Electrostatic Potential and Capacitance JEE Main PYQ - 2

Total Time: 50 Minute **Total Marks:** 80

Instructions

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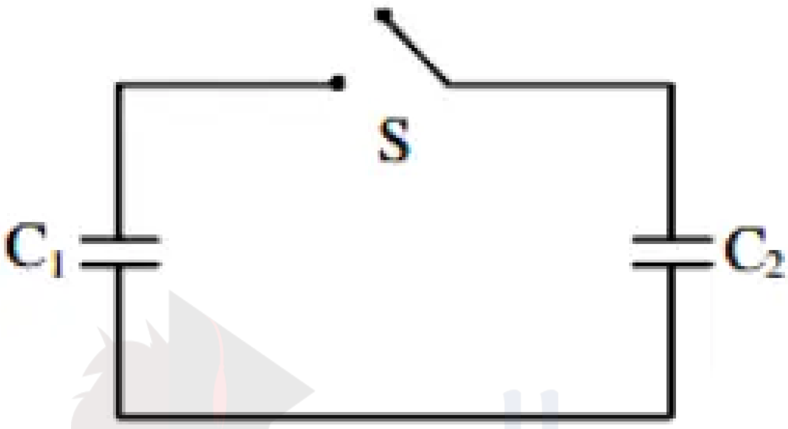
1. Test will auto submit when the Time is up.
2. The Test comprises of multiple choice questions (MCQ) with one or more correct answers.
3. The clock in the top right corner will display the remaining time available for you to complete the examination.

Navigating & Answering a Question

1. The answer will be saved automatically upon clicking on an option amongst the given choices of answer.
2. To deselect your chosen answer, click on the clear response button.
3. The marking scheme will be displayed for each question on the top right corner of the test window.

Electrostatic Potential and Capacitance

1. Two capacitors having capacitance C_1 and C_2 respectively are connected as shown in figure. Initially, capacitor C_1 is charged to a potential difference V volt by a battery. The battery is then removed and the charged capacitor C_1 is now connected to uncharged capacitor C_2 by closing the switch S. The amount of charge on the capacitor C_2, after equilibrium, is **(+4, -1)**



a. $\frac{C_1 C_2}{C_1+C_2} V$

b. $\frac{C_1+C_2}{C_1 C_2} V$

c. $(C_1 + C_2)V$

d. $(C_1 - C_2)V$

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2. An electric charge $10^{-6}\,\mu C$ is placed at the origin (0, 0) of an X-Y coordinate system. Two points P and Q are situated at $(\sqrt{3}, \sqrt{3})\,\mathrm{mm}$ and $(\sqrt{6}, 0)\,\mathrm{mm}$ respectively. The potential difference between the points P and Q will be: **(+4, -1)**

a. 0 V

b. $\sqrt{6}$ V

c. $\sqrt{3}$ V

d. 3 V

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3. A capacitor of capacitance $50pF$ is charged by $100V$ source. It is then connected to another uncharged identical capacitor. Electrostatic energy loss in the process is _____ nJ. (+4, -1)

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4. A slab of dielectric constant K has the same cross-sectional area as the plates of a parallel plate capacitor and thickness (3/4)d, where d is the separation of the plates. The capacitance of the capacitor when the slab is inserted between the plates will be: (+4, -1)
(Given C_0 = capacitance of capacitor with air as medium between plates.)

a. $\frac{4KC_0}{3+K}$

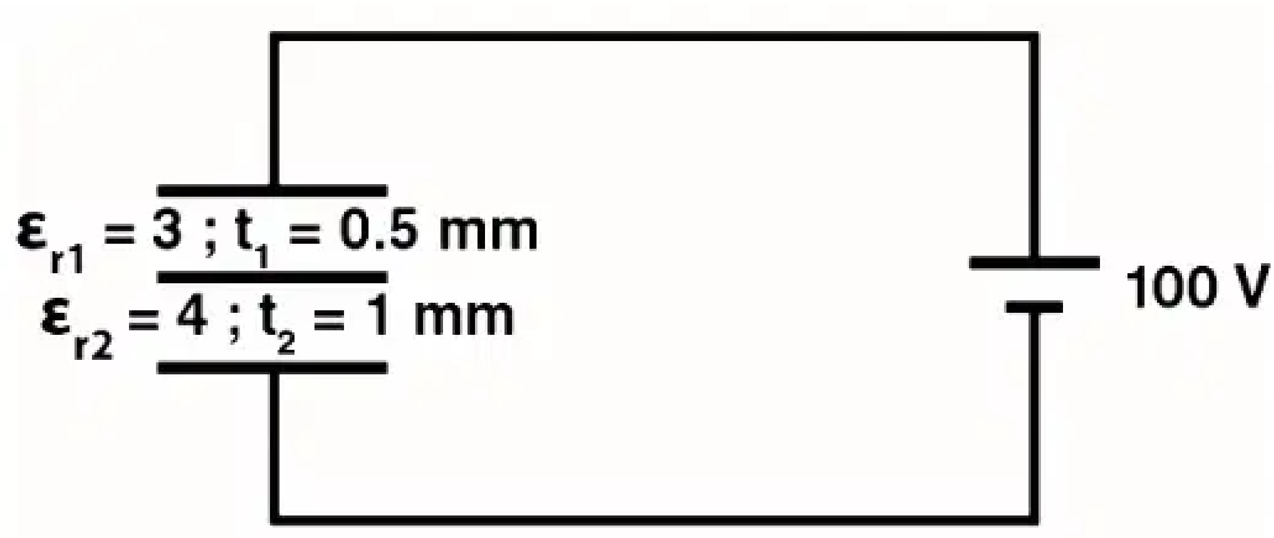
b. $\frac{3KC_0}{3+K}$

c. $\frac{3+K}{4KC_0}$

d. $\frac{K}{4+K}$

---

5. A composite parallel plate capacitor is made up of two different dielectric materials with different thickness (t_1 and t_2) as shown in figure. The two different dielectric materials are separated by a conducting foil F. The voltage of the conducting foil is _____V. (+4, -1)



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6. The total charge on the system of capacitors C_1 = 1 μF, C_2 = 2 μF, C_3 = 4 μF and C_4 = 3 μF, connected in parallel is : (+4, -1)

(Assume a battery of 20 V is connected to the combination)

a. $200\ \mu C$

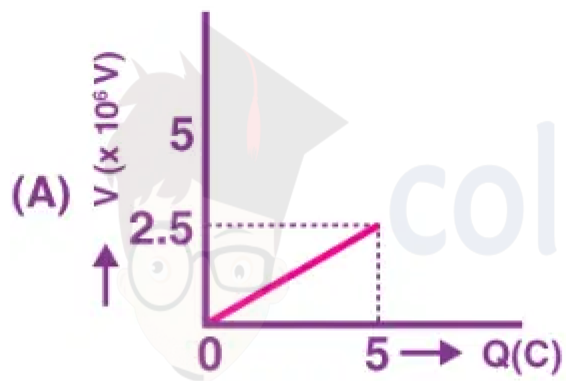
b. $200\ C$

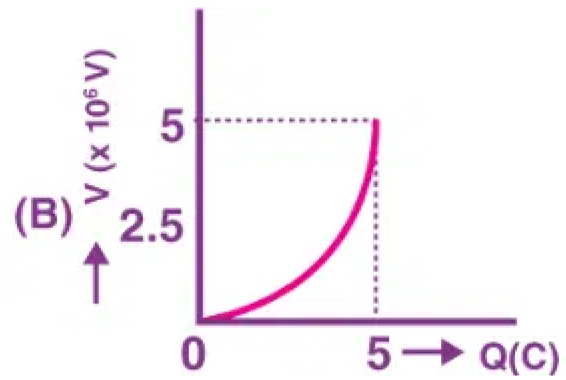
c. $10\ \mu C$

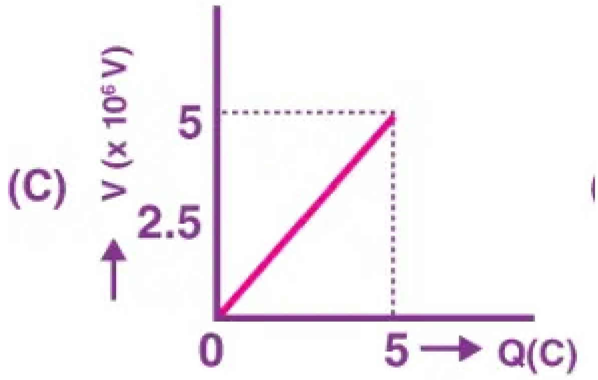
d. $10\ C$

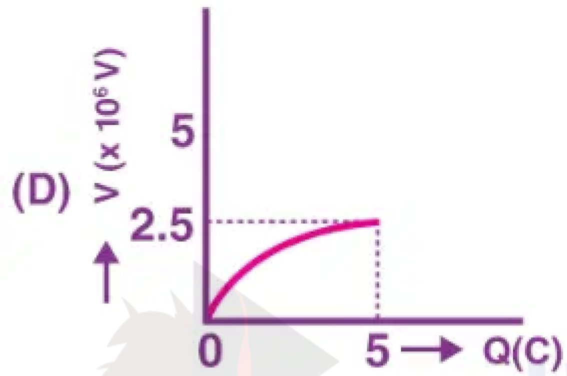
---

7. A condenser of 2μF capacitance is charged steadily from 0 to 5 C.Which of the following graph represents correctly the variation of potential difference (V) across it's plates with respect to the charge (Q) on the condenser? **(+4, -1)**

a. 

b. 

c. 

d. 

8. The total charge on the system of capacitance $C_1 = 1\,\mu F, C_2 = 2\,\mu F, C_3 = 4\,\mu F$ and $C_4 = 3\,\mu F$ connected in parallel is (Assume a battery of $20\,V$ is connected to the combination) **(+4, -1)**

a. $200\,\mu C$

b. $200\,C$

c. $10\,\mu C$

d. $10\,C$

9. In a series LR circuit $X_L = R$ and power factor of the circuit is P_1 When capacitor with capacitance C such that $X_L = X_C$ is put in series, the power factor becomes P_2 The ratio $\frac{P_1}{P_2}$ is **(+4, -1)**

a. $\frac{1}{2}$

b. $\frac{1}{\sqrt{2}}$

c. $\frac{\sqrt{3}}{\sqrt{2}}$

d. $2:1$

---

10. A wire of resistance R_1 is drawn out so that its length is increased by twice of its original length The ratio of new resistance to original resistance is: **(+4, -1)**

a. $9:1$

b. $1:9$

c. $4:1$

d. $3:1$

---

11. Two capacitors, each having capacitance $40\mu F$ are connected in series The space between one of the capacitors is filled with dielectric material of dielectric constant K such that the equivalence capacitance of the system became $24\mu F$ The value of K will be : **(+4, -1)**

a. 1.5

b. 2.5

c. 1.2

d. 3

---

12. Potential at the surface of a uniformly charged non-conducting sphere is V. Then the potential at its centre is **(+4, -1)**

a. 0

b. $\frac{V}{2}$

c. $2V$

d. $\frac{3V}{2}$

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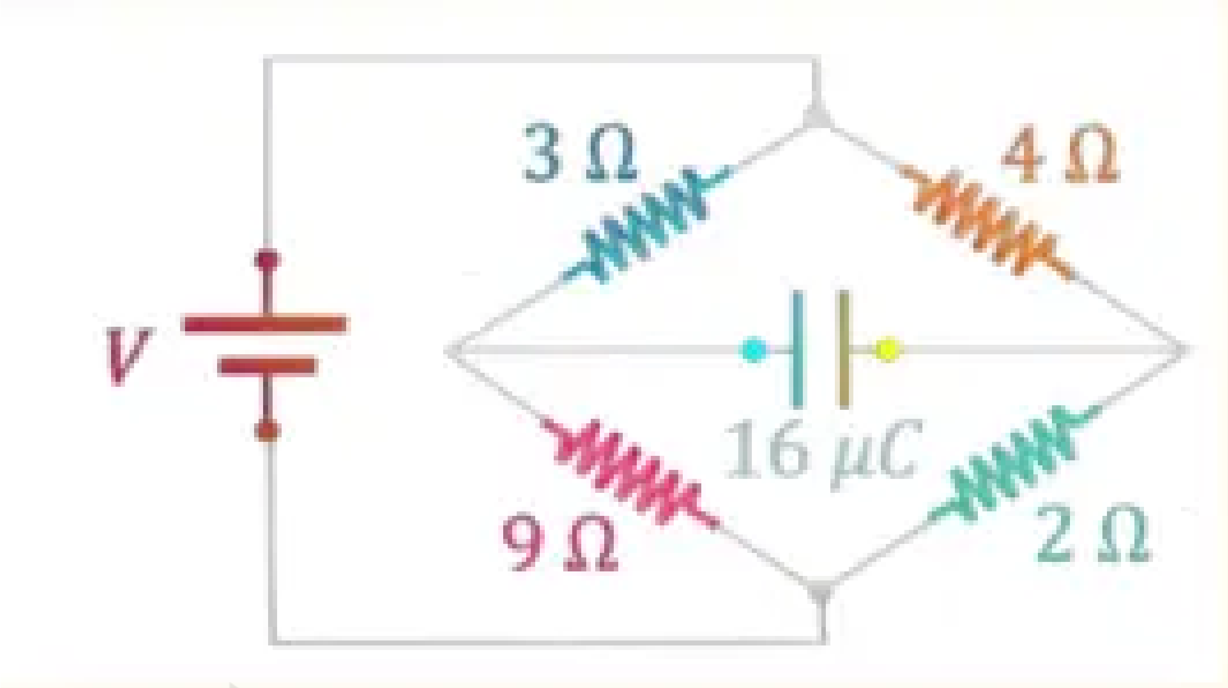
13. Find the energy stored in the capacitor in a given circuit. **(+4, -1)**



a. 0.2 mJ

b. 0.4 mJ

c. 0.6 mJ

d. 0.8 mJ

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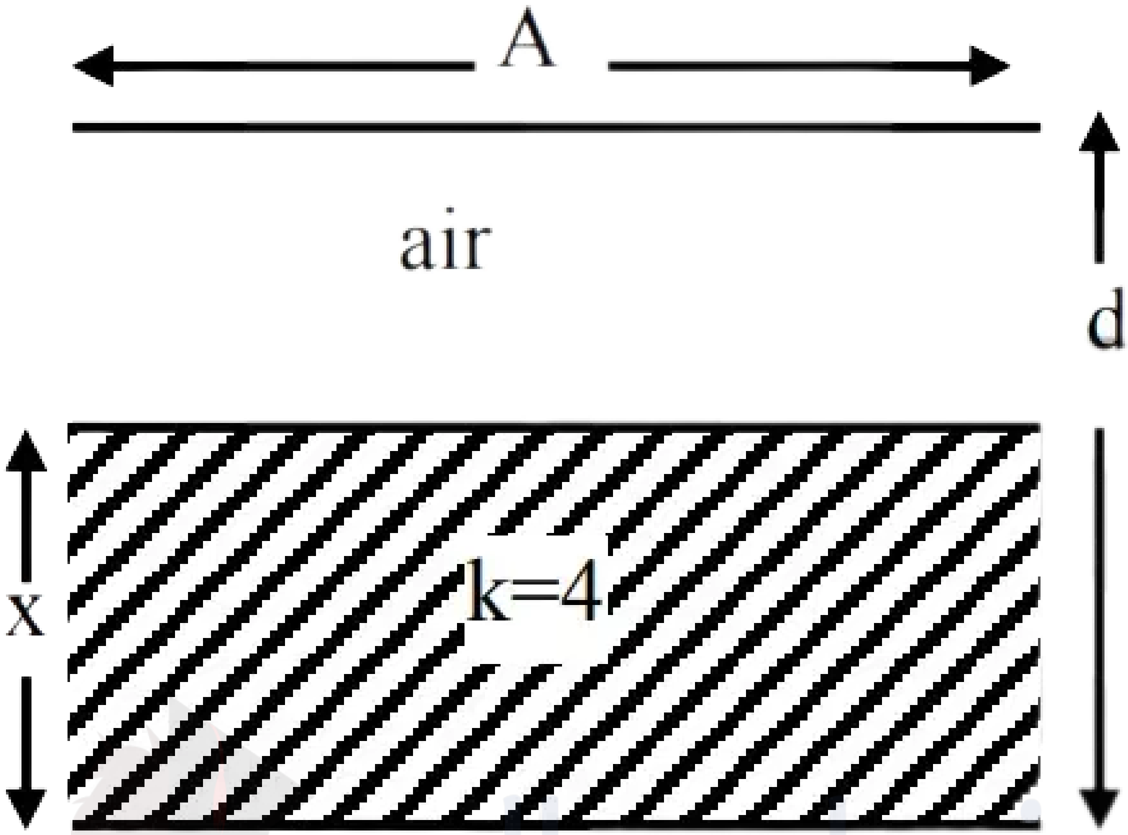
14. A parallel plate capacitor with plate area A and plate separation d is filled with a dielectric material of dielectric constant K = 4. The thickness of the dielectric material is x, where x < d. Let C1 and C2 be the capacitance of the system for $x = \frac{1}{3}d$ and $x = \frac{2}{3}d$, respectively. If C_1 = 2μF, the value of C_2 is _______ μF. **(+4, -1)**



15. A point charge of $10\,\mu C$ is placed at the origin At what location on the X-axis should a point charge of $40\,\mu C$ be placed so that the net electric field is zero at $x=2\,cm$ on the X-axis? **(+4, -1)**

a. $x=-4\,cm$

b. $x=4\,cm$

c. $x=8\,cm$

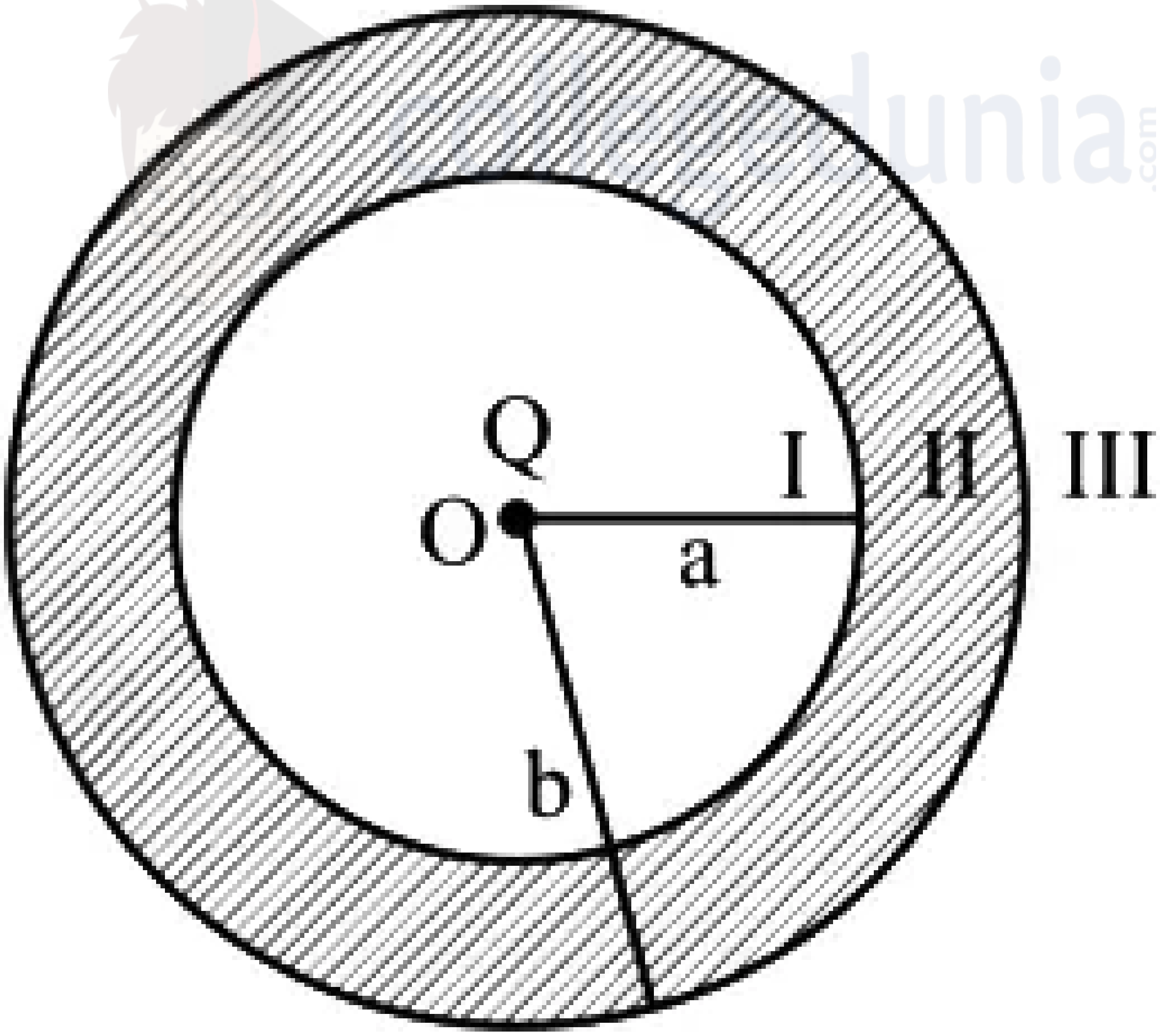
d. $x=6\,cm$

16. A parallel plate capacitor with air between the plate has a capacitance of $15\,pF$ The separation between the plate becomes twice and the space between them is filled with a medium of dielectric constant 3.5. Then the capacitance becomes $\frac{x}{4}pF$ The value of x is _______ **(+4, -1)**

17. A capacitor has capacitance $5\mu F$ when it's parallel plates are separated by air medium of thickness d A slab of material of dielectric constant 15 having area equal to that of plates but thickness $\frac{d}{2}$ is inserted between the plates Capacitance of the capacitor in the presence of slab will be ___μF **(+4, -1)**

18. A capacitor of capacitance $900\,\mu F$ is charged by a $100\,V$ battery The capacitor is disconnected from the battery and connected to another uncharged identical capacitor such that one plate of uncharged capacitor connected to positive plate and another plate of uncharged capacitor connected to negative plate of the charged capacitor The loss of energy in this process is measured as $x \times 10^{-2} J$ The value of x is ______ **(+4, -1)**

19. As shown in the figure, a point charge Q is placed at the centre of conducting spherical shell of inner radius a and outer radius b. The electric field due to charge Q in three different regions I, II and III is given by: (I: r $<$ a, II: $a < r < b$, III: $r > b$) **(+4, -1)**



a. $E_I = 0, E_{II} = 0, E_{III} = 0$

b. $E_I \neq 0, E_{II} = 0, E_{II} = 0$

c. $E_I = 0, E_{II} = 0, E_{III} \neq 0$

d. $E_I \neq 0, E_{II} = 0, E_{III} \neq 0$

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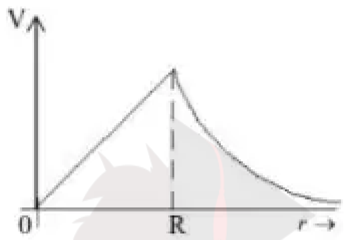
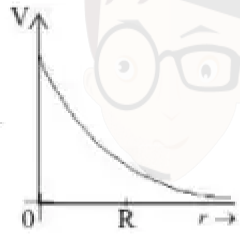
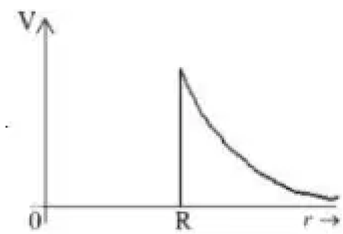
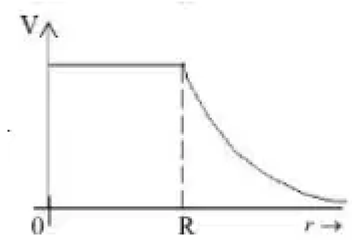
20. Which of the following correctly represents the variation of electric potential (V) of a charged spherical conductor of radius (R) with radial distance (r) from the center? (+4, -1)

a. 

b. 

c. 

d. 

Answers

1. **Answer: a**

Explanation:

$$V_{\text{common}} = \frac{C_1 V}{C_1 + C_2}$$
$$\Rightarrow \text{Charge on Capacitor} C_2$$
$$= C_2 V_{\text{common}}$$
$$= \frac{C_1 C_2 V}{C_1 + C_2}$$

So, the correct option is (A)

Concepts:

1. **Electrostatic Potential and Capacitance:**

Electrostatic Potential

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Some major things that we should know about electric potential:

- They are denoted by V and are a scalar quantity.
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Capacitance

The ability of a capacitor of holding the energy in form of an electric charge is defined as capacitance. Similarly, we can also say that capacitance is the storing ability of capacitors, and the unit in which they are measured is "farads".

Read More: Electrostatic Potential and Capacitance

The capacitor is in Series and in Parallel as defined below;

In Series

Both the Capacitors C_1 and C_2 can easily get connected in series. When the **capacitors are connected in series** then the total capacitance that is C_{total} is less than any one of the capacitor's capacitance.

In Parallel

Both Capacitor C_1 and C_2 are connected in parallel. When the capacitors are connected parallelly then the total capacitance that is C_{total} is any one of the capacitor's capacitance.

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2. Answer: a

Explanation:

To find the potential difference between points P and Q due to a charge placed at the origin, we use the formula for electric potential due to a point charge:

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

where V is the electric potential, $k \approx 8.99 \times 10^9 \, \text{Nm}^2/\text{C}^2$ is the Coulomb's constant, Q is the charge, and r is the distance from the charge.

1. Calculate the distance from the charge at the origin to point P $(\sqrt{3}, \sqrt{3}) \, \text{mm}$: $r_P = \sqrt{(\sqrt{3})^2 + (\sqrt{3})^2} = \sqrt{6} \, \text{mm} = \sqrt{6} \times 10^{-3} \, \text{m}$
2. Determine the distance from the charge to point Q $(\sqrt{6}, 0) \, \text{mm}$: $r_Q = \sqrt{(\sqrt{6})^2 + 0^2} = \sqrt{6} \, \text{mm} = \sqrt{6} \times 10^{-3} \, \text{m}$
3. Since both points P and Q are equidistant from the origin, the potentials at P and Q are the same: $V_P = \frac{k \cdot 10^{-6} \cdot 10^{-6}}{\sqrt{6} \times 10^{-3}} = V_Q$
4. Thus, the potential difference between the two points P and Q is: $\Delta V = V_P - V_Q = 0 \, \text{V}$

The correct answer is **0 V**. The potential at two equidistant points from the same charge is equal, leading to a potential difference of zero.

Concepts:

1. Electrostatic Potential:

The electrostatic potential is also known as the electric field potential, electric potential, or potential drop is defined as **"The amount of work that is done in order to move a unit charge from a reference point to a specific point inside the field without producing an acceleration."**

SI Unit of Electrostatic Potential:

SI unit of electrostatic potential - volt

Other units - statvolt

Symbol of electrostatic potential - V or φ

Dimensional formula - $ML^2T^3I^{-1}$

Electric Potential Formula:

The electric potential energy of the system is given by the following formula:

U = 1/(4πε°) × [q1q2/d]

Where q1 and q2 are the two charges that are separated by the distance d.

---

3. **Answer: 125 - 125**

Explanation:

Loss in electrostatic energy

$= \frac{1}{2}(\frac{1}{2}CV^2)$

$= \frac{1}{2} \times \frac{1}{2} \times 50 \times 10^{-12} \times (100)^2$

$= \frac{500}{4} \ nJ$

$= 125 \ nJ$

So, the answer is $125 \ nJ$.

Concepts:

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---

4. Answer: a

Explanation:

$$x + y + \frac{3d}{4} = dx + y = \frac{d}{4}$$
$$\frac{A\in_0}{d} = C_0$$
$$\Delta V = Ex + \frac{E}{K} \times \frac{3d}{4} + Ey = \frac{3Ed}{4K} + E(x + y)$$
$$\Delta V = E[\frac{3d}{4K} + \frac{d}{4}]$$
$$\Delta V = \frac{\sigma}{\in_0}[\frac{3d + dK}{4K}] = \frac{Qd}{A\in_0}[\frac{3 + K}{4K}]$$

$$\frac{Q}{\Delta V} = C = \frac{A\epsilon_0}{d}\left[\frac{4K}{K+3}\right]$$
$$C = \frac{C_0 4K}{3+K}$$
$$\therefore C = \frac{4KC_0}{3+K}$$

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5. **Answer: 60 - 60**

Explanation:

$$\frac{C_1}{C_2} = 3 \times \frac{t_2}{t_1} \times 4 = \frac{3}{2}$$
$$\frac{q}{C_1} = v_1$$
$$\frac{q}{C_2} = v_2$$
$$\frac{v_1}{v_2} = \frac{C_2}{C_1} = \frac{2}{3}$$

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6. **Answer: a**

Explanation:

Equivalent capacitance C is:
$C \ = \Sigma C_i$
$C = 1\ \mu F + 2\ \mu F + 4\ \mu F + 3\ \mu F$
$C = 10\ \mu F$
Charge, $Q \ = \ CV$
$Q = \ 10\ \mu F \times 20\ V$
$Q = 200\ \mu C$

So, the correct option is (A): $200\ \mu C$.

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7. **Answer: a**

Explanation:

Q=CV
$V=\frac{1}{C}\times Q$
A straight line with slope=$\frac{1}{C}$
Slope=$\frac{1}{C}=\frac{1}{C}\times 10^{-6}$
$=5\times 10^{5}$
So, the correct graph will be A

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---

8. **Answer: a**

Explanation:

The correct option is(A): 200 μC.

Concepts:

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9. **Answer: b**

Explanation:

The correct option is(B): $\frac{1}{\sqrt{2}}$.

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10. Answer: a

Explanation:

From the given options the correct answer is option (A): 9:1

$R_1 = \rho \frac{L_1}{A_1}$

$R_2 = \rho\left(\frac{3L_1}{\frac{A_1}{3}}\right)$

$\therefore \frac{R_2}{R_1} = 9$

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11. **Answer: a**

Explanation:

From the given options the correct answer is option (A): 1.5

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12. **Answer: d**

Explanation:

For a uniformly charged non-conducting sphere, the potential $V(r)$ inside the sphere (at a distance r from the center) is given by:

$$V(r) = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{R}\left(\frac{3}{2} - \frac{r^2}{2R^2}\right)$$

Here:

- Q is the total charge on the sphere.
- R is the radius of the sphere.
- r is the distance from the center (for the center, $r = 0$).

At the center $(r = 0)$:

$$V_{\text{center}} = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{R} \cdot \frac{3}{2}$$

At the surface $(r = R)$, the potential is:

$$V_{\text{surface}} = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{R}$$

From this, we see:

$$V_{\text{center}} = \frac{3}{2} V_{\text{surface}}$$

Therefore, the potential at the center is:

$$V_{\text{center}} = \frac{3V}{2}$$

Answer

The potential at the center of the sphere is:

$$\frac{3V}{2}$$

Concepts:

1. Electrostatic Potential and Capacitance:

Electrostatic Potential

The potential of a point is defined as the work done per unit charge that results in bringing a charge from infinity to a certain point.

Some major things that we should know about electric potential:

- They are denoted by V and are a scalar quantity.
- It is measured in volts.

Capacitance

The ability of a capacitor of holding the energy in form of an electric charge is defined as capacitance. Similarly, we can also say that capacitance is the storing ability of capacitors, and the unit in which they are measured is "farads".

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The capacitor is in Series and in Parallel as defined below;

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Both the Capacitors C_1 and C_2 can easily get connected in series. When the capacitors are connected in series then the total capacitance that is C_{total} is less than any one of the capacitor's capacitance.

In Parallel

Both Capacitor C_1 and C_2 are connected in parallel. When the capacitors are connected parallelly then the total capacitance that is C_{total} is any one of the capacitor's capacitance.

13. **Answer: b**

Explanation:

The correct option is (B): 0.4 mJ

Concepts:

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---

14. **Answer: 3 - 3**

Explanation:

$$\frac{1}{C_{eq}} = \frac{1}{C_{air}} + \frac{1}{C_{di}}$$
$$\frac{1}{C_{eq}} = \frac{2d}{3(\epsilon_0 A)} + \frac{d}{(3)4\epsilon_0 A} = \frac{3d}{4A\epsilon_0}$$
$$C_{eq} = \frac{4A\epsilon_0}{3d} = 2\mu F$$
$$\frac{A\epsilon_0}{d} = 1.5\mu F$$
$$\frac{1}{C'_{eq}} = \frac{d}{3(\epsilon_0 A)} + \frac{2d}{(3)4\epsilon_0 A} = \frac{(4+2)d}{12\epsilon_0 A} = \frac{6d}{12\epsilon_0 A} \Rightarrow C'_{eq} = 2[\frac{\epsilon_0 A}{d}] = 3\mu F$$

So, the correct answer is 3 μF

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In Parallel

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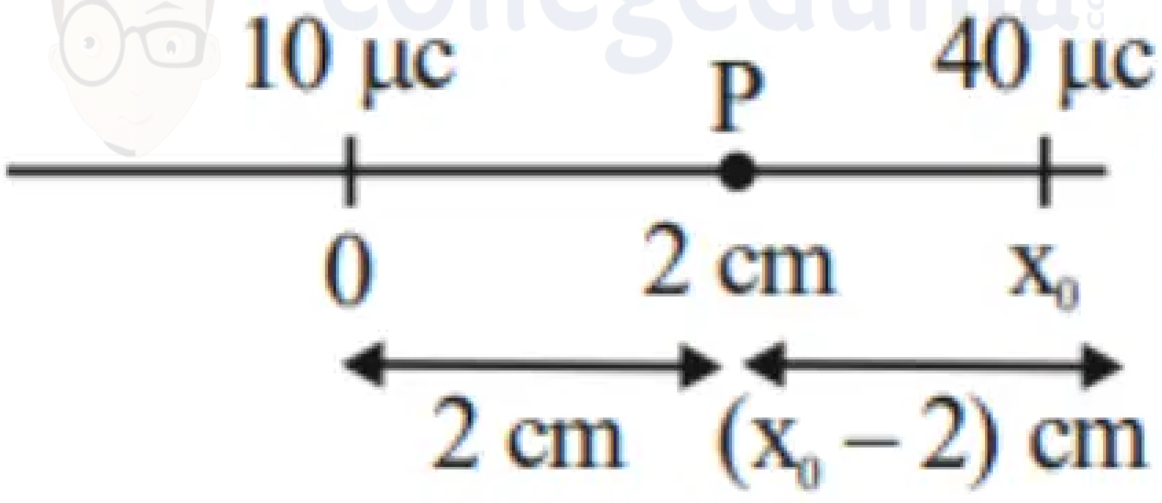
15. Answer: d

Explanation:

The correct answer is (D) : $x = 6\,cm$



$$E_P = \frac{K \times 10}{2^2} - \frac{K \times 40}{(x_0 - 2)^2} = 0$$
$$\frac{1}{2} = \frac{2}{x_0 - 2}$$
$$x_0 - 2 = 4$$
$$x_0 = 6\,cm$$

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16. **Answer: 105 - 105**

Explanation:

The capacitance of a parallel plate capacitor is given by:

$$C = \frac{\epsilon_0 A}{d}$$

where:

- ϵ_0 is the permittivity of free space,
- A is the area of the plates,
- d is the separation between the plates.

When a dielectric of constant K is introduced, the new capacitance becomes:

$$C' = K \frac{\epsilon_0 A}{d}$$

In the given problem:

- Initial capacitance $C = 15\,\text{pF}$,
- The separation between the plates becomes twice $(d \to 2d)$,
- A dielectric constant $K = 3.5$ is introduced.

The new capacitance is:

$$C' = K \frac{\epsilon_0 A}{2d} = \frac{K}{2} \times \frac{\epsilon_0 A}{d} = \frac{K}{2} \times C$$

Substitute $C = 15\,\text{pF}$ and $K = 3.5$:

$$C' = \frac{3.5}{2} \times 15 = \frac{52.5}{2} = 26.25\,\text{pF}$$

The problem states that $C' = \frac{x}{4}\,\text{pF}$. Equating:

$$\frac{x}{4} = 26.25 \implies x = 26.25 \times 4 = 105$$

Thus, the value of x is 105.

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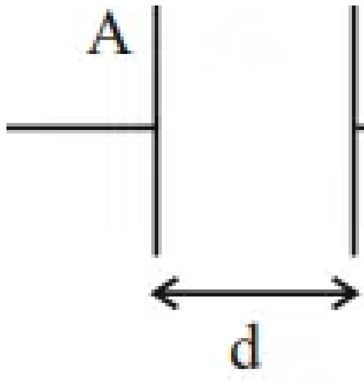
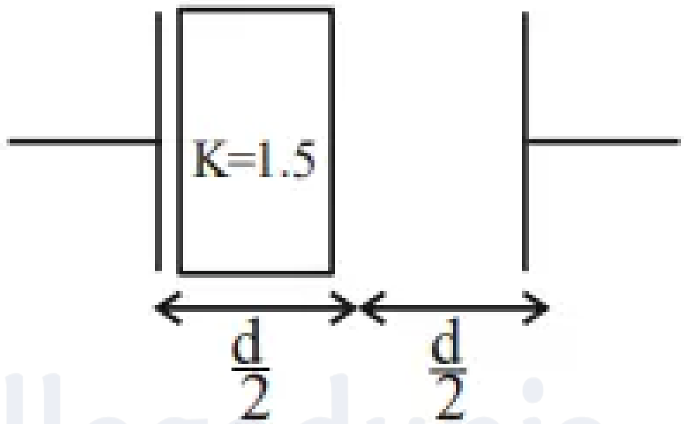
17. **Answer: 6 - 6**

Explanation:

The correct answer is 6.



$$\frac{\epsilon_0 A}{d} = 5\mu F$$



$$C_{new} = \frac{\epsilon_0 A}{\frac{\left(\frac{d}{2}\right)}{1.5} + \frac{\left(\frac{d}{2}\right)}{1}}$$

$$= \frac{\epsilon_0 A}{\left(\frac{d}{3}+\frac{d}{2}\right)} = \frac{6\epsilon_0 A}{5d}$$

$$= \frac{6}{5} \times 5\mu F = 6\mu F$$

Concepts:

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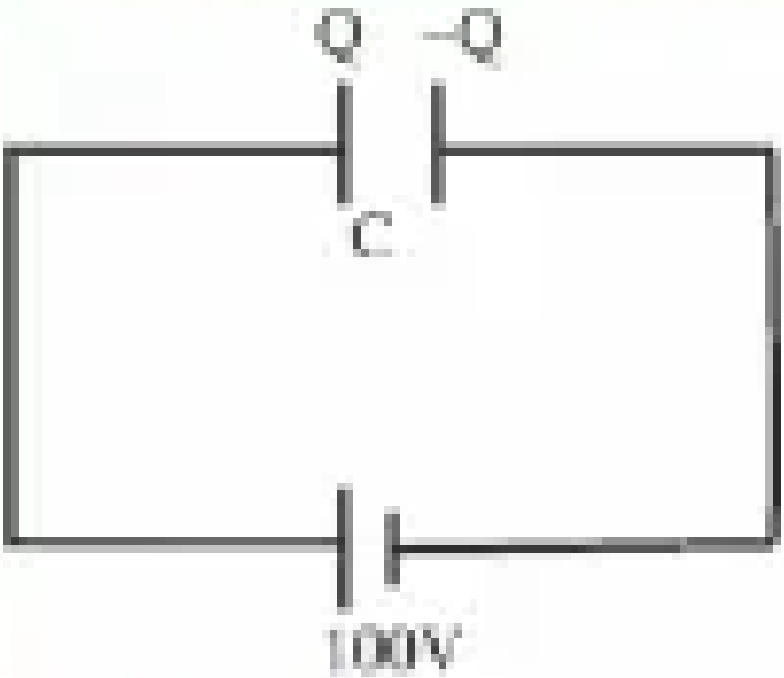
18. **Answer: 225 - 225**

Explanation:

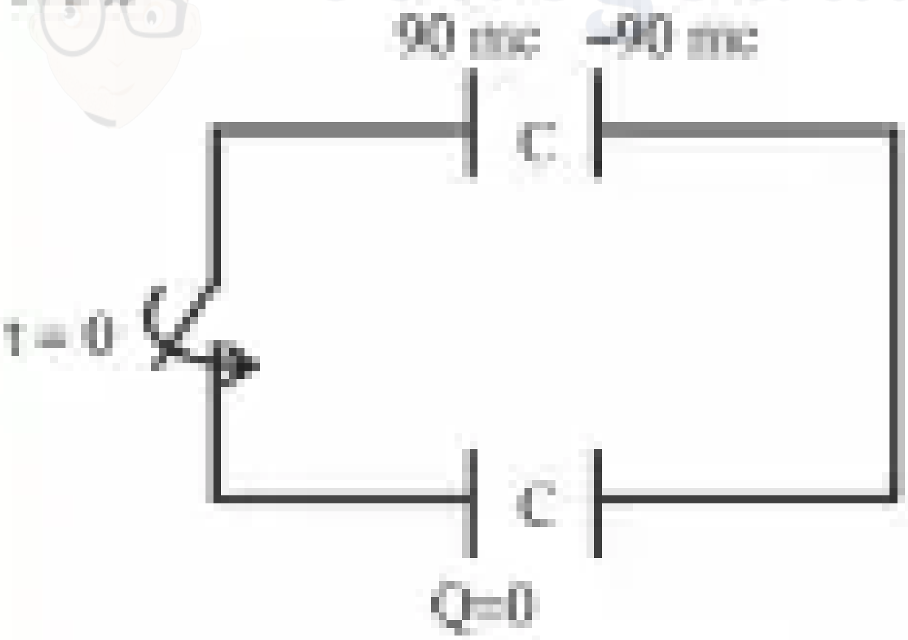
The correct answer is 225.

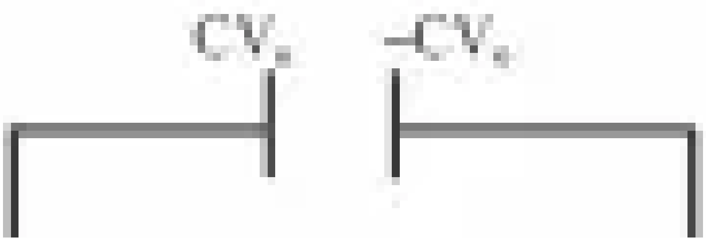


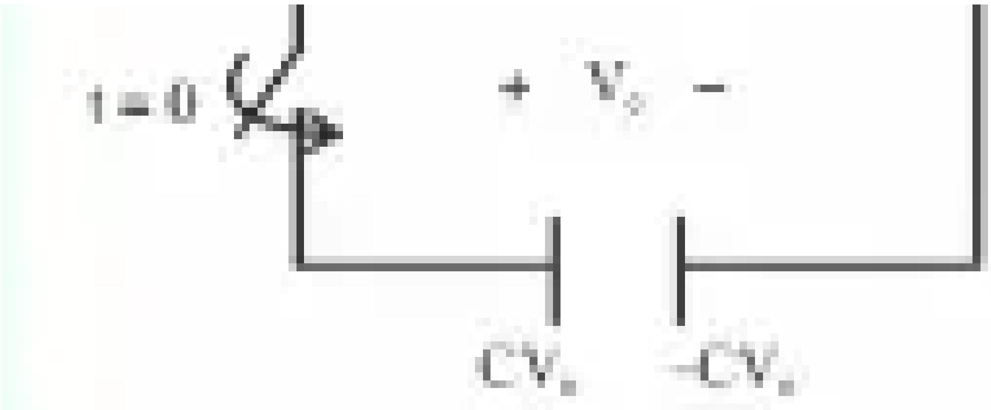
$C = 900\,\mu F$

$Q = CV = 900 \times 10^{-6} \times 100 = 9 \times 10^{-2} = 90$ M

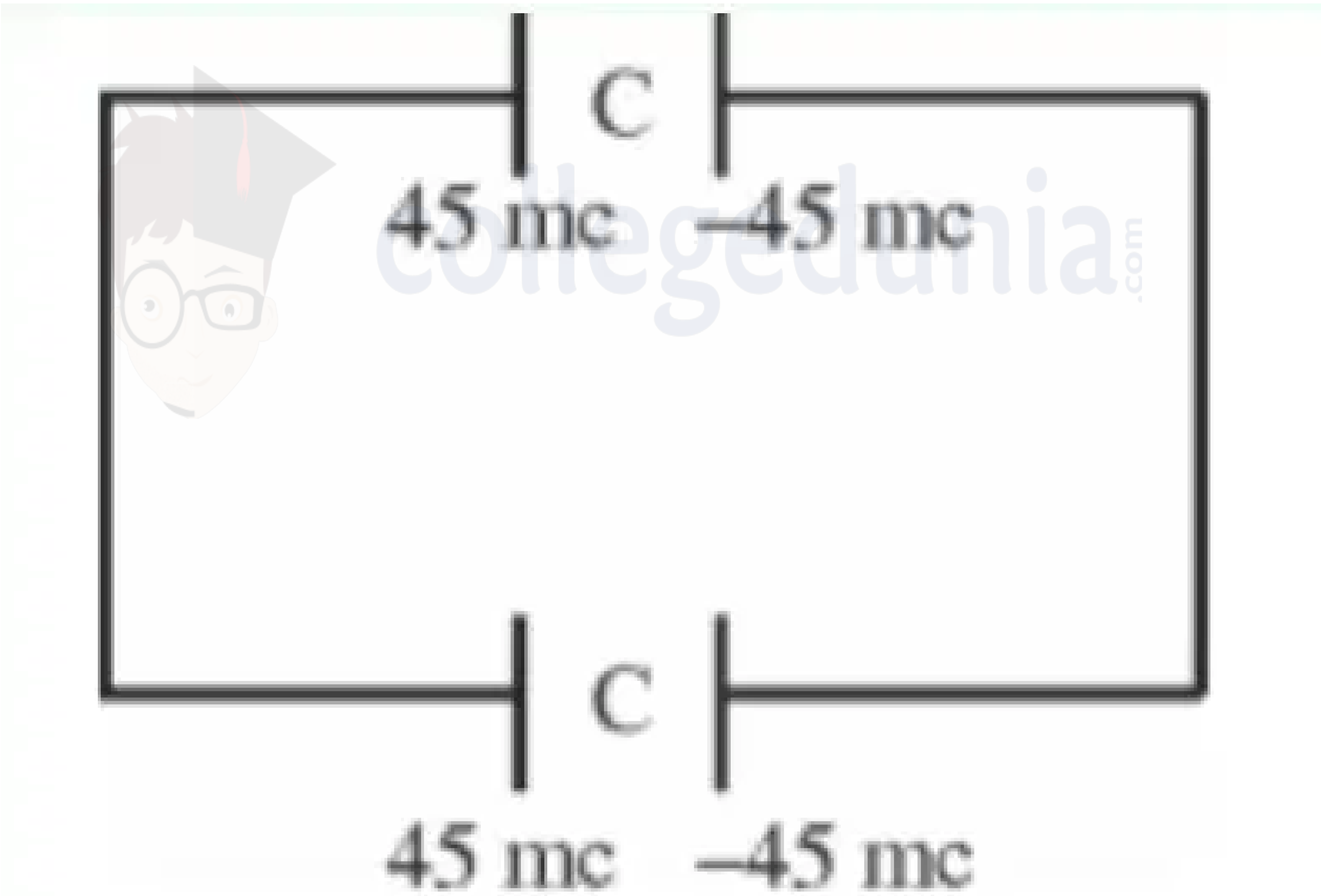
Now







Common potential will be developed across both capacitors by kVL
Total charge on left plates of capacitors should be conserved.
$\therefore 90\,mc + 0 = 2cv_0$
$cv_0 = 45\,mc$



Heat dissipated $= U_i - U_f$ [Change in energy stored in the capacitors]
$= \frac{1}{2}\frac{(90mc)^2}{900\mu F} - 2 \times \frac{1}{2}\frac{(45mc)^2}{900\mu F}\left[U = \frac{Q^2}{2c}\right]$
$= \frac{1}{2\times900\times10^{-6}}(8100 - 4050) \times 10^{-6}$
$= 2.25$ Joule
OR

$$\text{Heat} = \frac{1}{2}\frac{C_1C_2}{C_1+C_2}(V_1-V_2)^2$$
$$= \frac{1}{2}\frac{C^2}{2C}(100-0)^2$$
$$= \frac{1}{2}\frac{900\times10^{-6}}{2}\times10^4 = \frac{9}{4}\text{ Joule } = 2.25 \text{ Joule}$$

Concepts:

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19. **Answer: d**

Explanation:

The correct answer is (D) : $E_I \neq 0, E_{II} = 0, E_{III} \neq 0$
Electric field inside material of conductor is zero.

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---

20. **Answer: d**

Explanation:

For a charged spherical conductor, the variation of electric potential (V) with radial distance (r) from the center can be represented by the equation:
$V = \frac{kQ}{r}$
This equation indicates an inverse proportionality between the electric potential and the radial distance. As the radial distance (r) increases, the electric potential (V) decreases.
So, the correct representation of the variation of electric potential (V) of a charged spherical conductor with radial distance (r) from the center is:
$V \propto \frac{1}{r}$
This relationship represents option (D) "Electric potential (V) is inversely proportional to the radial distance (r)" from the given choices.

So, the correct option is (D).

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