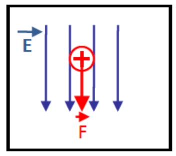
شرح وتدريبات الوحدة الثالثة potential Electric الجهد الكهربائي منهج انسباير

Electric potential

3.1 Electric Potential Energy



1- **Electric potential energy of a charge:** U

"The energy gained by a charge because of its position in an electric field."

Change in potential energy of a charge: ΔU

It equals negative the work done by the electric force to transfer the charge from one point to the another point in the electric field.

$$\Delta U_{a\text{-}b} = -W_{a\text{-}b}$$ (where: $\Delta U_{a\text{-}b} = U_b - U_a$)

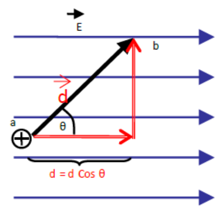
The potential energy of a charge: U_b

It equals negative the work done by the electric force to transfer the charge from infinity to a point in the electric field.

$$\Delta U_{\infty\text{-}b} = U_b - U_\infty = U_b = -W_{\infty\text{-}b}$$ (considering $U_\infty = 0$ at ∞)

Change in potential energy of a charge in a uniform electric field:

When a charge is transferred with a constant velocity in a uniform electric field, the change of its potential energy will be given by:

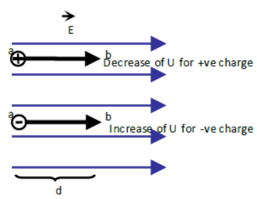


$$\Delta U_{a\text{-}b} = U_b - U_a = -q\,E\,d$$

- $\Delta U_{a\text{-}b}$: Change in potential energy of a charge
- q: The transferred charge
- E: The electric field
- d: The displacement parallel to the field

Note: -The potential energy of a positive charge decreases in the direction of the electric field.

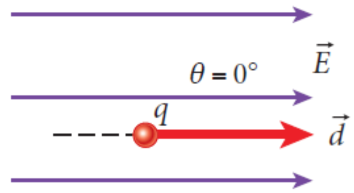
-The potential energy of a negative charge decreases opposite to the direction of the electric field.



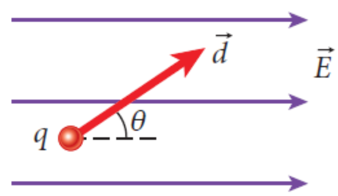
Special Case: Charge in a Constant Electric Field

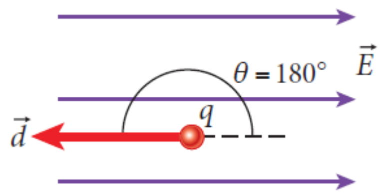
- **the work done by the field on the charge is given by**

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



moving charge, q: in the same direction as the electric field,

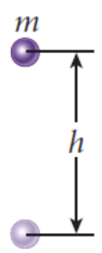




Movement of charge, q: is opposite to the direction of the electric field

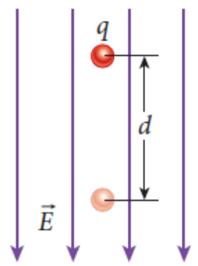
---

- **the change in the gravitational potential energy of the mass**



$$\Delta U = -W = -\vec{F}_g\bullet\vec{d} = -mgh$$

A mass falls in a gravitational field.



$$\Delta U = -W = -q\vec{E}\bullet\vec{d} = -qEd$$

positive charge moves in the same direction as an electric field

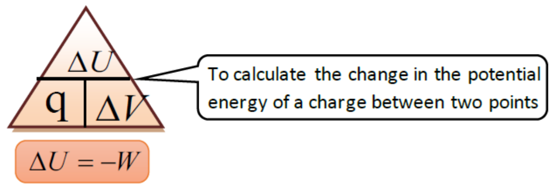
3.2 Definition of Electric Potential

Change in electric potential and the electric potential:

-Change in electric potential: ΔV

"The change in potential energy of a positive test charge divided by the test charge."

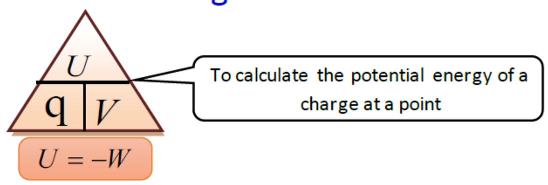
$$\Delta V = \frac{\Delta U}{q}$$



-Electric potential: V

"The potential energy of a positive test charge divided by the test charge."

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



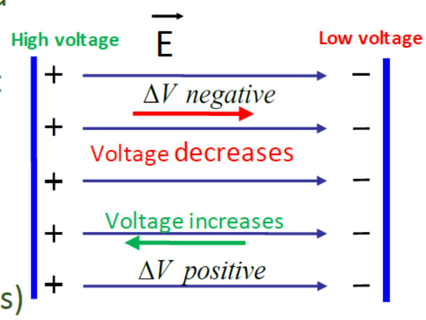
Notes:

-The electric potential and the potential difference both are measured in volt(Jule/Coulomb).

-The electric potential, like the electric field is a property independent of the charge at the point.

-The electric potential decreases in the direction of the field, and increases in a direction opposite to the field.

-The electric potential has the same value at all points on any line parallel to the charged planes (perpendicular to the electric field lines)



-In a uniform electric $\Delta V = \frac{\Delta U}{q} = \frac{-qEd}{q} \Rightarrow \Delta V = -Ed$

Example:

An electron is accelerated from rest between two points, through a potential difference of 20 V, in a uniform electric field 5000 V/m .

Solution:

1-Calculate the change in kinetic energy of the electron between these two points .

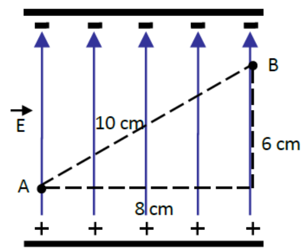
$$\Delta k = -\Delta U = -q\Delta V \quad \Rightarrow \quad \Delta k = -1.6\times10^{-19}(-20) = 3.2\times10^{-18}\,J$$

2-Find the distance after which the electron gains this kinetic energy.

$$\Delta V = -Ed \quad \Rightarrow \quad -20 = -5000d \quad \Rightarrow \quad d = 0.004m$$

3-Find the speed of the electron at the end of this distance.

$$\Delta k = \frac{1}{2}mv^2 \quad \Rightarrow \quad v = \sqrt{\frac{2\Delta k}{m}} \quad \Rightarrow \quad v = \sqrt{\frac{2\times3.2\times10^{-18}}{9.11\times10^{-31}}} \quad \Rightarrow \quad v = 2.65\times10^{6}\,m/s$$



Example: In the figure A, and B, are two pointe in a uniform electric field 4×10^4 V/m . Using information on the figure, calculate:

1-Calculate the change in electric potential from A to B.

Solution: $\Delta V = -E\,d \Rightarrow \Delta V_{A\to B} = -4\times10^4 \times 0.06 = -2400$ v

2- Calculate the change in electric potential from B to A.

Solution: $\Delta V = -E\,d \Rightarrow \Delta V_{B\to A} = -4\times10^4 \times (-0.06) = +2400$ v

3- Calculate the change in electric potential energy of a proton when transferred from A to B.

Solution: $\Delta P.E_{A\to B} = q\,\Delta V \Rightarrow \Delta P.E_{A\to B} = 1.6\times10^{-19} \times (-2400) = -3.84\times10^{-16}$ j

4- Calculate the change in electric potential energy of a proton when transferred from B to A.

Solution: $\Delta P.E_{B\to A} = q\,\Delta V \Rightarrow \Delta P.E_{B\to A} = 1.6\times10^{-19} \times (+2400) = +3.84\times10^{-16}$ j

Enrichment

Batteries:

"A battery is basically a device that converts chemical energy directly into electrical energy."

The weight of the batteries needs to be as small as possible.
They need to be rapidly rechargeable for hundreds of cycles.
They need to deliver as constant a potential difference as possible.
They need to be available at an affordable price.

Lithium ion batteries:

	Advantages	Disadvantages
1	Has a much higher energy density, than conventional batteries	If a lithium ion battery is completely discharged, it can no longer be recharged.
2	They can be recharged hundreds of times.	Rising temperature decreases the efficiency of a lithium ion battery.
3	They have no "memory" effect and thus, do not need to be conditioned to hold their charge.	If the batteries are discharged too quickly, the constituents can catch fire or explode.

Other unit of electric field:

$$[E] = \frac{[F]}{[q]} = \frac{1\,\text{N}}{1\,\text{C}} = \left(\frac{1\,\text{N}}{1\,\text{C}}\right)\frac{1\,\text{V}}{\left(\frac{1\,\text{J}}{1\,\text{C}}\right)}\left(\frac{1\,\text{J}}{(1\,\text{N})(1\,\text{m})}\right) = \frac{1\,\text{V}}{1\,\text{m}}$$

Concept Check 23.1

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.

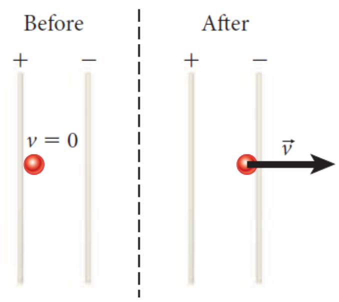
Example 3.1 Energy Gain of a Proton

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.

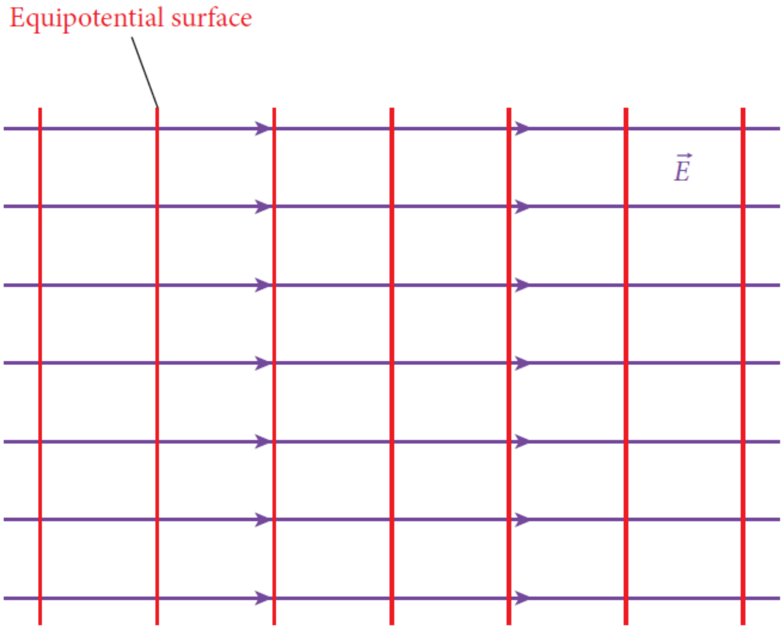
What is the kinetic energy of the proton when it reaches the negative plate?

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

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



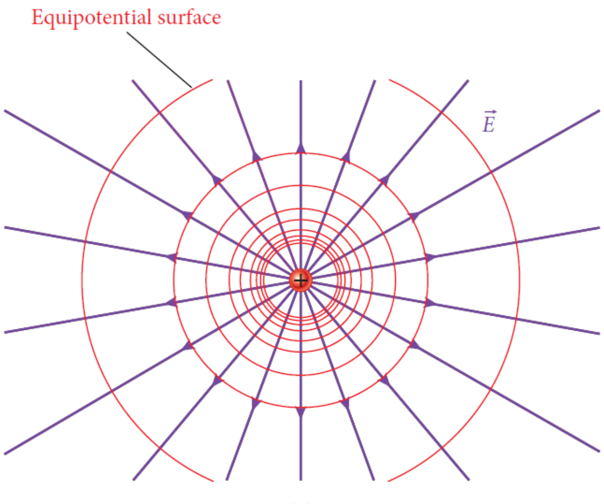
3.3 Equipotential Surfaces and Lines

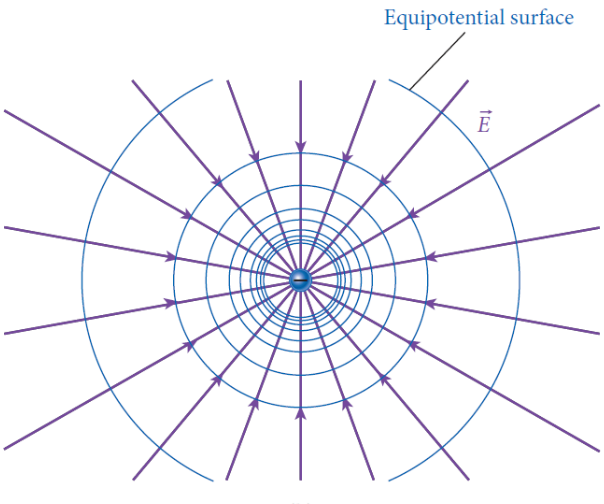


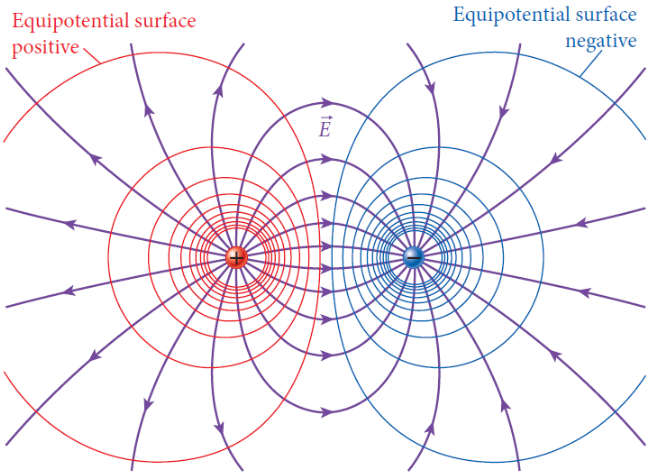
Equipotential surfaces (red lines) from a constant electric field.
The purple lines with the arrowheads represent the electric field.

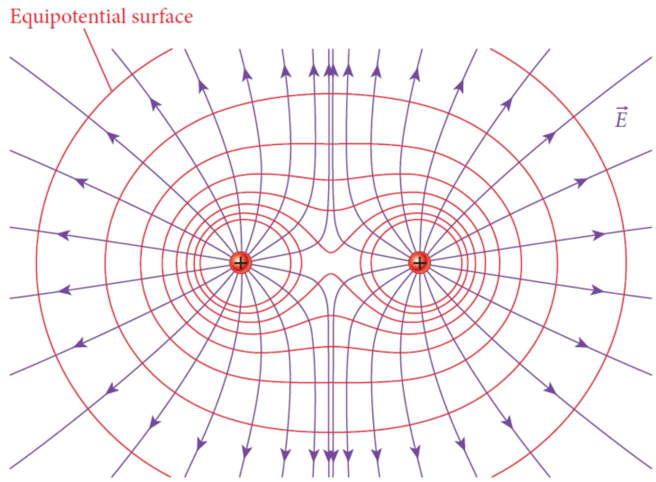
Notes

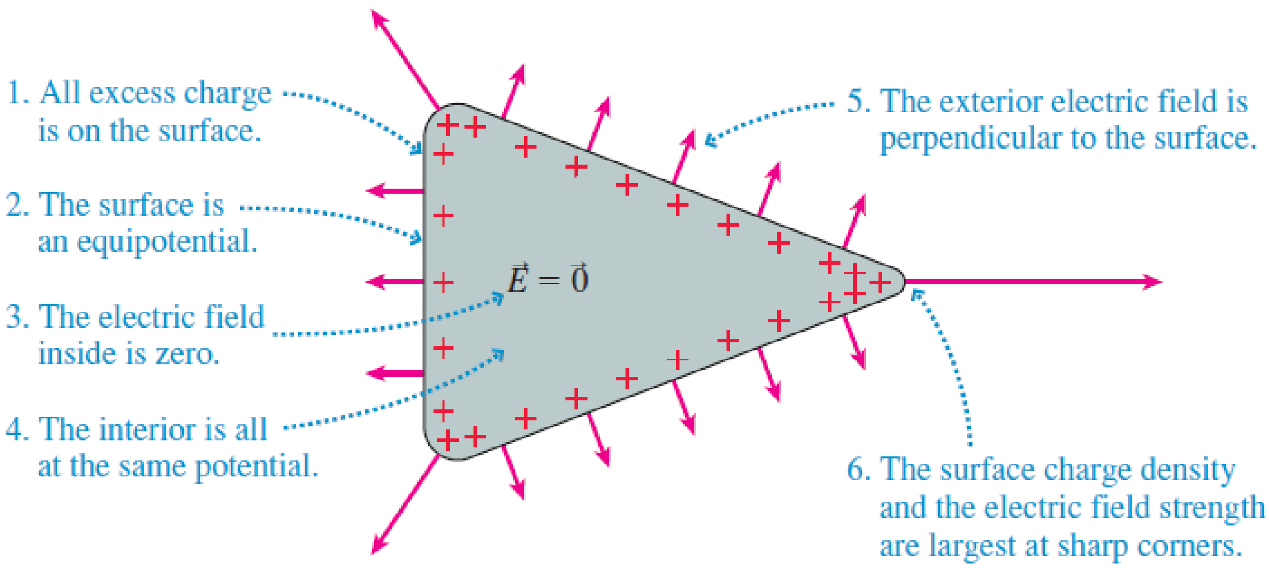
1. The surface of any conductor forms an equipotential surface.
2. Equipotential surfaces are always perpendicular to the electric field lines at any point in space.



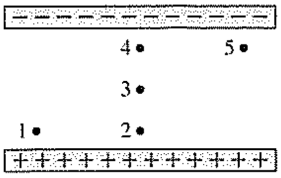



Equipotential surface
positive
Equipotential surface
negative
$\vec{E}$


Equipotential surface
$\vec{E}$


1. All excess charge is on the surface.
2. The surface is an equipotential.
3. The electric field inside is zero.
4. The interior is all at the same potential.
$\vec{E} = \vec{0}$
5. The exterior electric field is perpendicular to the surface.
6. The surface charge density and the electric field strength are largest at sharp corners.

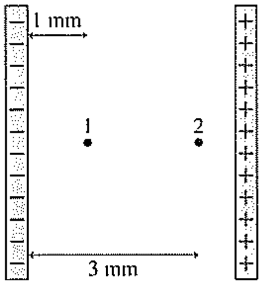
11. Rank in order, from largest to smallest, the electric potentials V_1 to V_5 at points 1 to 5.



Order:

Explanation:

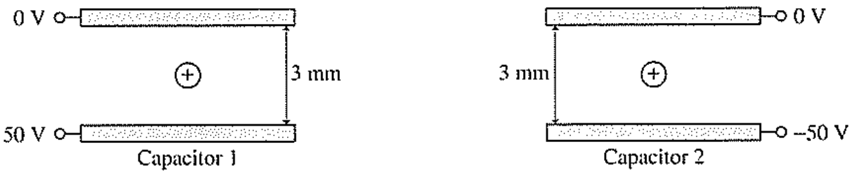
12. The figure shows two points inside a capacitor. Let $V = 0$ V at the negative plate.



a. What is the ratio V_2/V_1 of the electric potentials at these two points? Explain.

b. What is the ratio E_2/E_1 of the electric field strengths at these two points? Explain.

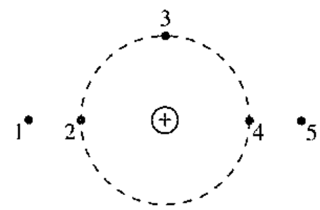
13. The figure shows two capacitors, each with a 3 mm separation. A proton is released from rest in the center of each capacitor.



a. Draw an arrow on each proton to show the direction it moves.

b. Which proton reaches a capacitor plate first? Or are they simultaneous? Explain.

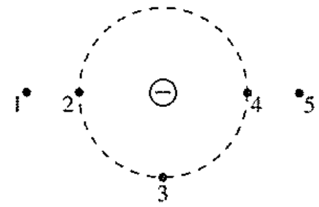
Rank in order, from largest to smallest, the electric potentials V_1 to V_5 at points 1 to 5.



Order:

Explanation:

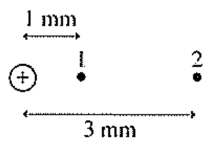
Rank in order, from least negative to most negative, the electric potentials V_1 to V_5 at points 1 to 5.



Order:

Explanation:

The figure shows two points near a positive point charge.



a. What is the ratio V_1/V_2 of the electric potentials at these two points? Explain.

b. What is the ratio E_1/E_2 of the electric field strengths at these two points? Explain.

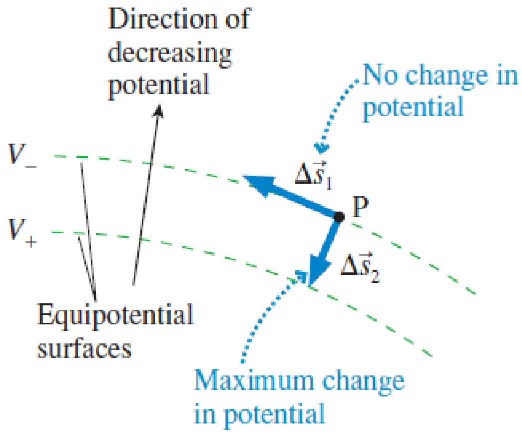
3.4 Electric Potential of Various Charge Distributions

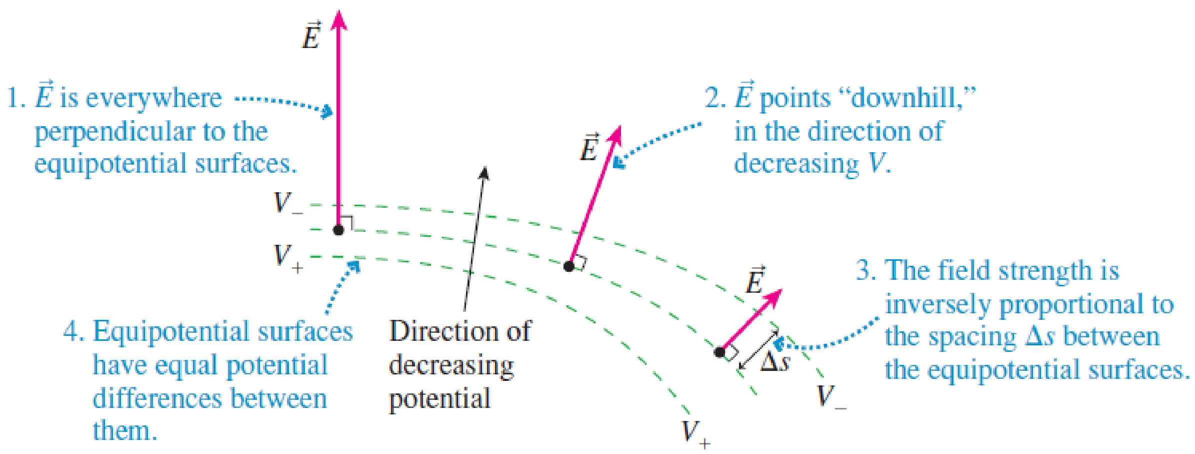
- to relate the work done to the change in electric potential

$$\Delta V = V_f - V_i = -\frac{W_e}{q} = -\int_i^f \vec{E}\bullet d\vec{s}$$

- the usual convention is to set the electric potential to zero at infinity. With this convention, we can express the potential at some point r in space as

$$V(\vec{r}) - V(\infty) \equiv V(\vec{r}) = -\int_\infty^{\vec{r}} \vec{E}\bullet d\vec{s}.$$





Concept Check 23.3

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?

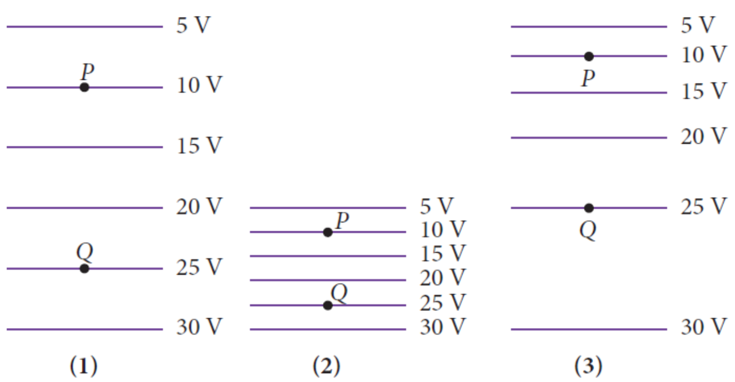
a) All three cases involve the same work.

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.

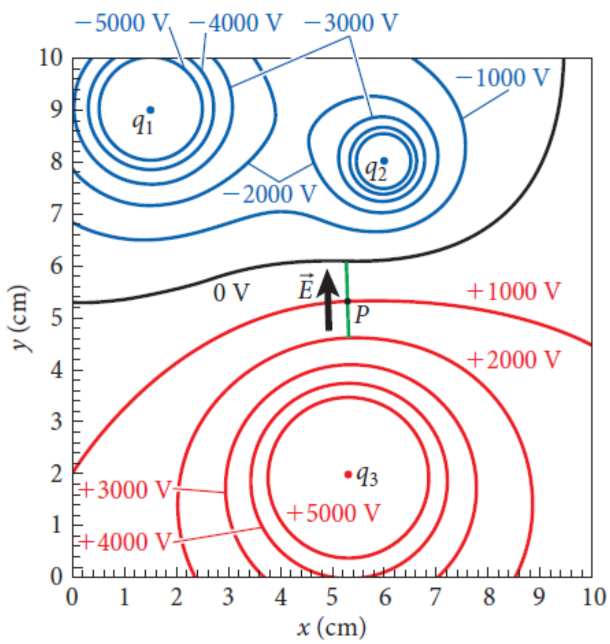
e) Cases 1 and 3 involve the same amount of work, which is more than is involved in case 2.



Point Charge

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

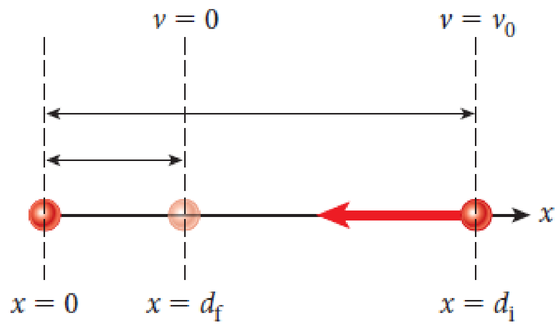
$$\boxed{V = \frac{kq}{r}}$$



- q_1 and q_2 are negative charges. why?
- q_3 is positive. why?
- The black line has voltage = zero

Fixed and Moving Positive Charges

$$\Delta K + \Delta U = 0 \Rightarrow \Delta K = -\Delta U \Rightarrow$$
$$0 - \tfrac{1}{2}mv_0^2 = -q_{\text{moving}}\Delta V \Rightarrow$$
$$\tfrac{1}{2}mv_0^2 = q_{\text{moving}}\Delta V.$$

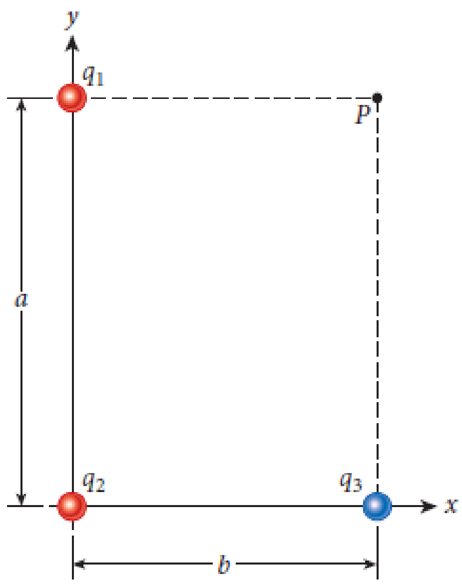


$$\Delta V = V_f - V_i = k\frac{q_{\text{fixed}}}{d_f} - k\frac{q_{\text{fixed}}}{d_i} = kq_{\text{fixed}}\left(\frac{1}{d_f} - \frac{1}{d_i}\right)$$

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

System of Point Charges

$$V = \sum_{i=1}^{3}\frac{kq_i}{r_i} = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3}\right) = k\left(\frac{q_1}{b} + \frac{q_2}{\sqrt{a^2+b^2}} + \frac{q_3}{a}\right)$$



3.5 Finding the Electric Field from the Electric Potential

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

Concept Check 23.7

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

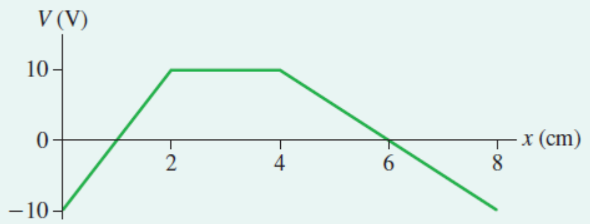
c) $\vec{E} = 5x\hat{x} + 2\hat{y}$

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

e) $\vec{E} = 0$

FIGURE 29.11 is a graph of the electric potential in a region of space where $\vec{E}$ is parallel to the x-axis. Draw a graph of E_x versus x.

FIGURE 29.11 Graph of V versus position x.



MODEL The electric field is the *negative* of the slope of the potential graph.

SOLVE There are three regions of different slope:

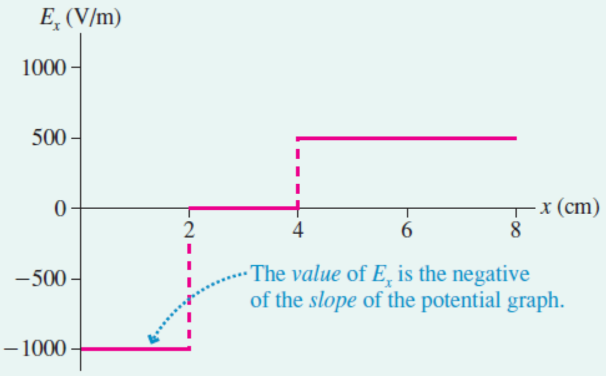
$$0 < x < 2 \text{ cm} \quad \begin{cases} \Delta V/\Delta x = (20 \text{ V})/(0.020 \text{ m}) = 1000 \text{ V/m} \\ E_x = -1000 \text{ V/m} \end{cases}$$

$$2 < x < 4 \text{ cm} \quad \begin{cases} \Delta V/\Delta x = 0 \text{ V/m} \\ E_x = 0 \text{ V/m} \end{cases}$$

$$4 < x < 8 \text{ cm} \quad \begin{cases} \Delta V/\Delta x = (-20 \text{ V})/(0.040 \text{ m}) = -500 \text{ V/m} \\ E_x = 500 \text{ V/m} \end{cases}$$

The results are shown in FIGURE 29.12.

FIGURE 29.12 Graph of E_x versus position x.



ASSESS The electric field $\vec{E}$ points to the left (E_x is negative) for $0 < x < 2$ cm and to the right (E_x is positive) for $4 < x < 8$ cm. Notice that **the electric field is zero in a region of space where the potential is not changing.**

Concept Check 23.8

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?

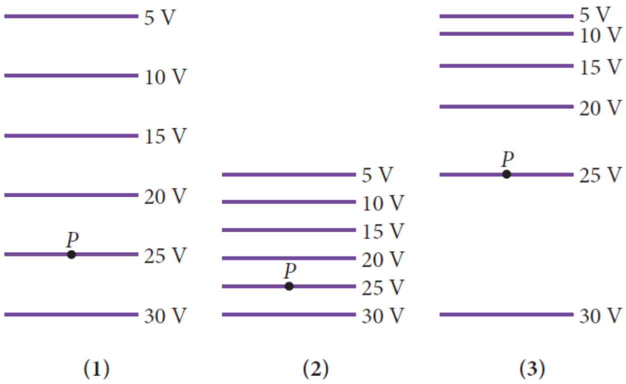
a) $E_1 = E_2 = E_3$

b) $E_1 > E_2 > E_3$

c) $E_1 < E_2 < E_3$

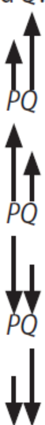
d) $E_3 > E_1 > E_2$

e) $E_3 < E_1 < E_2$



Concept Check 23.9

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*?



a) *PQ*

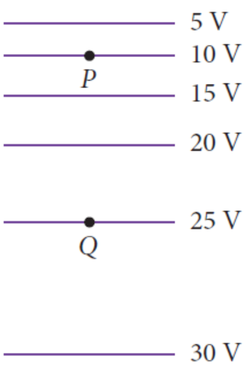
b) *PQ*

c) *PQ*

d) *PQ*

00

e) *PQ*



Concept Check 23.10

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

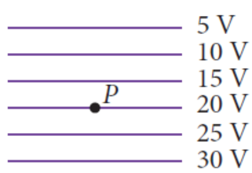
a) up

b) down

c) left

d) right

e) The electric field at *P* is zero.



Concept Check 23.11

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.

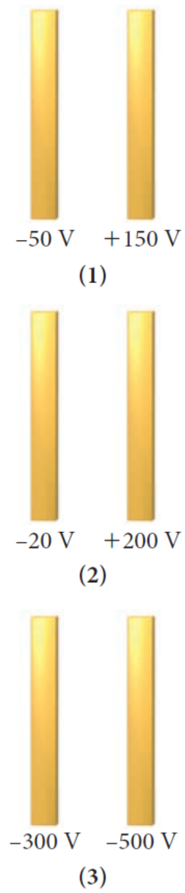
a) 1 > 2 > 3

b) 3 > 2 > 1

c) The magnitudes for 3 and 2 are equal and greater than the magnitude for 1.

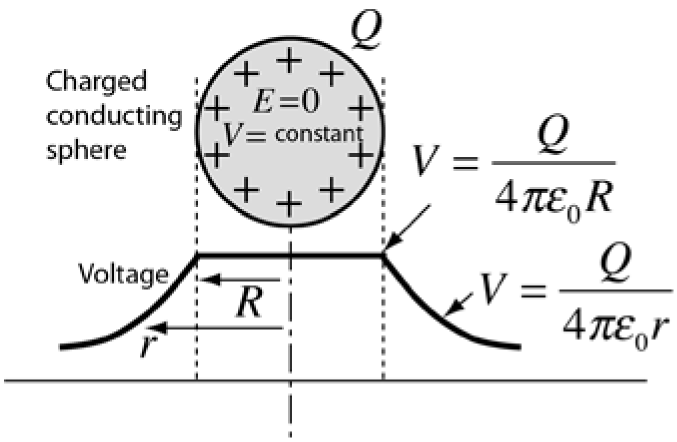
d) The three magnitudes are equal.

e) The magnitude for 2 is greater than that for 1 and 3, which are the same.

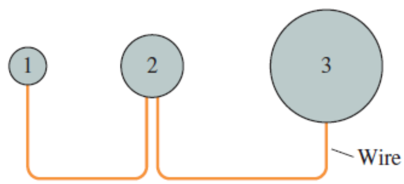


Potential of a Conductor

Since the electric field is equal to the rate of change of potential, this implies that the voltage inside a conductor at equilibrium is constrained to be constant at the value it reaches at the surface of the conductor.

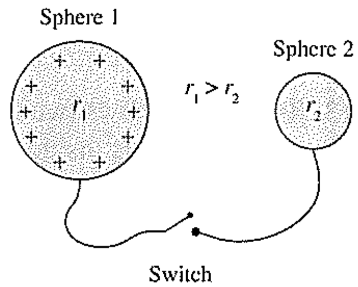


Three charged metal spheres of different radii are connected by a thin metal wire. The potential and electric field at the surface of each sphere are V and E. Which of the following is true?



a. $V_1 = V_2 = V_3$ and $E_1 = E_2 = E_3$
b. $V_1 = V_2 = V_3$ and $E_1 > E_2 > E_3$
c. $V_1 > V_2 > V_3$ and $E_1 = E_2 = E_3$
d. $V_1 > V_2 > V_3$ and $E_1 > E_2 > E_3$
e. $V_3 > V_2 > V_1$ and $E_3 = E_2 = E_1$
f. $V_3 > V_2 > V_1$ and $E_3 > E_2 > E_1$

Two metal spheres are connected by a metal wire that has a switch in the middle. Initially the switch is open. Sphere 1, with the larger radius, is given a positive charge. Sphere 2, with the smaller radius, is neutral. Then the switch is closed. Afterward, sphere 1 has charge Q_1, is at potential V_1, and the electric field strength at its surface is E_1. The values for sphere 2 are Q_2, V_2, and E_2.

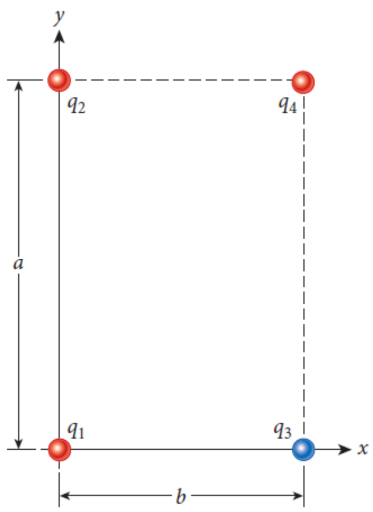


a. Is V_1 larger than, smaller than, or equal to V_2? Explain.

b. Is Q_1 larger than, smaller than, or equal to Q_2? Explain.

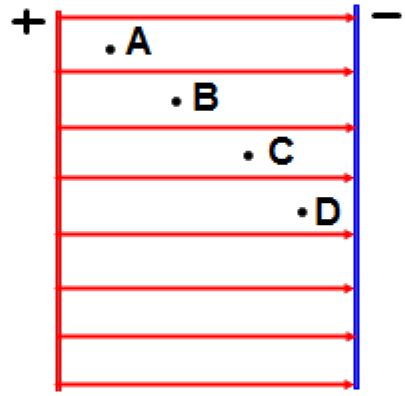
c. Is E_1 larger than, smaller than, or equal to E_2? Explain.

23.6 Electric Potential Energy of a System of Point Charges



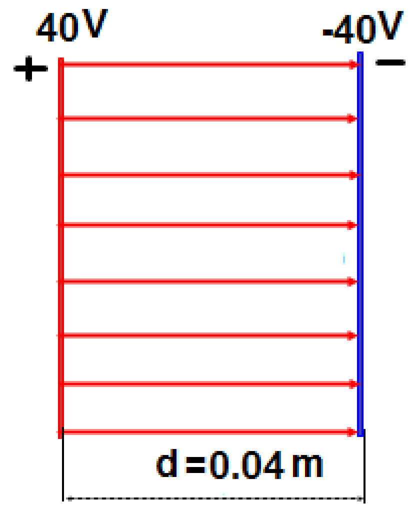
$$U = \frac{kq_1q_2}{a} + \frac{kq_1q_3}{b} + \frac{kq_2q_3}{\sqrt{a^2+b^2}} + \frac{kq_1q_4}{\sqrt{a^2+b^2}} + \frac{kq_2q_4}{b} + \frac{kq_3q_4}{a}$$

1. An electric field is created by two parallel plates. At which of the following points is the electric field the strongest?
   A. A B. B C.C D.D
   E. The electric field is the same at all points

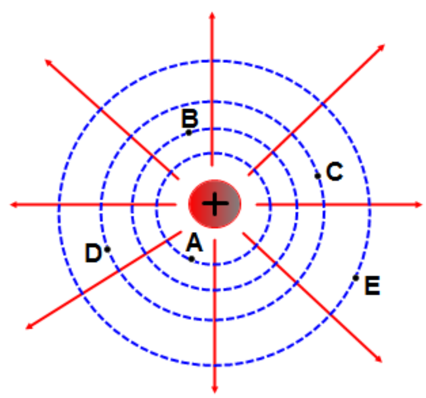


2. An electric field is created by two parallel plates. Which of the following points corresponds to the higher electric potential?
   A. A B. B C.C D.D
   E. The electric potential is the same at all points

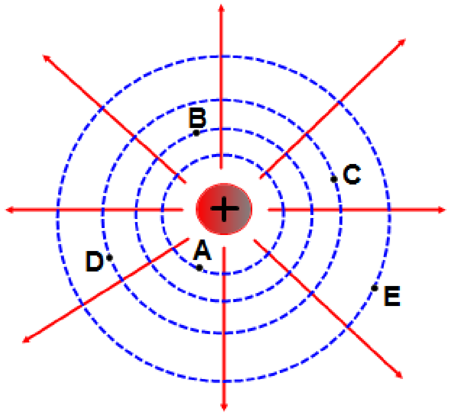
3. A uniform electric field is created by two parallel plates separated by a distance of 0.04 m. What is the magnitude of the electric field established between the plates?
   A. 20 V/m
   B. 200 V/m
   C. 2,000 V/m
   D. 20,000 V/m
   E. 0 V/m



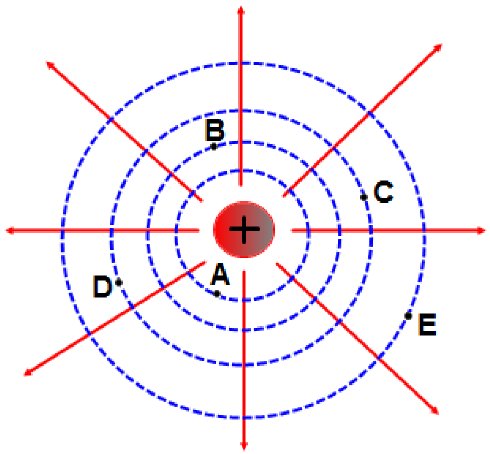
4. An electric field due to a positive charge is represented by the diagram. Which of the following points has higher potential?
   A. A
   B. B
   C. C
   D. D
   E. E

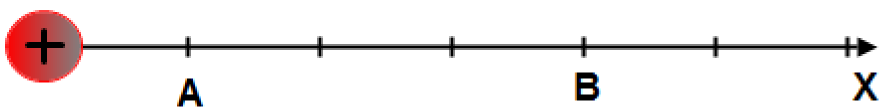


5. An electric field due to a positive charge is represented by the diagram. At which of the following points is the electric field strongest in magnitude?
   A. A
   B. B
   C. C
   D. D
   E. E

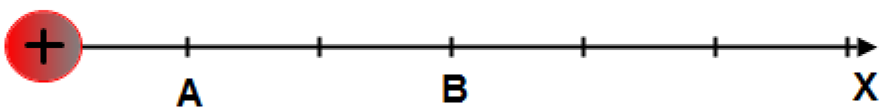


6. An electric field due to a positive charge is represented by the diagram. Between which of the following two points does the electric field do zero work on a moving charge?
   A. A and B
   B. B and C
   C. C and D
   D. D and E
   E. E and A



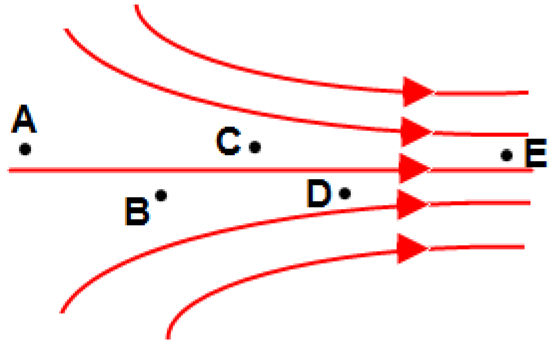


7. In the above diagram, the electric potential at point A is V. What is the electric potential at point B in terms of V?
   A. 2 V B. 4 V C. V D. $\frac{1}{2}$ V E. $\frac{1}{4}$ V

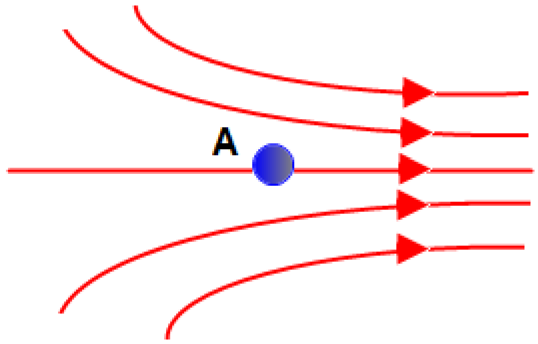


8. In the above diagram, the magnitude of the electric field at point A is E. What is the electric field at point B in terms of E?
   A. 3 E B. 9 E C. E D. $\frac{1}{9}$ E E. $\frac{1}{3}$ E

9. A non-uniform electric field is represented by the diagram. At which of the following points is the electric field greatest in magnitude?
   A. A B. B C.C
   D.D E.E



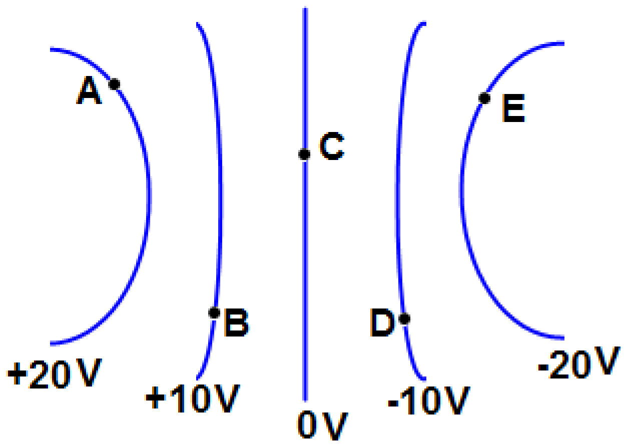
10. A small conducting sphere is placed in a region of a non-uniform electric field. What is the direction of the electric force on the sphere applied by the field?



A.  B.  C. 

D.  E. 

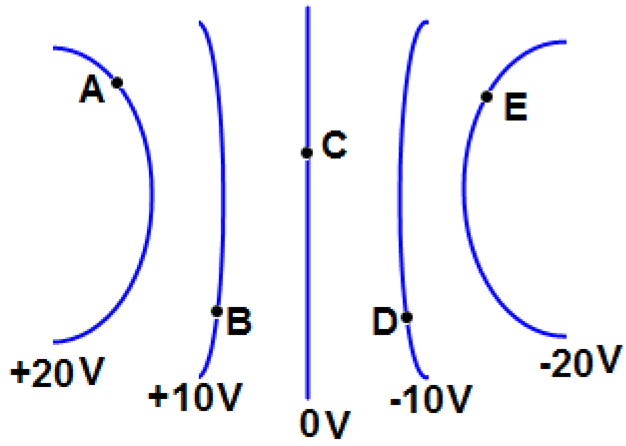
11. A non-uniform electric field is represented by equipotential lines. What is the direction of the electric field at point A?



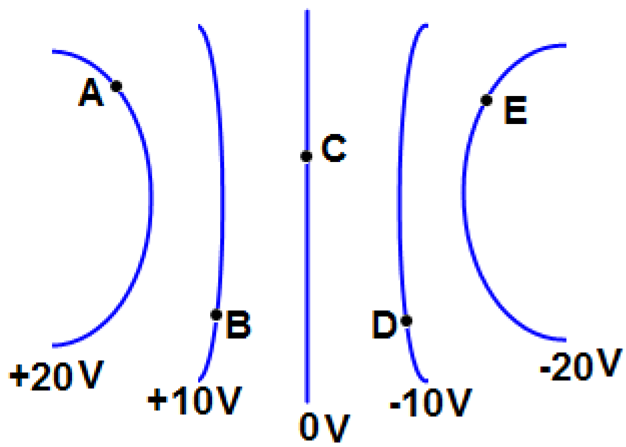
A.  B.  C. 

D.  E. 

12. A non-uniform electric field is represented by equipotential lines. How much work is done by the electric field when a positive charge of magnitude 1 μC moves from point A to point E?
A. 0 μJ B. 20 μJ C. 40 μJ D. 60 μJ
E. 80 μJ



13. A non-uniform electric field is represented by equipotential lines. A positive charge with a magnitude of 1 μC moves in the following path: A→B→C→D→E→A. How much work is done by the electric field?
A. 0 μJ B. 20 μJ C. 40 μJ D. 60 μJ
E. 80 μJ



1. E
2. A
3. C
4. A
5. A
6. C
7. E
8. D
9. E
10. A
11. E
12. C
13. A