
- c) 4.22 V
- d) 10.2 V
- e) 25.7 V

Solved Problem 3.2

04

A positive charge of $4.50 \mu\text{C}$ is fixed in place. A particle of mass 6.00 g and charge $+3.00 \mu\text{C}$ is fired with an initial speed of 66.0 m/s directly toward the fixed charge from a distance of 4.20 cm away. How close does the moving charge get to the fixed charge before it comes to rest and starts moving away from the fixed charge?



Concept Check 3.4 – Page 71

3.4 Electric Potential of Various Charge Distributions

Solved Problem 3.2

04

A positive charge of $4.50 \mu\text{C}$ is fixed in place. A particle of mass 6.00 g and charge $+3.00 \mu\text{C}$ is fired with an initial speed of 66.0 m/s directly toward the fixed charge from a distance of 4.20 cm away. How close does the moving charge get to the fixed charge before it comes to rest and starts moving away from the fixed charge?

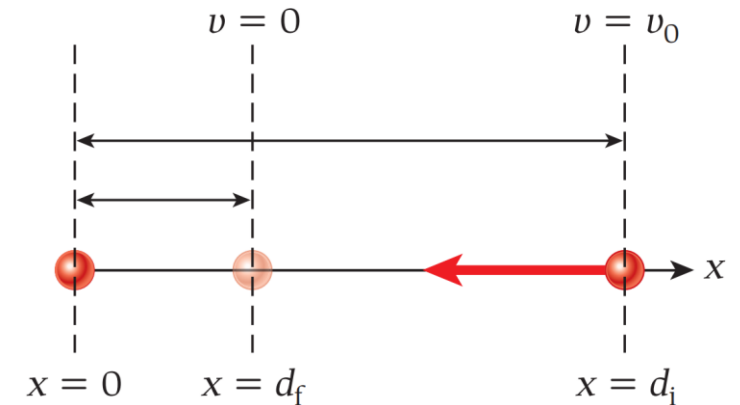
$$\Delta K + \Delta U = 0 \Rightarrow \Delta K = -\Delta U \Rightarrow$$

$$0 - \frac{1}{2}mv_0^2 = -q_{\text{moving}}\Delta V \Rightarrow$$

$$\frac{1}{2}mv_0^2 = q_{\text{moving}}\Delta V$$

$$\Delta V = V_f - V_i = k\frac{q_{\text{fixed}}}{d_f} - k\frac{q_{\text{fixed}}}{d_i} = kq_{\text{fixed}}\left(\frac{1}{d_f} - \frac{1}{d_i}\right)$$

$$\frac{1}{2}mv_0^2 = q_{\text{moving}}\Delta V = kq_{\text{moving}}q_{\text{fixed}}\left(\frac{1}{d_f} - \frac{1}{d_i}\right) \Rightarrow$$



Concept Check 3.4 – Page 71

3.4 Electric Potential of Various Charge Distributions



Solved Problem 3.2

04

A positive charge of **4.50 μC** is fixed in place. A particle of mass **6.00 g** and charge **+3.00 μC** is fired with an initial speed of **66.0 m/s** directly toward the fixed charge from a distance of **4.20 cm** away. How close does the moving charge get to the fixed charge before it comes to rest and starts moving away from the fixed charge?

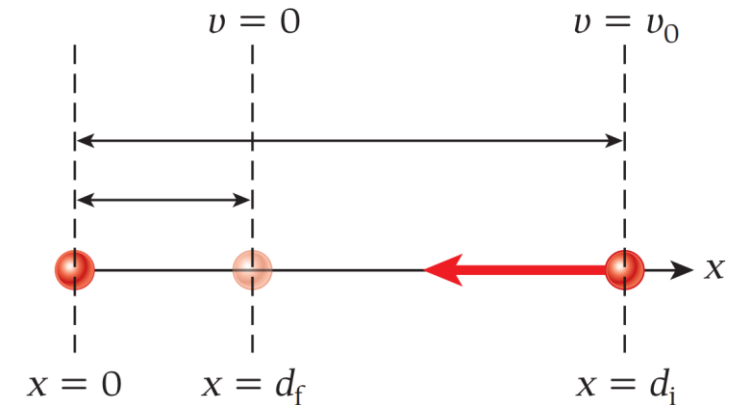
$$\frac{1}{d_f} - \frac{1}{d_i} = \frac{mv_0^2}{2kq_{\text{moving}}q_{\text{fixed}}} \Rightarrow$$

$$\frac{1}{d_f} = \frac{1}{d_i} + \frac{mv_0^2}{2kq_{\text{moving}}q_{\text{fixed}}}$$

$$\frac{1}{d_f} = \frac{1}{0.0420 \text{ m}} + \frac{(0.00600 \text{ kg})(66.0 \text{ m/s})^2}{2(8.99 \times 10^9 \text{ N m}^2/\text{C}^2)(3.00 \times 10^{-6} \text{ C})(4.50 \times 10^{-6} \text{ C})} = 131.485$$

$$d_f = 0.00760545 \text{ m}$$

$$d_f = 0.00761 \text{ m} = 0.761 \text{ cm}$$

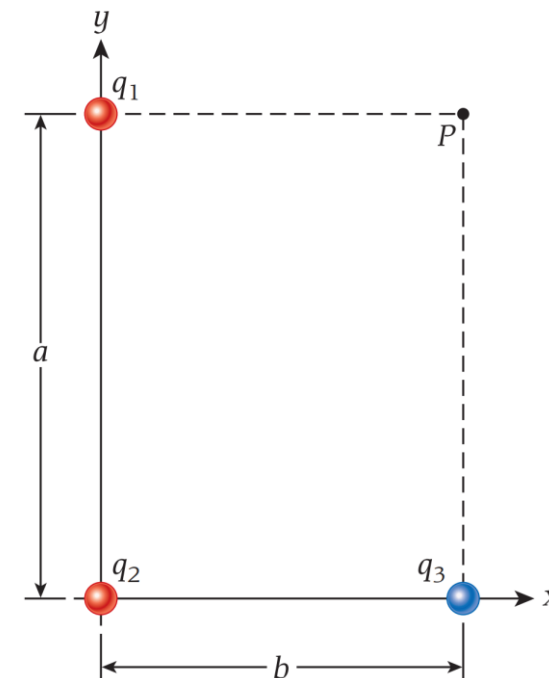


Concept Check 3.4 – Page 71

3.4 Electric Potential of Various Charge Distributions

Example 3.4

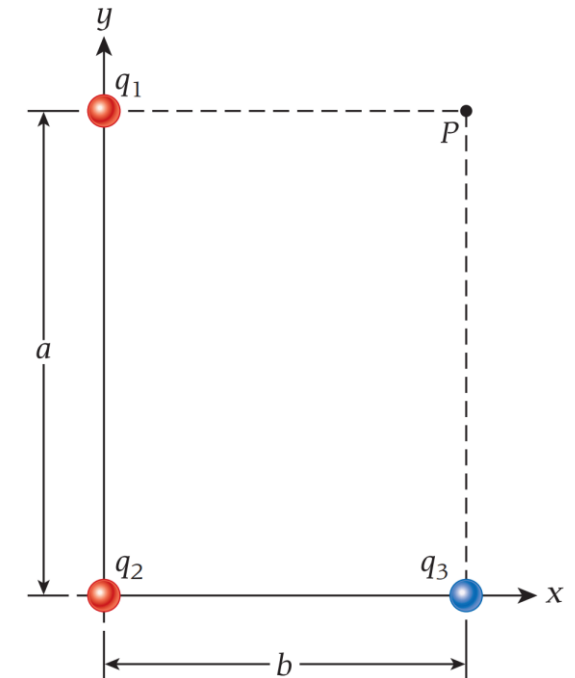
Three-point charges: $q_1 = +1.50 \mu\text{C}$, $q_2 = +2.50 \mu\text{C}$, and $q_3 = -3.50 \mu\text{C}$ are shown in the figure. Charge q_1 is located at $(0, a)$, q_2 is located at $(0, 0)$, and q_3 is located at $(b, 0)$, where $a = 8.00 \text{ m}$ and $b = 6.00 \text{ m}$. What is the electric potential at point P ?



Example 3.4

Three-point charges: $q_1 = +1.50 \mu\text{C}$, $q_2 = +2.50 \mu\text{C}$, and $q_3 = -3.50 \mu\text{C}$ are shown in the figure. Charge q_1 is located at $(0, a)$, q_2 is located at $(0, 0)$, and q_3 is located at $(b, 0)$, where $a = 8.00 \text{ m}$ and $b = 6.00 \text{ m}$. What is the electric potential at point P ?

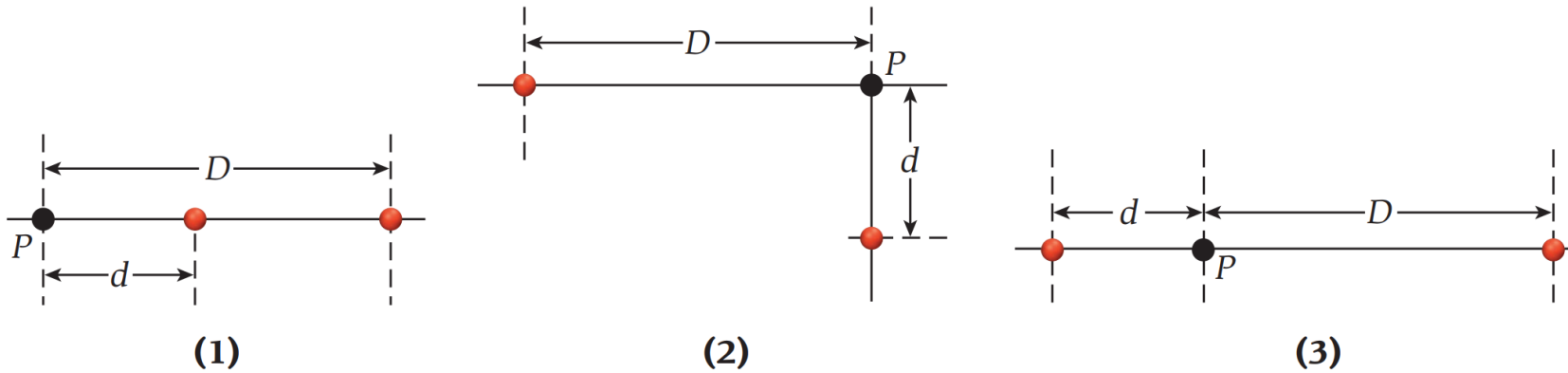
$$\begin{aligned}
 V &= \sum_{i=1}^3 \frac{kq_i}{r_i} = k \left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} \right) = k \left(\frac{q_1}{b} + \frac{q_2}{\sqrt{a^2 + b^2}} + \frac{q_3}{a} \right) \\
 &= (8.99 \times 10^9 \text{ N m}^2/\text{C}^2) \left(\frac{1.50 \times 10^{-6} \text{ C}}{6.00 \text{ m}} + \frac{2.50 \times 10^{-6} \text{ C}}{\sqrt{(8.00 \text{ m})^2 + (6.00 \text{ m})^2}} + \frac{-3.50 \times 10^{-6} \text{ C}}{8.00 \text{ m}} \right) \\
 &= 562 \text{ V}
 \end{aligned}$$



Concept Check 3.5

o6

Two **protons** are located in space in the three ways shown in the figure. Rank the three cases from highest to lowest net electric potential, V , produced at point P .



- a) $2 > 3 > 1$
- b) All three potentials are the same.
- c) $3 > 2 > 1$
- d) The potentials are equal for cases 1 and 3, with the potential for case 2 lower.
- e) $1 > 2 > 3$

Concept Check 3.5 – Page 73

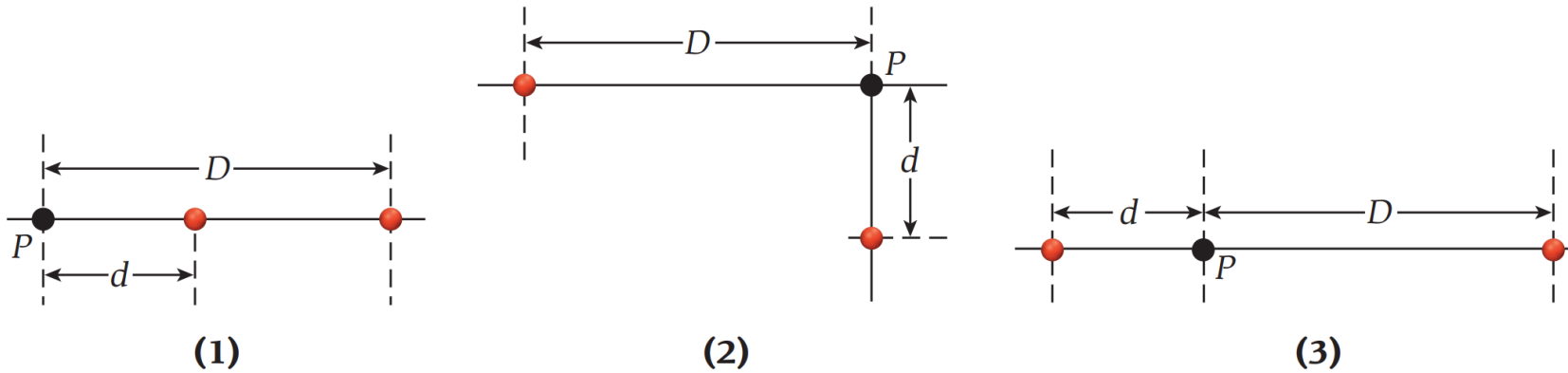
3.4 Electric Potential of Various Charge Distributions



Concept Check 3.5

o6

Two **protons** are located in space in the three ways shown in the figure. Rank the three cases from highest to lowest net electric potential, V , produced at point P .



- a) $2 > 3 > 1$
- b) All three potentials are the same.
- c) $3 > 2 > 1$
- d) The potentials are equal for cases 1 and 3, with the potential for case 2 lower.
- e) $1 > 2 > 3$

Concept Check 3.5 – Page 73

3.4 Electric Potential of Various Charge Distributions



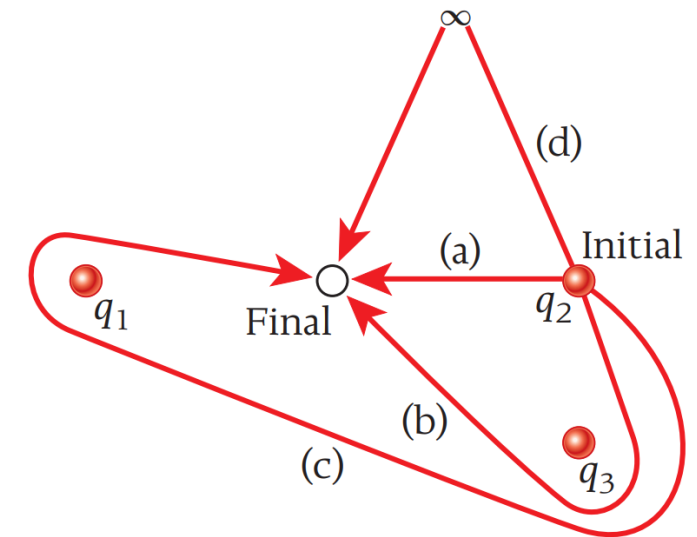
Concept Check 3.6

07

Three identical **positive** point charges are located at fixed points in space. Then charge q_2 is moved from its initial location to a final location as shown in the figure. **Four** different paths, marked (a) through (d), are shown.

- Path (a) follows the shortest line;
- path (b) takes q_2 around q_3 ;
- path (c) takes q_2 around q_3 and q_1 ;
- path (d) takes q_2 out to infinity and then to the final location.

Which path requires the least work?



a) path (a)

d) path (d)

b) path (b)

e) The work is the same for all the paths.

c) path (c)



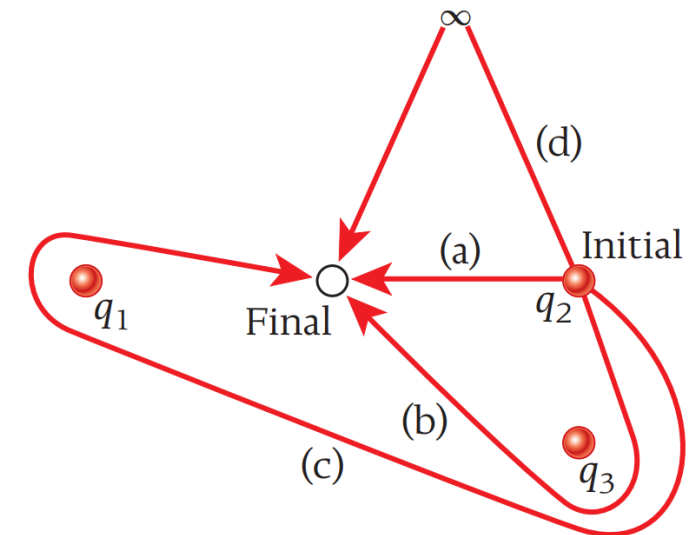
Concept Check 3.6

07

Three identical **positive** point charges are located at fixed points in space. Then charge q_2 is moved from its initial location to a final location as shown in the figure. **Four** different paths, marked (a) through (d), are shown.

- Path (a) follows the shortest line;
- path (b) takes q_2 around q_3 ;
- path (c) takes q_2 around q_3 and q_1 ;
- path (d) takes q_2 out to infinity and then to the final location.

Which path requires the least work?



a) path (a)

d) path (d)

b) path (b)

e) The work is the same for all the paths.

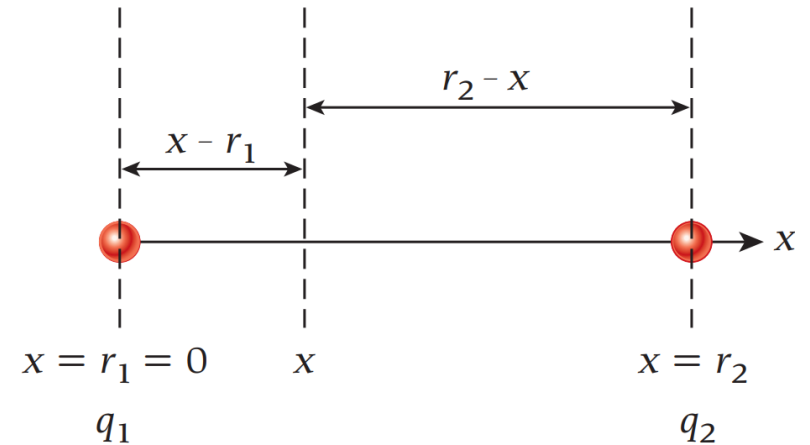
c) path (c)



Solved Problem 3.3

o8

A charge of $q_1 = 0.829 \text{ nC}$ is placed at $r_1 = 0.0$ on the x-axis. Another charge of $q_2 = 0.275 \text{ nC}$ is placed at $r_2 = 11.9 \text{ cm}$ on the x-axis. At which point along the x-axis between the two charges does the electric potential resulting from both of them have a minimum?



Solved Problem 3.3

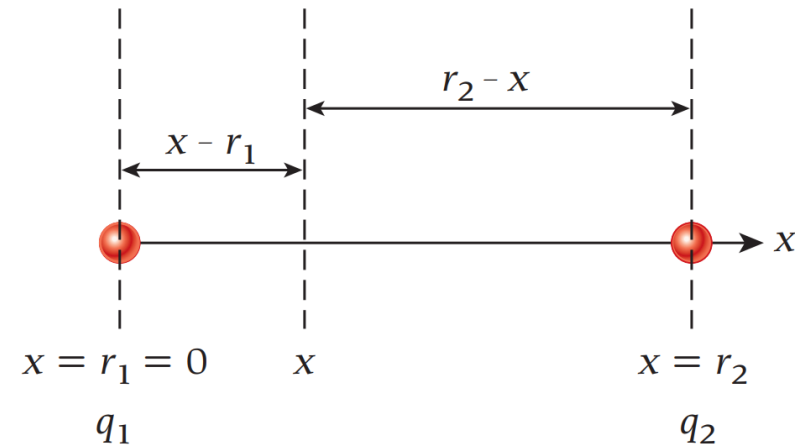
A charge of $q_1 = 0.829 \text{ nC}$ is placed at $r_1 = 0.0$ on the x-axis. Another charge of $q_2 = 0.275 \text{ nC}$ is placed at $r_2 = 11.9 \text{ cm}$ on the x-axis. At which point along the x-axis between the two charges does the electric potential resulting from both of them have a minimum?

A minimum value exists when the derivative of the sum of the potentials equals zero. The partial derivative of the electric potential is the electric field. Electric field equals zero at the equilibrium point. Find the equilibrium point.

$$E_1 = E_2 \quad \frac{q_1}{(x)^2} = \frac{q_2}{(0.119 - x)^2}$$

$$\frac{kq_1}{r_1^2} = \frac{kq_2}{r_2^2} \quad \frac{0.829 \times 10^{-9}}{(x)^2} = \frac{0.275 \times 10^{-9}}{(0.119 - x)^2}$$

$$\frac{q_1}{r_1^2} = \frac{q_2}{r_2^2} \quad x = 0.0755 \text{ m} = 7.55 \text{ cm}$$



Solved Problem 3.3 – Page 73

3.4 Electric Potential of Various Charge Distributions

Self-Test Opportunity 3.4

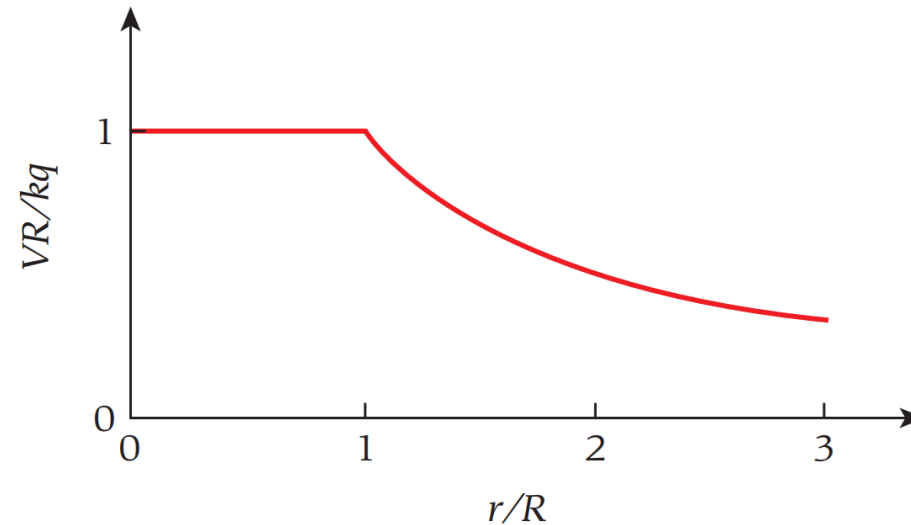
09

Sketch the graph of the electric potential due to a **hollow conducting charged sphere** as a function of the radial coordinate r from zero to three times the sphere's radius, R .

Self-Test Opportunity 3.4

09

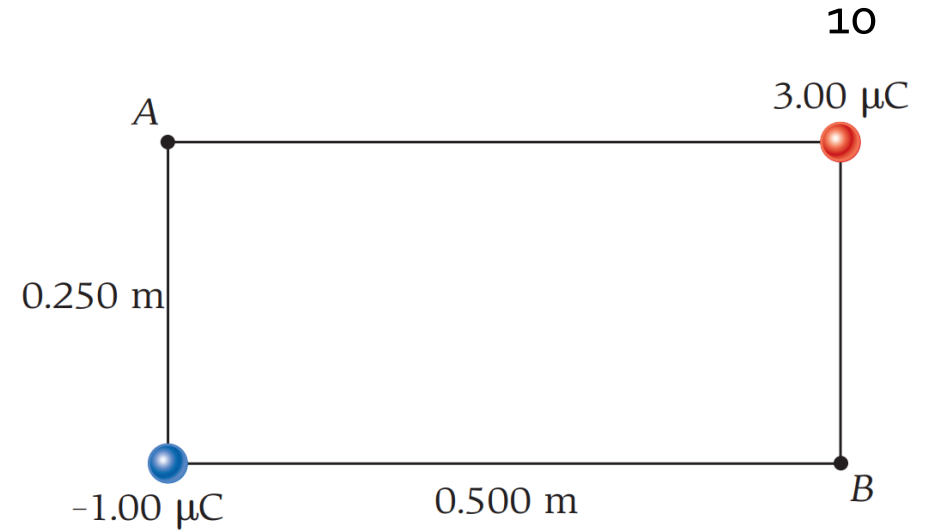
Sketch the graph of the electric potential due to a **hollow conducting charged sphere** as a function of the radial coordinate r from zero to three times the sphere's radius, R .



Exercise 3.33

Two point charges are located at two corners of a rectangle, as shown in the figure.

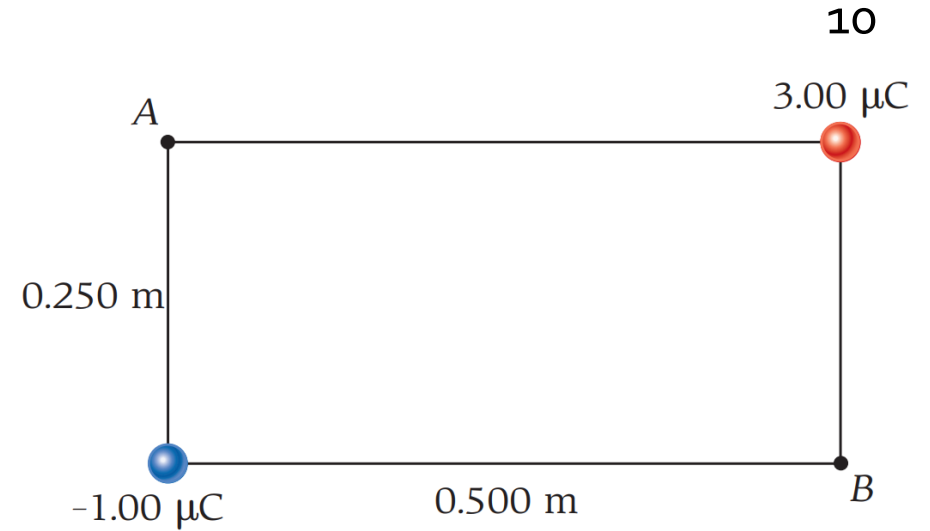
- a) What is the electric potential at point A?
- b) What is the potential difference between points A and B?



Exercise 3.33

Two point charges are located at two corners of a rectangle, as shown in the figure.

- a) What is the electric potential at point A?
- b) What is the potential difference between points A and B?



$$V_A = k \left(\frac{q_1}{r_1} + \frac{q_2}{r_2} \right) = k \times 10^{-6} \times \left(\frac{-1}{0.25} + \frac{3}{0.5} \right) = 1.8 \text{ kV}$$

$$\begin{aligned} V_{AB} &= V_A - V_B = k \left(\frac{q_1}{r_1} + \frac{q_2}{r_2} \right) - k \left(\frac{q_1}{r_2} + \frac{q_2}{r_1} \right) = k(q_1 - q_2) \left(\frac{1}{r_1} - \frac{1}{r_2} \right) \\ &= (8.99 \cdot 10^9 \text{ N m}^2/\text{C}^2) (-1.00 \cdot 10^{-6} \text{ C} - 3.00 \cdot 10^{-6} \text{ C}) \left(\frac{1}{0.250 \text{ m}} - \frac{1}{0.500 \text{ m}} \right) = -7.192 \cdot 10^4 \text{ V} \approx -7.19 \text{ kV}. \end{aligned}$$

Exercise 3.34

11

Four identical point charges (**+1.61 nC**) are placed at the corners of a rectangle, which measures **3.00 m** by **5.00 m**. If the electric potential is taken to be zero at infinity, what is the potential at the geometric center of this rectangle?

Exercise 3.34

11

Four identical point charges (**+1.61 nC**) are placed at the corners of a rectangle, which measures **3.00 m** by **5.00 m**. If the electric potential is taken to be zero at infinity, what is the potential at the geometric center of this rectangle?

$$V = \sum_{i=1}^4 \frac{kq}{r} = \frac{4kq}{(1/2)\sqrt{a^2 + b^2}} = \frac{8(8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2)(1.61 \cdot 10^{-9} \text{ C})}{\sqrt{(3.00 \text{ m})^2 + (5.00 \text{ m})^2}} = 19.9 \text{ V}.$$

Exercise 3.35

12

If a Van de Graaff generator has an electric potential of $1.00 \times 10^5 \text{ V}$ and a diameter of **20.0 cm**, find how many more protons than electrons are on its surface.

Exercise 3.35

12

If a Van de Graaff generator has an electric potential of $1.00 \times 10^5 \text{ V}$ and a diameter of 20.0 cm , find how many more protons than electrons are on its surface.

$$V = \frac{kQ}{r} = 1.00 \cdot 10^5 \text{ V, where } r = d/2 \text{ is the radius.}$$

The total charge, Q , is: $Q = \frac{Vr}{k} = \frac{Vd}{2k}$. The total charge is a result of the number of electrons, $Q = n|e|$, where n is given by:

$$n = \frac{Vd}{2k|e|} = \frac{(1.00 \cdot 10^5 \text{ V})(0.200 \text{ m})}{2(8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2)(1.602 \cdot 10^{-19} \text{ C})} = 6.95 \cdot 10^{12} \text{ electrons.}$$

Exercise 3.36

13

One issue encountered during the exploration of Mars has been the accumulation of static charge on land-roving vehicles, resulting in a potential of 100. V or more. Calculate how much charge must be placed on the surface of a sphere of radius **1.00 m** for the electric potential just above the surface to be **100. V**. Assume that the charge is uniformly distributed.

Exercise 3.36

13

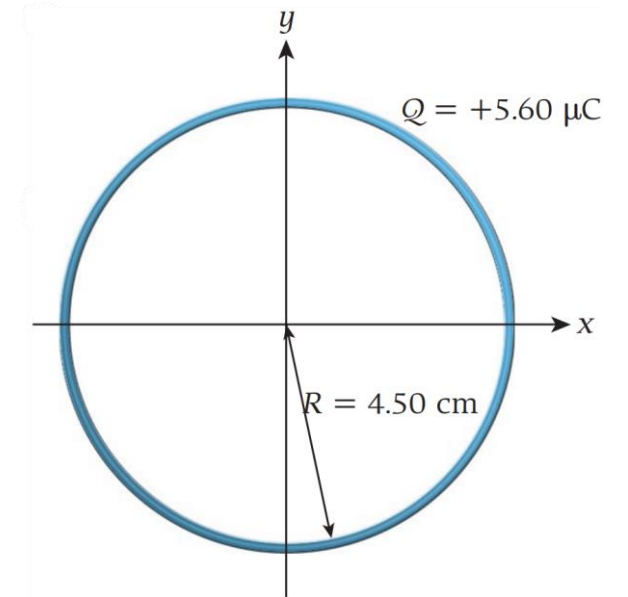
One issue encountered during the exploration of Mars has been the accumulation of static charge on land-roving vehicles, resulting in a potential of 100. V or more. Calculate how much charge must be placed on the surface of a sphere of radius **1.00 m** for the electric potential just above the surface to be **100. V**. Assume that the charge is uniformly distributed.

$$q = \frac{Vr}{k} = \frac{(100. \text{ V})(1.00 \text{ m})}{8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2} = 11.1 \text{ nC.}$$

Exercise 3.37

14

A charge $Q = +5.60 \mu\text{C}$ is uniformly distributed on a thin cylindrical plastic shell. The radius, R , of the shell is 4.50 cm . Calculate the electric potential at the origin of the xy -coordinate system shown in the figure. Assume that the electric potential is zero at points infinitely far away from the origin.

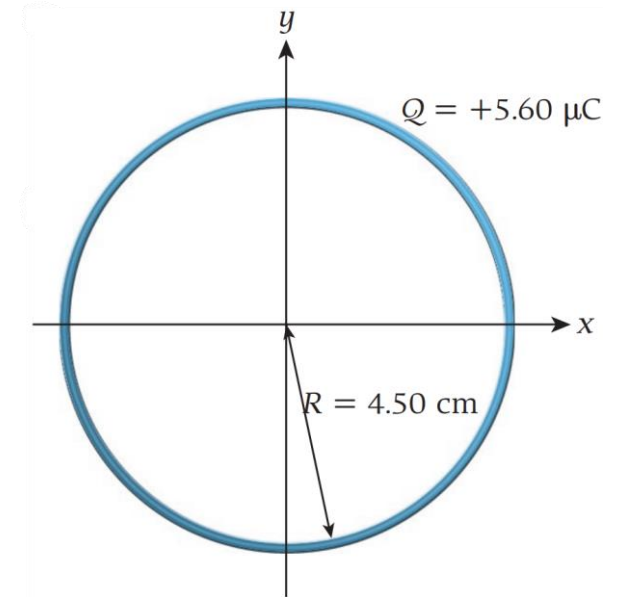


Exercise 3.37

14

A charge $Q = +5.60 \mu\text{C}$ is uniformly distributed on a thin cylindrical plastic shell. The radius, R , of the shell is 4.50 cm . Calculate the electric potential at the origin of the xy -coordinate system shown in the figure. Assume that the electric potential is zero at points infinitely far away from the origin.

$$V = \frac{kQ}{r} = \frac{(8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2)(5.60 \cdot 10^{-6} \text{ C})}{(0.0450 \text{ m})} = 1118444 \text{ V} = 1.12 \text{ MV}.$$



Exercise 3.38

15

A hollow spherical conductor with a **5.00-cm** radius has a surface charge of **8.00 nC**.

- a) What is the potential **8.00 cm** from the center of the sphere?
- b) What is the potential **3.00 cm** from the center of the sphere?
- c) What is the potential at the center of the sphere?

Exercise 3.38

15

A hollow spherical conductor with a **5.00-cm** radius has a surface charge of **8.00 nC**.

- a) What is the potential **8.00 cm** from the center of the sphere?
- b) What is the potential **3.00 cm** from the center of the sphere?
- c) What is the potential at the center of the sphere?

$$(a) \quad V = \frac{kQ}{r_1} = \frac{(8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2)(8.00 \cdot 10^{-9} \text{ C})}{0.0800 \text{ m}} = 8.987 \cdot 10^2 \text{ V} \approx 8.99 \cdot 10^2 \text{ V}$$

$$(b) \quad V = \frac{kQ}{r_2} = \frac{kQ}{R} = \frac{(8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2)(8.00 \cdot 10^{-9} \text{ C})}{0.0500 \text{ m}} = 1438 \text{ V} \approx 144 \text{ V}$$

$$(c) \quad V = \frac{kQ}{r_3} = \frac{kQ}{R} = 1400 \text{ V}$$

The potential everywhere inside the conductor is equal to the potential at the surface of the conductor.

Exercise 3.41

A spherical water drop **50.0 μm** in diameter has a uniformly distributed charge of **+20.0 pC**. Find the potential at its surface

Exercise 3.41

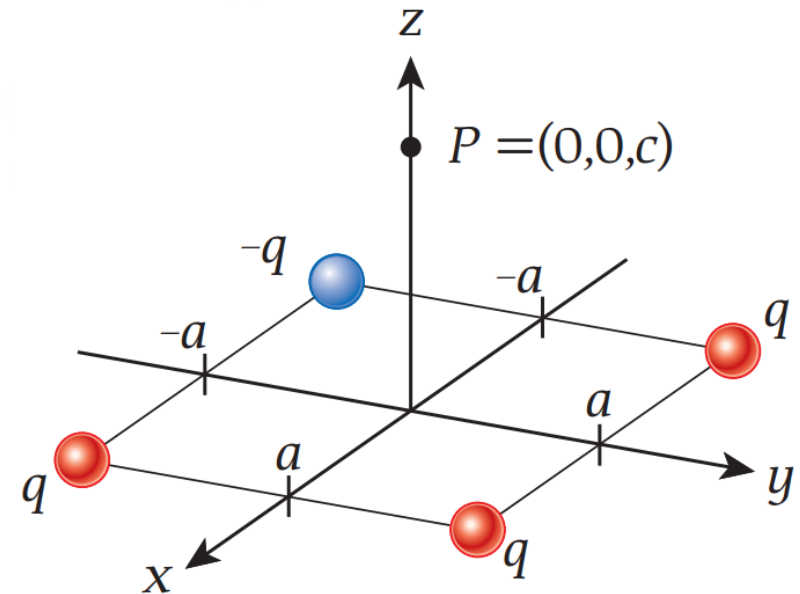
A spherical water drop **50.0 μm** in diameter has a uniformly distributed charge of **+20.0 pC**. Find the potential at its surface

$$V = \frac{(8.9875 \cdot 10^9 \text{ N m}^2 / \text{C}^2)(20.0 \text{ pC})}{50.0 \text{ μm} / 2} = 7190 \text{ V}$$

Exercise 3.43

17

Four point charges are arranged in a square with side length $2a$, where $a = 2.70 \text{ cm}$. The charges have the same magnitude, 1.50 nC ; three of them are positive and one is negative as shown in the figure. What is the value of the electric potential generated by these four point charges at point $P = (0,0,c)$, where $c = 4.10 \text{ cm}$?



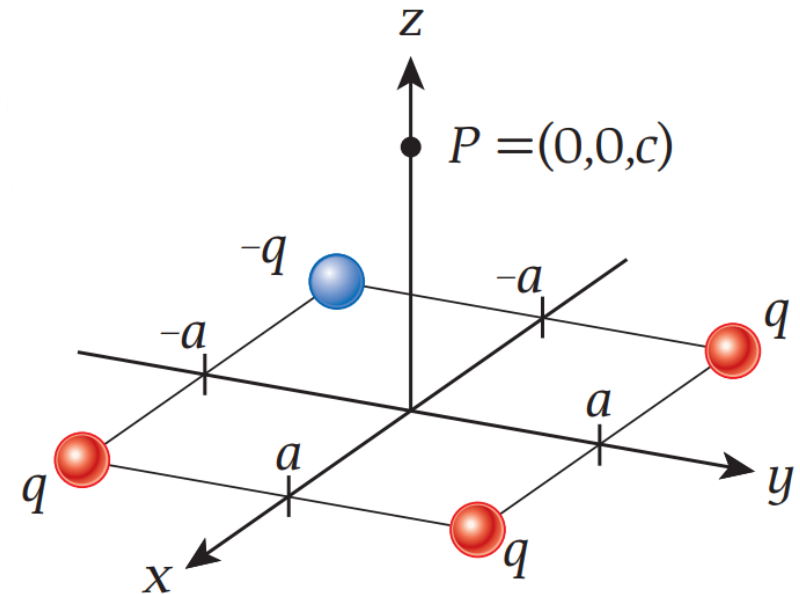
Exercise 3.43

17

Four point charges are arranged in a square with side length $2a$, where $a = 2.70 \text{ cm}$. The charges have the same magnitude, 1.50 nC ; three of them are positive and one is negative as shown in the figure. What is the value of the electric potential generated by these four point charges at point $P = (0,0,c)$, where $c = 4.10 \text{ cm}$?

$$\begin{aligned} V &= k \left(\frac{q}{r} + \frac{q}{r} + \frac{q}{r} - \frac{q}{r} \right) = k \frac{2q}{r} \\ &= 9 \times 10^9 \times \frac{2 \times (1.5 \times 10^{-9})}{0.056} \\ &= 482 \text{ V} \end{aligned}$$

$$\begin{aligned} r &= \sqrt{r_x^2 + r_y^2 + r_z^2} \\ &= \sqrt{2.7^2 + 2.7^2 + 4.1^2} \\ &= 5.6 \text{ cm} = 0.056 \text{ m} \end{aligned}$$



Finding the Electric Field from the Electric Potential

Chapter 3
Lesson 5 – Revision Paper

3.5 – Finding the Electric Field from the Electric Potential

$$-q dV = q \vec{E} \cdot \vec{s}$$

$$E_x = -\frac{\partial V}{\partial x}; \quad E_y = -\frac{\partial V}{\partial y}; \quad E_z = -\frac{\partial V}{\partial z}$$

$$\vec{E} = -\vec{\nabla} V \equiv -\left(\frac{\partial V}{\partial x}, \frac{\partial V}{\partial y}, \frac{\partial V}{\partial z}\right)$$

$$|E_s| = \left| -\frac{\Delta V}{\Delta s} \right|$$

Concept Check 3.7

Suppose an electric potential is described by $V(x, y, z) = -(5x^2 + y + z)$ in volts. Which of the following expressions describes the associated electric field, in units of volts per meter?

a) $\vec{E} = 5\hat{x} + 2\hat{y} + 2\hat{z}$

b) $\vec{E} = 10x\hat{x}$

c) $\vec{E} = 5x\hat{x} + 2\hat{y}$

d) $\vec{E} = 10x\hat{x} + \hat{y} + \hat{z}$

e) $\vec{E} = 0$

Concept Check 3.7

Suppose an electric potential is described by $V(x, y, z) = -(5x^2 + y + z)$ in volts. Which of the following expressions describes the associated electric field, in units of volts per meter?

a) $\vec{E} = 5\hat{x} + 2\hat{y} + 2\hat{z}$

b) $\vec{E} = 10x\hat{x}$

c) $\vec{E} = 5x\hat{x} + 2\hat{y}$

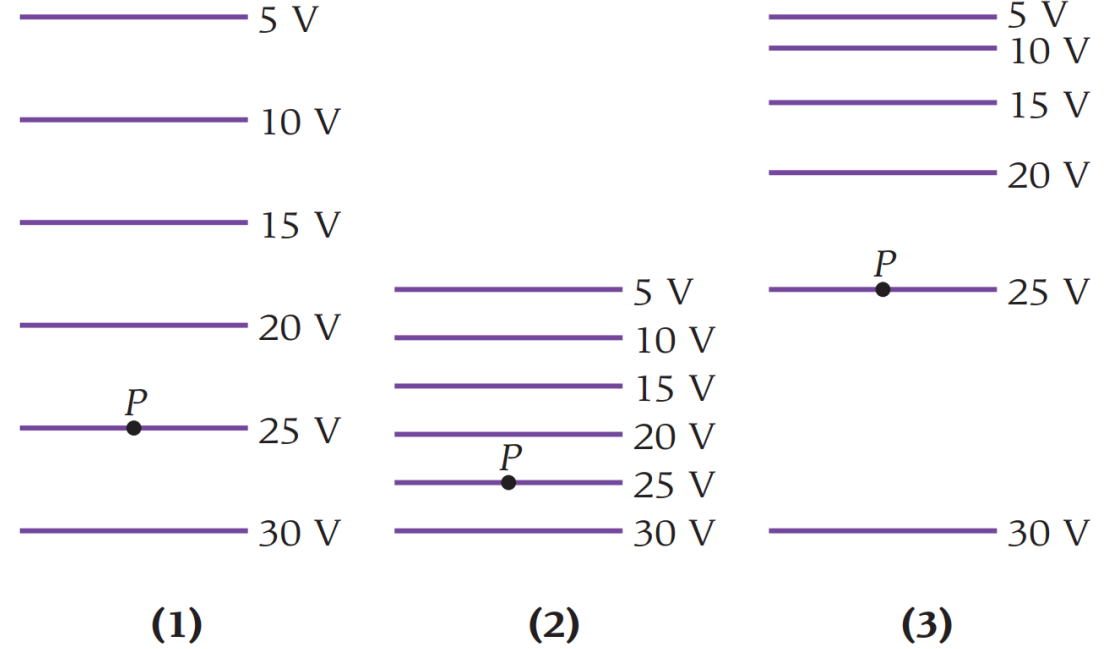
d) $\vec{E} = 10x\hat{x} + \hat{y} + \hat{z}$

e) $\vec{E} = 0$

Concept Check 3.8

In the figure, the lines represent equipotential lines. How does the magnitude of the electric field, E , at point P compare for the three cases?

- a) $E_1 = E_2 = E_3$
- b) $E_1 > E_2 > E_3$
- c) $E_1 < E_2 < E_3$
- d) $E_3 > E_1 > E_2$
- e) $E_3 < E_1 < E_2$



Concept Check 3.8

In the figure, the lines represent equipotential lines. How does the magnitude of the electric field, E , at point P compare for the three cases?

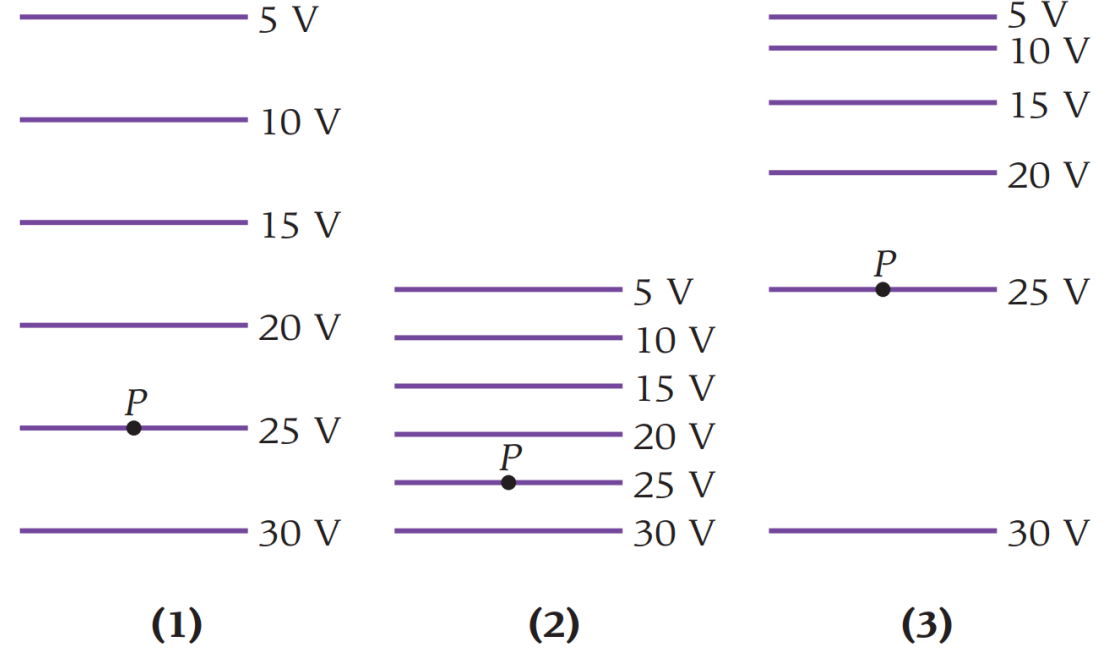
a) $E_1 = E_2 = E_3$

b) $E_1 > E_2 > E_3$

c) $E_1 < E_2 < E_3$

d) $E_3 > E_1 > E_2$

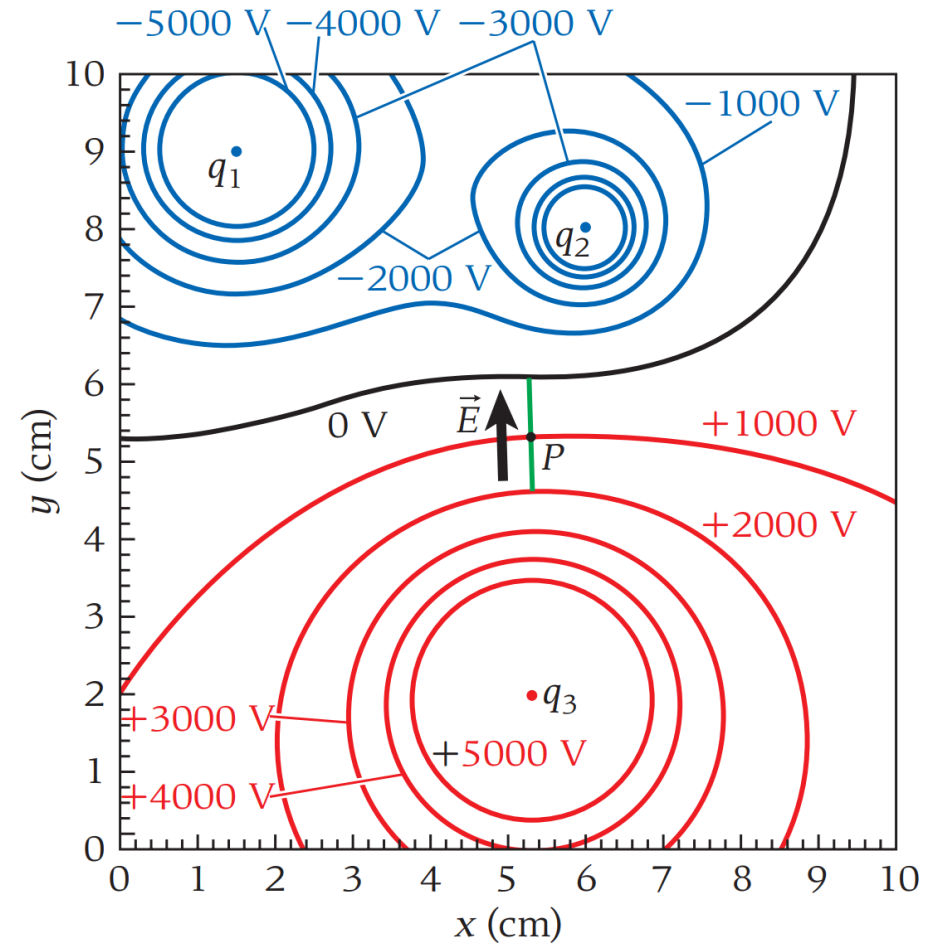
e) $E_3 < E_1 < E_2$



Example 3.6

Calculate the electric field at point P .

03



Example 3.6 – Page 77

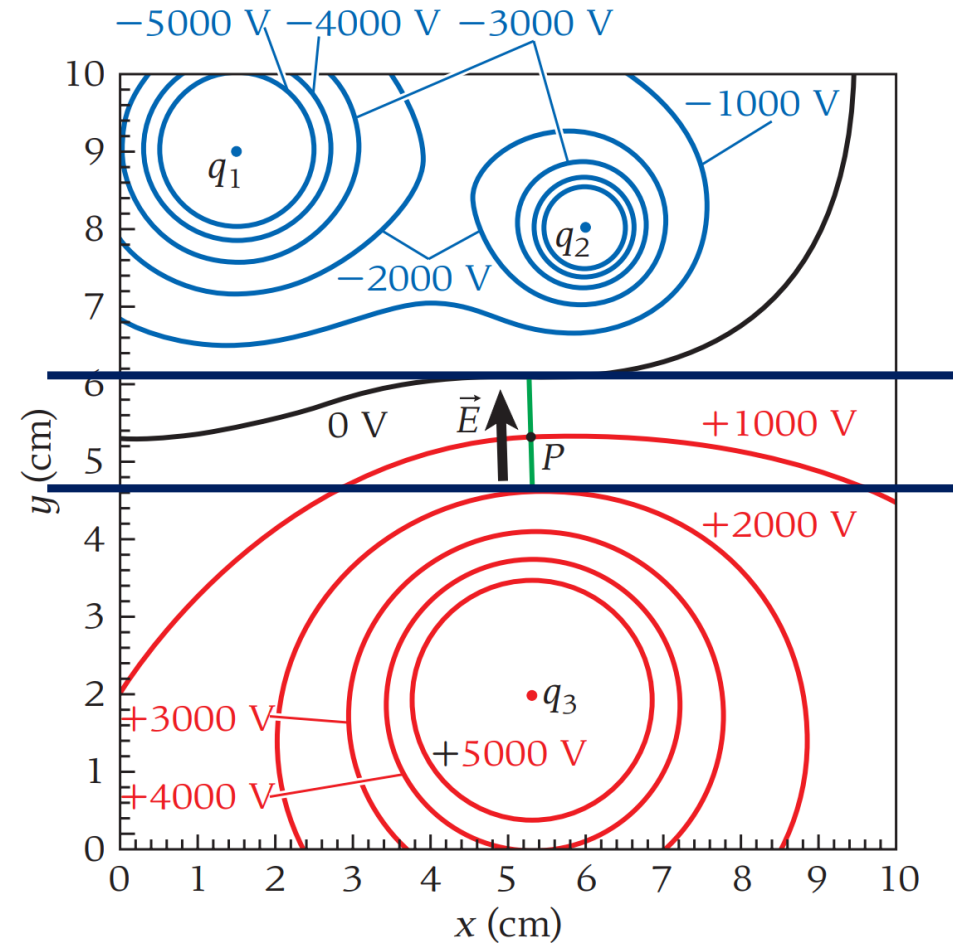
3.5 Finding the Electric Field from the Electric Potential



Example 3.6

Calculate the electric field at point **P**.

$$|E_s| = \left| -\frac{\Delta V}{\Delta s} \right| = \left| \frac{(+2000 \text{ V}) - (0 \text{ V})}{1.5 \text{ cm}} \right| = 1.3 \times 10^5 \text{ V/m}$$



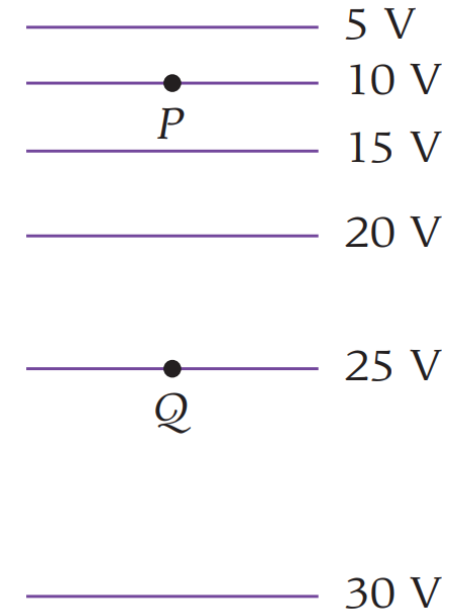
Example 3.6 – Page 77

3.5 Finding the Electric Field from the Electric Potential

Concept Check 3.9

04

In the figure, the lines represent equipotential lines. A positive charge is placed at point P , and then another positive charge is placed at point Q . Which set of vectors best represents the relative magnitudes and directions of the electric field forces exerted on the positive charges at P and Q ?



Concept Check 3.9 – Page 78

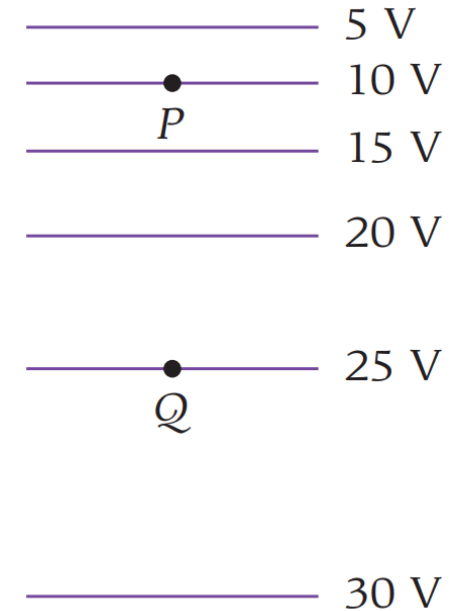
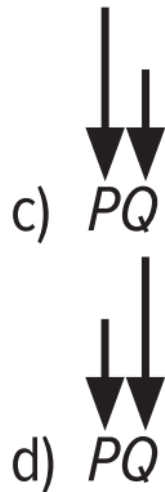
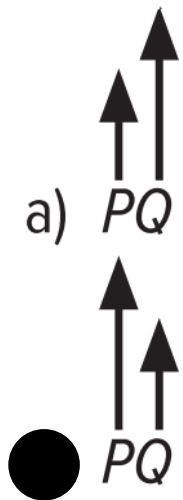
3.5 Finding the Electric Field from the Electric Potential



Concept Check 3.9

04

In the figure, the lines represent equipotential lines. A positive charge is placed at point P , and then another positive charge is placed at point Q . Which set of vectors best represents the relative magnitudes and directions of the electric field forces exerted on the positive charges at P and Q ?



Concept Check 3.9 – Page 78

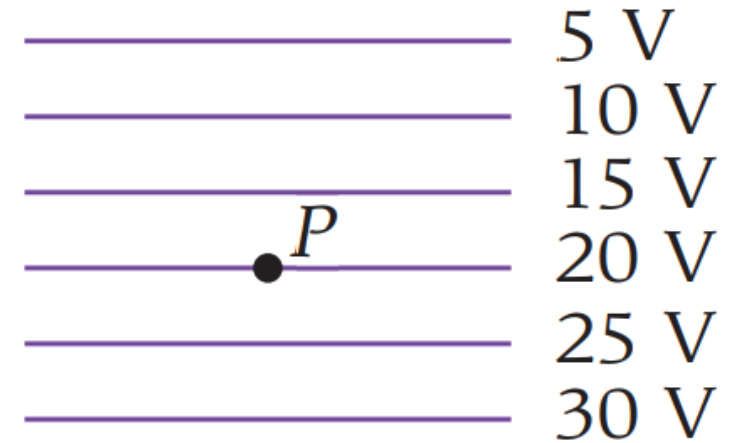
3.5 Finding the Electric Field from the Electric Potential

Concept Check 3.10

05

In the figure, the lines represent equipotential lines. What is the direction of the electric field at point ***P***?

- a) up
- b) down
- c) left
- d) right
- e) The electric field at *P* is zero.

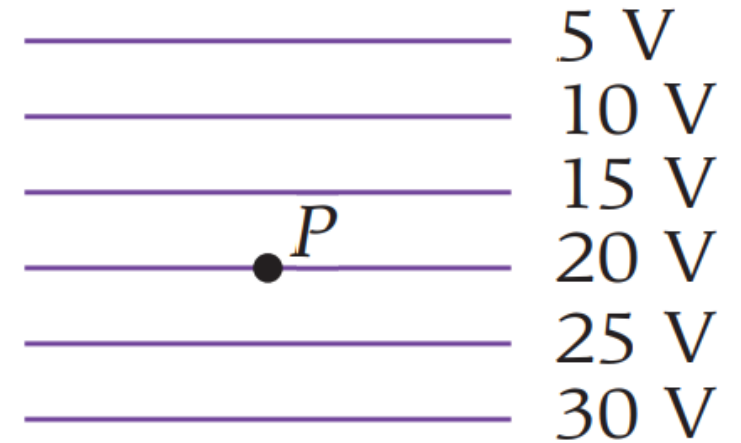


Concept Check 3.10

05

In the figure, the lines represent equipotential lines. What is the direction of the electric field at point **P**?

- a) up
- b) down
- c) left
- d) right
- e) The electric field at P is zero.

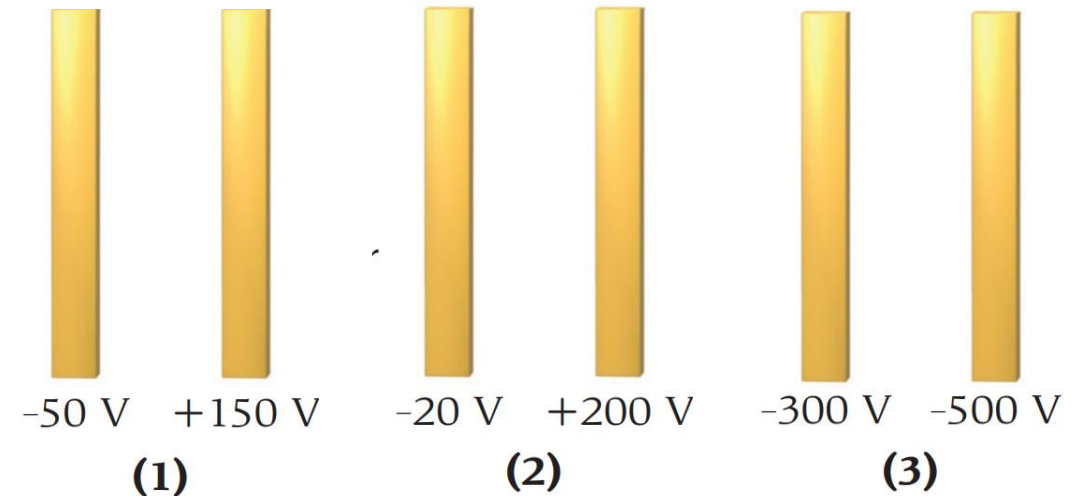


Concept Check 3.11

o6

Three pairs of parallel plates have the same plate separation and potentials on each plate as indicated in the drawing. The electric field, E , is uniform between each pair of plates and perpendicular to them. Rank the magnitude of E between the plates, from highest to lowest.

- a) $1 > 2 > 3$
- b) $3 > 2 > 1$
- c) The magnitudes for 3 and 2 are equal and greater than the magnitude for 1.
- d) The three magnitudes are equal.
- e) The magnitude for 2 is greater than that for 1 and 3, which are the same.

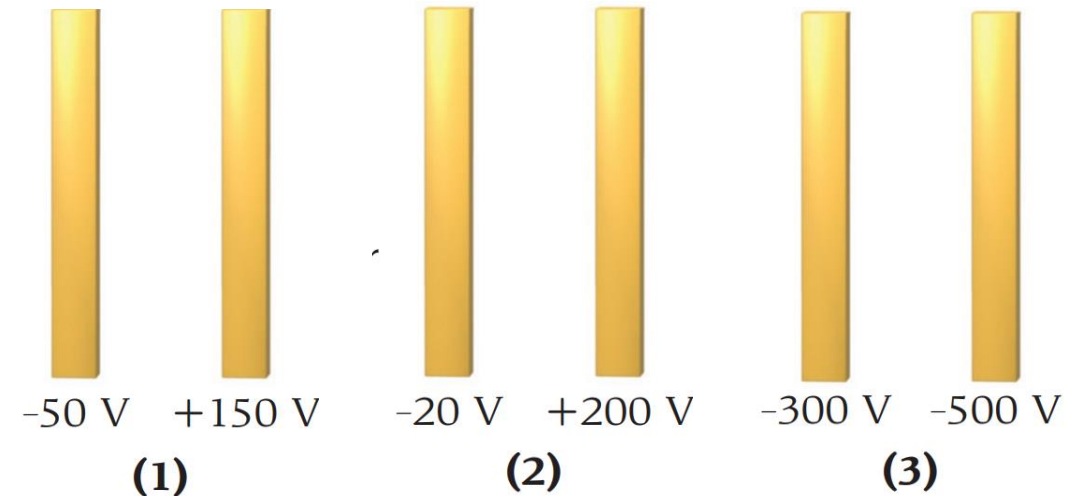


Concept Check 3.11

o6

Three pairs of parallel plates have the same plate separation and potentials on each plate as indicated in the drawing. The electric field, E , is uniform between each pair of plates and perpendicular to them. Rank the magnitude of E between the plates, from highest to lowest.

- a) $1 > 2 > 3$
- b) $3 > 2 > 1$
- c) The magnitudes for 3 and 2 are equal and greater than the magnitude for 1.
- d) The three magnitudes are equal.
- e) The magnitude for 2 is greater than that for 1 and 3, which are the same.



Exercise 3.47

07

An electric field is established in a nonuniform rod. A voltmeter is used to measure the potential difference between the left end of the rod and a point a distance x from the left end. The process is repeated, and it is found that the data are described by the relationship $\Delta V = 270x^2$, where ΔV has the units V/m^2 . What is the x-component of the electric field at a point **13.0 cm** from the left end?

Exercise 3.47

07

An electric field is established in a nonuniform rod. A voltmeter is used to measure the potential difference between the left end of the rod and a point a distance x from the left end. The process is repeated, and it is found that the data are described by the relationship $\Delta V = 270x^2$, where ΔV has the units V/m^2 . What is the x -component of the electric field at a point **13.0 cm** from the left end?

$$E = -\frac{\Delta V}{\Delta x}.$$

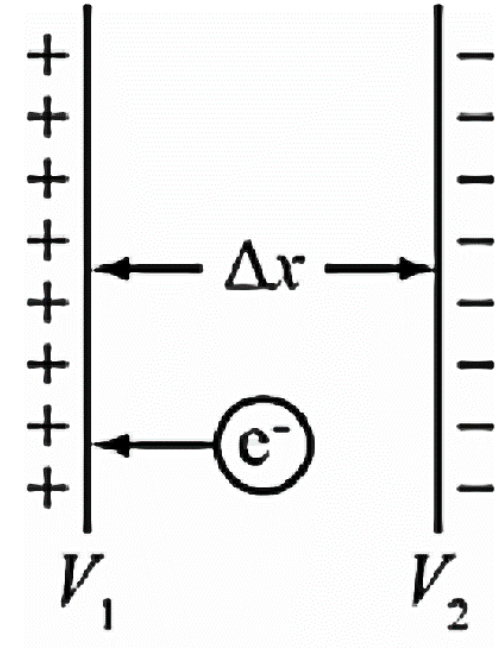
$$E_x = -\left[\frac{dV}{dx}\right]_{x=13.0 \text{ cm}} = -2V_0[x]_{x=13.0 \text{ cm}} = -2(270. \text{ V/m}^2)(0.130 \text{ m}) = 70.2 \text{ V/m}.$$

Exercise 3.48

o8

Two parallel plates are held at potentials of **+200.0 V** and **-100.0 V**. The plates are separated by **1.00 cm**.

- a) Find the electric field between the plates.
- b) An electron is initially placed halfway between the plates. Find its kinetic energy when it hits the positive plate.



Exercise 3.48

o8

Two parallel plates are held at potentials of **+200.0 V** and **-100.0 V**. The plates are separated by **1.00 cm**.

- a) Find the electric field between the plates.
- b) An electron is initially placed halfway between the plates.
Find its kinetic energy when it hits the positive plate.

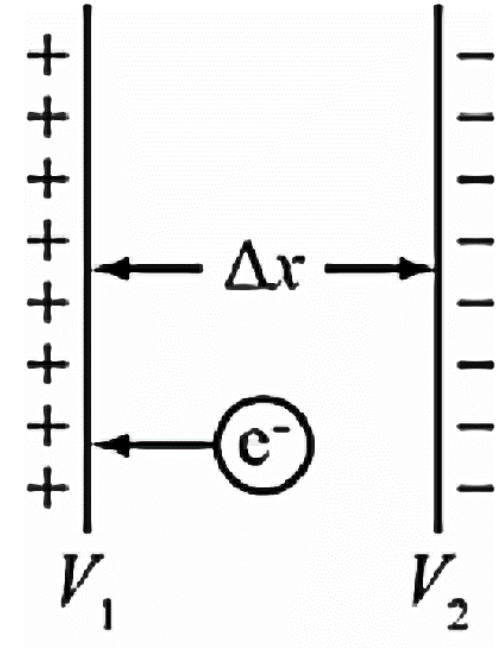
$$E = -\left|\frac{dV}{dx}\right| \approx \frac{\Delta V}{\Delta x}, \text{ where } \Delta x = 1.00 \text{ cm. Therefore, } E = \frac{300.0 \text{ V}}{0.0100 \text{ m}} = 3.00 \cdot 10^4 \text{ V/m.}$$

$$\text{b. } \Delta K = W_e$$

$$= qEd$$

$$= (1.602 \times 10^{-19}) \times (3 \times 10^4) \times (0.005)$$

$$= 2.4 \times 10^{-17} \text{ J}$$



Exercise 3.49

09

A **2.50-mg** dust particle with a charge of **1.00 μC** falls at a point **$x = 2.00 \text{ m}$** in a region where the electric potential varies according to **$V(x) = (2.00 \text{ V/m}^2)x^2 - (3.00 \text{ V/m}^3)x^3$** . With what acceleration will the particle start moving after it touches down?

Exercise 3.49

09

A **2.50-mg** dust particle with a charge of **1.00 μC** falls at a point **$x = 2.00 \text{ m}$** in a region where the electric potential varies according to **$V(x) = (2.00 \text{ V/m}^2)x^2 - (3.00 \text{ V/m}^3)x^3$** . With what acceleration will the particle start moving after it touches down?

$$a = \frac{F}{m} = \frac{qE}{m}$$

$$= \frac{(1 \times 10^{-6})(28)}{(2.5 \times 10^{-6})}$$

$$= 11.2 \text{ m/s}^2$$

$$E_x = -\frac{\partial V}{\partial x} = -4x + 9x^2$$

$$E(2) = 4(2) - 9(2)^2 = 28 \text{ V/m}$$

Exercise 3.50

10

The electric potential in a volume of space is given by $V(x,y,z) = x^2 + xy^2 + yz$. Determine the electric field in this region at the coordinate **(3,4,5)**.

Exercise 3.50

10

The electric potential in a volume of space is given by $V(x,y,z) = x^2 + xy^2 + yz$. Determine the electric field in this region at the coordinate **(3,4,5)**.

In three dimensions, the electric field is:

$$\vec{E}(x, y, z) = -\nabla V = -\left(\frac{\partial V}{\partial x} \hat{x} + \frac{\partial V}{\partial y} \hat{y} + \frac{\partial V}{\partial z} \hat{z} \right).$$

Therefore, if $V(x, y, z) = x^2 + xy^2 + yz$, $\frac{\partial V}{\partial x} = 2x + y^2$, $\frac{\partial V}{\partial y} = 2xy + z$ and $\frac{\partial V}{\partial z} = y$:

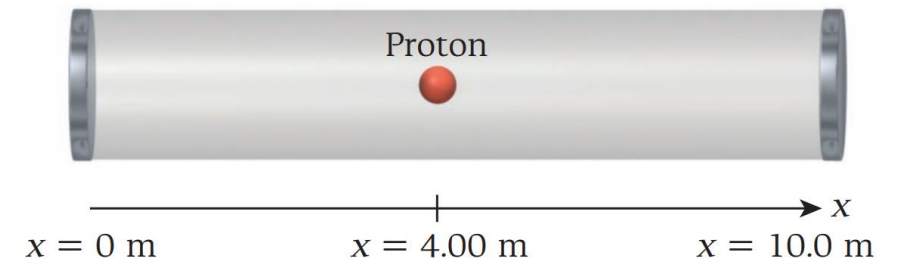
$$\begin{aligned}\vec{E}(x, y, z) &= -(2x + y^2) \hat{x} - (2xy + z) \hat{y} - y \hat{z} \\ \vec{E}(3, 4, 5) &= -(2(3) + (4)^2) \hat{x} - (2(3)(4) + (5)) \hat{y} - (4) \hat{z} = -22\hat{x} - 29\hat{y} - 4\hat{z}\end{aligned}$$

Exercise 3.51

11

The electric potential inside a **10.0-m**-long linear particle accelerator is given by $V = (3000 - 5x^2/\text{m}^2) \text{ V}$, where x is the distance from the left plate along the accelerator tube, as shown in the figure.

- a) Determine an expression for the electric field along the accelerator tube.
- b) A proton is released (from rest) at $x = 4.00 \text{ m}$.
Calculate the acceleration of the proton just after it is released.



Exercise 3.51

11

The electric potential inside a **10.0-m**-long linear particle accelerator is given by $V = (3000 - 5x^2/\text{m}^2) \text{ V}$, where x is the distance from the left plate along the accelerator tube, as shown in the figure.

a) Determine an expression for the electric field along the accelerator tube.

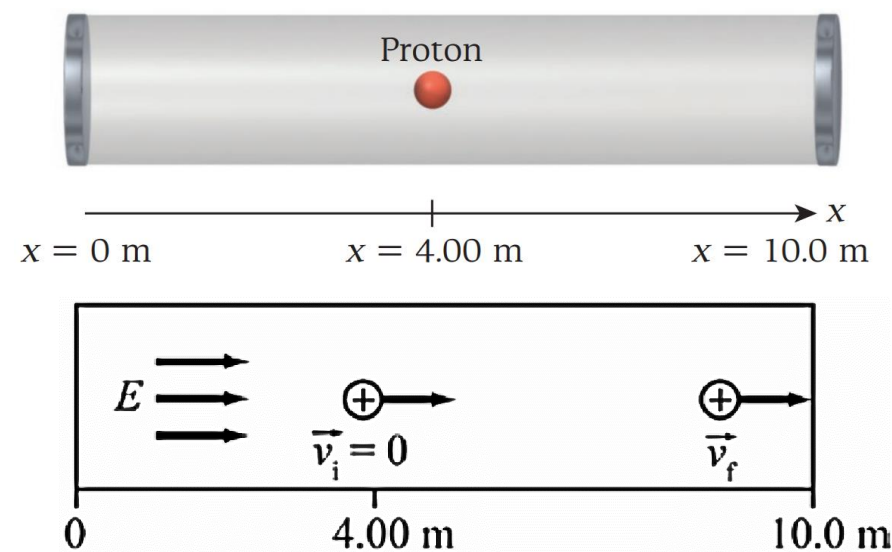
b) A proton is released (from rest) at $x = 4.00 \text{ m}$.

Calculate the acceleration of the proton just after it is released.

$$(a) \quad E(x) = -\frac{d}{dx} \left(3000 - \frac{5x^2}{\text{m}^2} \right) \text{ V} = 10x \text{ V/m}^2$$

$$(b) \quad F(x) = m_p a(x) \Rightarrow a(x) = \frac{F(x)}{m_p} = \frac{qE(x)}{m_p} = \frac{10qx \text{ V/m}^2}{m_p}$$

$$(b) \quad a(4.00 \text{ m}) = \frac{10(1.602 \cdot 10^{-19} \text{ C})(4.00 \text{ m}) \text{ V/m}^2}{1.673 \cdot 10^{-27} \text{ kg}} = 3.8302 \cdot 10^9 \text{ m/s}^2$$



Exercise 3.51 – Page 84

3.5 Finding the Electric Field from the Electric Potential

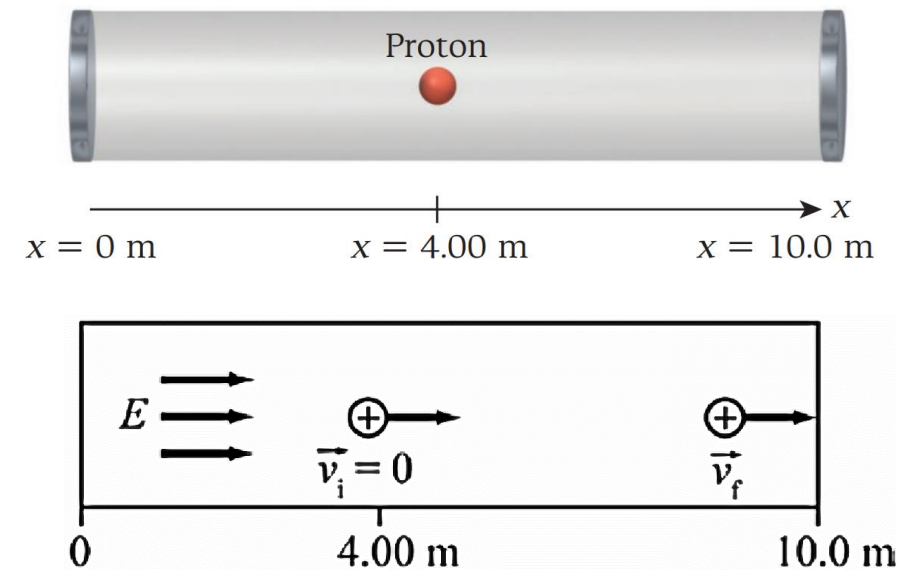


Exercise 3.51

11

The electric potential inside a **10.0-m**-long linear particle accelerator is given by $V = (3000 - 5x^2/\text{m}^2) \text{ V}$, where x is the distance from the left plate along the accelerator tube, as shown in the figure.

c) What is the impact speed of the proton when (and if) it collides with the plate?



Exercise 3.51

11

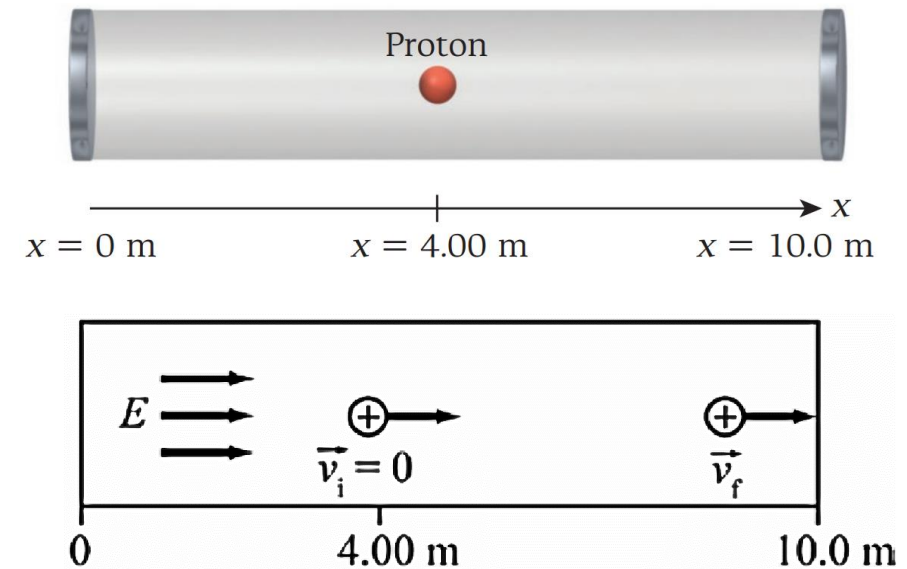
The electric potential inside a **10.0-m**-long linear particle accelerator is given by $V = (3000 - 5x^2/\text{m}^2) \text{ V}$, where x is the distance from the left plate along the accelerator tube, as shown in the figure.

c) What is the impact speed of the proton when (and if) it collides with the plate?

$$(c) \quad \Delta V = V(x_2) - V(x_1) = -\frac{5 \text{ V}}{\text{m}^2} (x_2^2 - x_1^2)$$

$$\Delta K = -\Delta U \Rightarrow \frac{1}{2} m_p v_f^2 = 5q \text{ V/m}^2 (x_2^2 - x_1^2) \Rightarrow v_f = \sqrt{\frac{10q}{m_p} (x_2^2 - x_1^2) \text{ V/m}^2}.$$

$$(c) \quad v_f = \sqrt{\frac{10(1.602 \cdot 10^{-19} \text{ C})}{1.673 \cdot 10^{-27} \text{ kg}} [(10.0 \text{ m})^2 - (4.00 \text{ m})^2] \text{ V/m}^2} = 2.836 \cdot 10^5 \text{ m/s}$$



Exercise 3.52

12

An infinite plane of charge has a uniform charge distribution of $+4.00 \text{ nC/m}^2$ and is located in the yz -plane at $x = 0$. A $+11.0\text{-nC}$ fixed point charge is located at $x = +2.00 \text{ m}$.

- a) Find the electric potential $V(x)$ on the x -axis from $0 < x < +2.00 \text{ m}$.
- b) At what position(s) on the x -axis between $x = 0$ and $x = +2.00 \text{ m}$ is the electric potential a minimum?
- c) Where on the x -axis between $x = 0 \text{ m}$ and $x = +2.00 \text{ m}$ could a positive point charge be placed and not move?

Exercise 3.52

12

An infinite plane of charge has a uniform charge distribution of **+4.00 nC/m²** and is located in the yz-plane at **x = 0**. A **+11.0-nC** fixed point charge is located at **x = +2.00 m**.

- a) Find the electric potential **V(x)** on the x-axis from **0 < x < +2.00 m**.
- b) At what position(s) on the x-axis between **x = 0** and **x = +2.00 m** is the electric potential a minimum?
- c) Where on the x-axis between **x = 0 m** and **x = +2.00 m** could a positive point charge be placed and not move?

$$V(x) = V_1 + V_2$$

$$E_1 = E_2$$

$$x = \mathbf{0.134\ m}$$

$$= Ex + \frac{kq}{(2-x)^2}$$

$$\frac{\sigma}{2\epsilon_0} = \frac{kq}{(2-x)^2}$$

$$= \frac{\sigma}{2\epsilon_0} x + \frac{kq}{(2-x)^2}$$

$$x = \mathbf{0.134\ m}$$

Exercise 3.52 – Page 84

3.5 Finding the Electric Field from the Electric Potential

Electric Potential Energy of a System of Point Charges

Chapter 3
Lesson 6 – Revision Paper

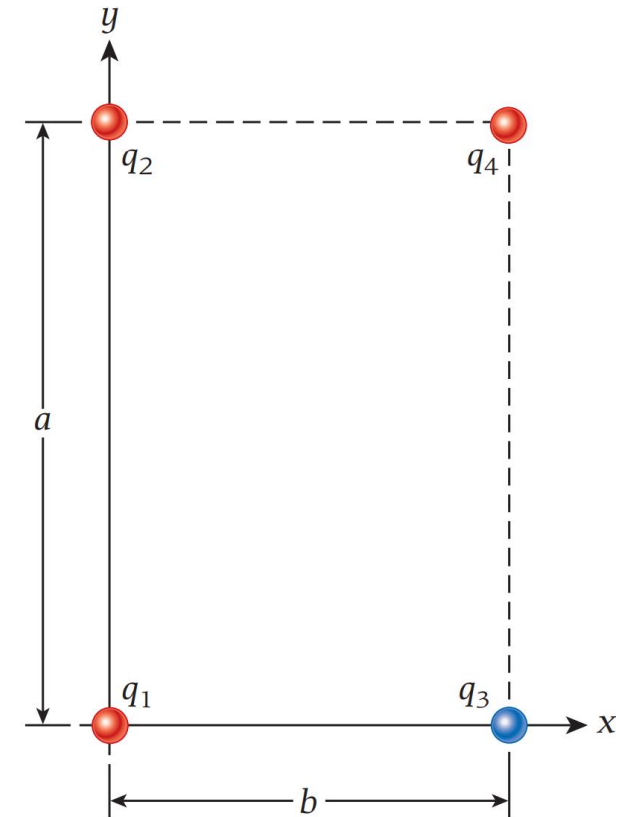
3.6 – Electric Potential Energy of a System of Point Charges

$$U = qV$$

$$U = \frac{kq_1q_2}{r}$$

Example 3.7

Four point charges shown in the figure have the values $q_1 = +1.0 \mu\text{C}$, $q_2 = +2.0 \mu\text{C}$, $q_3 = -3.0 \mu\text{C}$, and $q_4 = +4.0 \mu\text{C}$. The charges are placed with $a = 6.0 \text{ m}$ and $b = 4.0 \text{ m}$. What is the electric potential energy of this system of four point charges?



01

Example 3.7 – Page 80

3.6 Electric Potential Energy of a System of Point Charges

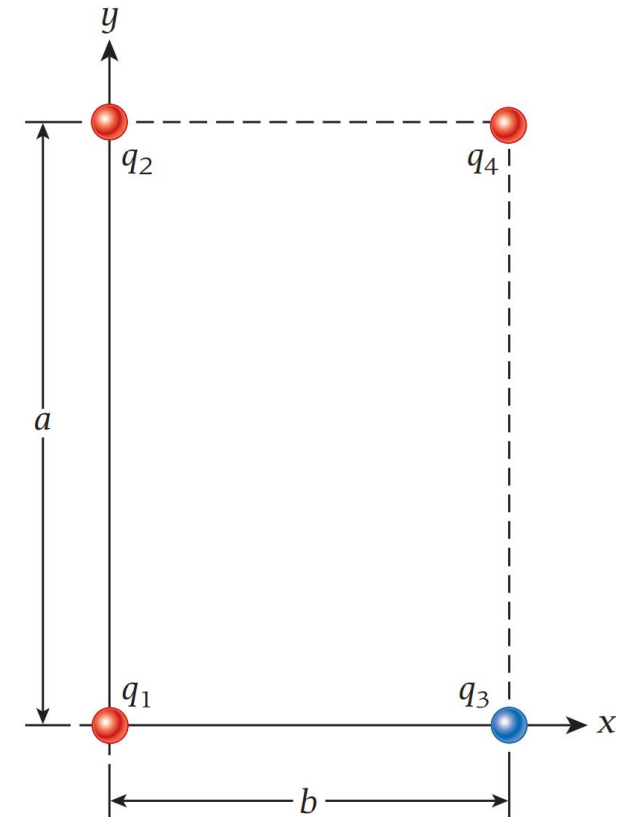


Example 3.7

Four point charges shown in the figure have the values $q_1 = +1.0 \mu\text{C}$, $q_2 = +2.0 \mu\text{C}$, $q_3 = -3.0 \mu\text{C}$, and $q_4 = +4.0 \mu\text{C}$. The charges are placed with $a = 6.0 \text{ m}$ and $b = 4.0 \text{ m}$. What is the electric potential energy of this system of four point charges?

$$U = \frac{kq_1q_2}{a} + \frac{kq_1q_3}{b} + \frac{kq_2q_3}{\sqrt{a^2 + b^2}} + \frac{kq_1q_4}{\sqrt{a^2 + b^2}} + \frac{kq_2q_4}{b} + \frac{kq_3q_4}{a}$$

$$U = (3.0 \times 10^{-3} \text{ J}) + (-6.7 \times 10^{-3} \text{ J}) + (-7.5 \times 10^{-3} \text{ J}) + (5.0 \times 10^{-3} \text{ J}) + (1.8 \times 10^{-2} \text{ J}) + (-1.8 \times 10^{-2} \text{ J}) = -6.2 \times 10^{-3} \text{ J}$$



Exercise 3.57

Nuclear fusion reactions require that positively charged nuclei be brought into close proximity, against the electrostatic repulsion. As a simple example, suppose a **proton** is fired at a second, stationary proton from a large distance away. What kinetic energy must be given to the moving proton to get it to come within $1.00 \times 10^{-15} \text{ m}$ of the target? Assume that there is a head-on collision and that the target is fixed in place.

Exercise 3.57

02

Nuclear fusion reactions require that positively charged nuclei be brought into close proximity, against the electrostatic repulsion. As a simple example, suppose a **proton** is fired at a second, stationary proton from a large distance away. What kinetic energy must be given to the moving proton to get it to come within $1.00 \times 10^{-15} \text{ m}$ of the target? Assume that there is a head-on collision and that the target is fixed in place.

If the proton comes to a complete stop at $r = 1.00 \cdot 10^{-15} \text{ m}$, then all of its initial kinetic energy is converted to potential energy:

$$U = \frac{k|e|^2}{r} = \frac{(8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2)(1.602 \cdot 10^{-19} \text{ C})^2}{1.00 \cdot 10^{-15} \text{ m}} = 2.31 \cdot 10^{-13} \text{ J or } 1.44 \text{ MeV.}$$

Exercise 3.58

03

Fission of a uranium nucleus (containing 92 protons) produces a barium nucleus (56 protons) and a krypton nucleus (36 protons). The fragments fly apart as a result of electrostatic repulsion; they ultimately emerge with a total of **200. MeV** of kinetic energy. Use this information to estimate the size of the uranium nucleus; that is, treat the barium and krypton nuclei as point charges and calculate the separation between them at the start of the process.

Exercise 3.58

03

Fission of a uranium nucleus (containing 92 protons) produces a barium nucleus (56 protons) and a krypton nucleus (36 protons). The fragments fly apart as a result of electrostatic repulsion; they ultimately emerge with a total of **200. MeV** of kinetic energy. Use this information to estimate the size of the uranium nucleus; that is, treat the barium and krypton nuclei as point charges and calculate the separation between them at the start of the process.

$$U_i = \frac{kq_1q_2}{r} = K_f \Rightarrow r = \frac{k(36)(56)|e|^2}{K_f} = \frac{(8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2)(2016)(1.602 \cdot 10^{-19} \text{ C})^2}{(200 \cdot 10^6 \text{ eV})(1.602 \cdot 10^{-19} \text{ J/(1 eV)})} = 1.45 \cdot 10^{-14} \text{ m.}$$

Exercise 3.59

04

A deuterium ion and a tritium ion each have charge $+e$. What work has to be done on the deuterium ion in order to bring it within $1.00 \times 10^{-14} \text{ m}$ of the tritium ion? This is the distance within which the two ions can fuse, as a result of strong nuclear interactions that overcome electrostatic repulsion, to produce a helium-5 nucleus. Express the work in electron-volts.

Exercise 3.59

04

A deuterium ion and a tritium ion each have charge $+e$. What work has to be done on the deuterium ion in order to bring it within $1.00 \times 10^{-14} \text{ m}$ of the tritium ion? This is the distance within which the two ions can fuse, as a result of strong nuclear interactions that overcome electrostatic repulsion, to produce a helium-5 nucleus. Express the work in electron-volts.

Assuming the first ion is brought in from an infinite distance, then the work needed to bring it a distance of $r = 10^{-14} \text{ m}$ to the other ion is the potential energy of the two ions:

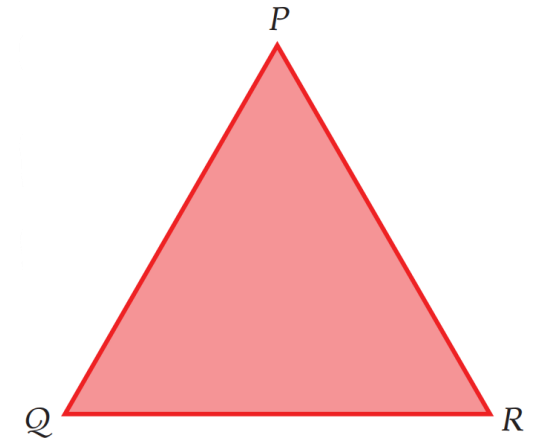
$$U = \frac{k|e|^2}{r} = \frac{(8.9875 \cdot 10^9 \text{ N m}^2/\text{C}^2)(1.602 \cdot 10^{-19} \text{ C})^2}{10^{-14} \text{ m}} \left(\frac{1 \text{ eV}}{1.602 \cdot 10^{-19} \text{ J}} \right) = 143,980 \text{ eV} \approx 144 \text{ keV}.$$

Exercise 3.60

05

Three charges, q_1 , q_2 , and q_3 , are located at the corners of an equilateral triangle with side length of **1.20 m**. Find the work done in each of the following cases:

- a) to bring the first particle, $q_1 = 1.00 \text{ pC}$, to P from infinity
- b) to bring the second particle, $q_2 = 2.00 \text{ pC}$, to Q from infinity
- c) to bring the last particle, $q_3 = 3.00 \text{ pC}$, to R from infinity
- d) Find the total potential energy stored in the final configuration of q_1 , q_2 , and q_3 .

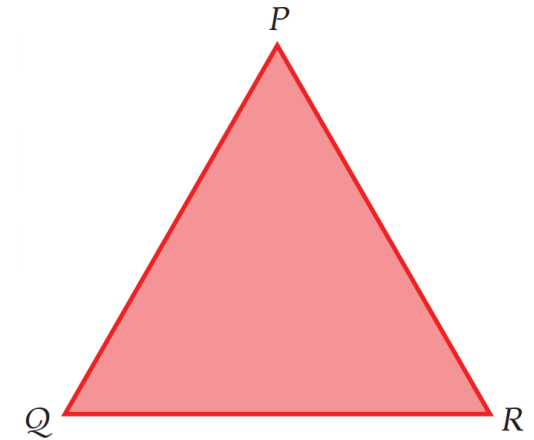


Exercise 3.6o

05

Three charges, q_1 , q_2 , and q_3 , are located at the corners of an equilateral triangle with side length of **1.20 m**. Find the work done in each of the following cases:

- a) to bring the first particle, $q_1 = 1.00 \text{ pC}$, to P from infinity
- b) to bring the second particle, $q_2 = 2.00 \text{ pC}$, to Q from infinity
- c) to bring the last particle, $q_3 = 3.00 \text{ pC}$, to R from infinity
- d) Find the total potential energy stored in the final configuration of q_1 , q_2 , and q_3 .



(a) $W_1 = 0 \text{ J}$

(b) $W_2 = \frac{(8.99 \cdot 10^9 \text{ N m}^2/\text{C}^2)(1.0 \cdot 10^{-12} \text{ C})(2.0 \cdot 10^{-12} \text{ C})}{(1.20 \text{ m})} = 1.498 \cdot 10^{-14} \text{ J}$

(c) $W_3 = \frac{(8.99 \cdot 10^9 \text{ N m}^2/\text{C}^2)}{1.20 \text{ m}} \left[(1.0 \cdot 10^{-12} \text{ C})(3.0 \cdot 10^{-12} \text{ C}) + (2.0 \cdot 10^{-12} \text{ C})(3.0 \cdot 10^{-12} \text{ C}) \right]$
 $= 6.743 \cdot 10^{-14} \text{ J}$

(d) $U_{\text{tot}} = (0 \text{ J}) + (1.498 \cdot 10^{-14} \text{ J}) + (6.743 \cdot 10^{-14} \text{ J}) = 8.241 \cdot 10^{-14} \text{ J}$

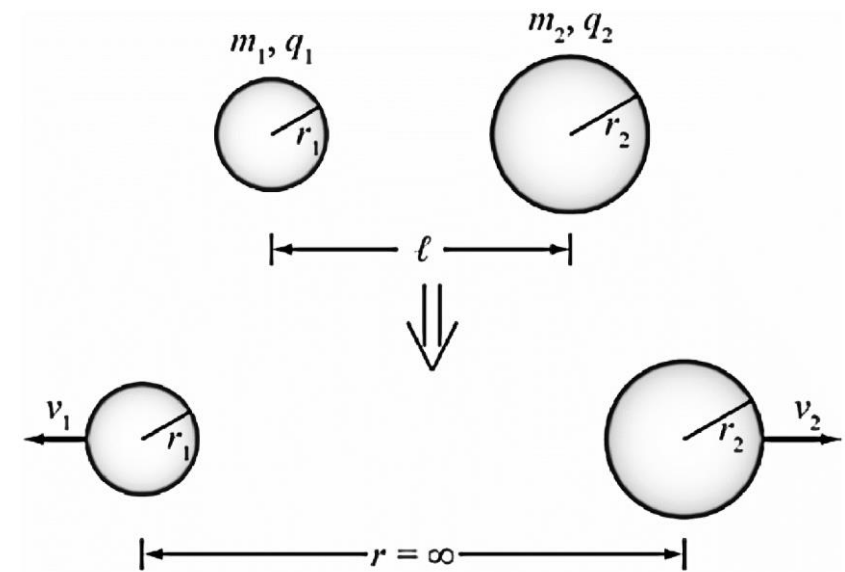
Exercise 3.6o – Page 85

3.6 Electric Potential Energy of a System of Point Charges

Exercise 3.61

o6

Two metal balls of mass $m_1 = 5.00 \text{ g}$ (diameter = 5.00 mm) and $m_2 = 8.00 \text{ g}$ (diameter = 8.00 mm) have positive charges of $q_1 = 5.00 \text{ nC}$ and $q_2 = 8.00 \text{ nC}$, respectively. A force holds them in place so that their centers are separated by 8.00 mm . What will their velocities be after the force has been removed and they are separated by a large distance?



Exercise 3.60 – Page 85

3.6 Electric Potential Energy of a System of Point Charges



Exercise 3.61

o6

Two metal balls of mass $m_1 = 5.00 \text{ g}$ (diameter = 5.00 mm) and $m_2 = 8.00 \text{ g}$ (diameter = 8.00 mm) have positive charges of $q_1 = 5.00 \text{ nC}$ and $q_2 = 8.00 \text{ nC}$, respectively. A force holds them in place so that their centers are separated by 8.00 mm . What will their velocities be after the force has been removed and they are separated by a large distance?

$$\Delta K_1 + \Delta K_2 = \Delta U$$

$$P_f = P_i$$

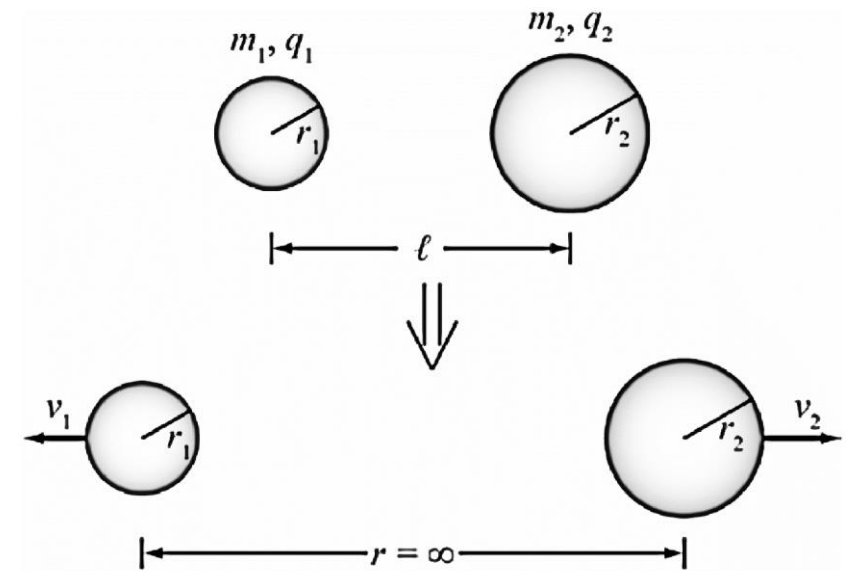
$$m_1 v_1 + m_2 v_2 = 0$$

$$v_1 = \frac{-m_2 v_2}{m_1} \\ = 0.105 \text{ m/s}$$

$$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{k q_1 q_2}{r^2}$$

$$m_1 v_1^2 + m_2 v_2^2 = \frac{2k q_1 q_2}{r^2}$$

$$m_1 \left(\frac{-m_2 v_2}{m_1} \right)^2 + m_2 v_2^2 = \frac{2k q_1 q_2}{r^2} \rightarrow v_2 = 0.0658 \text{ m/s}$$



Exercise 3.61 – Page 85

3.6 Electric Potential Energy of a System of Point Charges



Chapter 3 – Revision Paper

Resources

- *Electric Potential, Chapter 23, from University Physics with Modern Physics, 2e by Bauer and Westfall ©2014*

THIS FILE IS FOR EDUCATIONAL PURPOSES ONLY.

This file is under Fair Use:

Copyright Disclaimer under section 107 of the Copyright Act of 1976, allowance is made for "fair use" for purposes such as criticism, comment, news reporting, teaching, scholarship, education and research. Fair use is a use permitted by copyright statute that might otherwise be infringing.

All rights and credit go directly to its rightful owners. No copyright infringement intended.

Related Files:

Physics Teacher Guide Term 1 2022-2023

[<https://t.me/InLibrary/1021>]

Physics Student Book EN Term 1 2022-2023

[<https://t.me/InLibrary/1001>]

Physics Student Book AR Term 1 2022-2023

[<https://t.me/InLibrary/997>]

Physics Chapter 2 Summary 2022-2023

[<https://t.me/InLibrary/1237>]

Physics Chapter 1 Revision Paper 2022-2023

[<https://t.me/InLibrary/1215>]