Electrostatic Potential and Capacitance JEE Main PYQ - 3

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. The surface charge density of a thin charged disc of radius R is σ. The value of the electric field at the centre of the disc is $\frac{\sigma}{2\epsilon_0}$. With respect to the field at the centre, the electric field along the axis at a distance R from the centre of the disc :

   (+4, −1)

   a. reduces by 70.7%

   b. reduces by 29.3%

   c. reduces by 9.7%

   d. reduces by 14.6%

2. Voltage rating of a parallel plate capacitor is $500\,V$. Its dielectric can withstand a maximum electric field of 10^6 V/m. The plate area is $10^{-4}\,m^2$. What is the dielectric constant is the capacitance is $15\,pF$? (given $\epsilon_0 = 8.86 \times 10^{-12} C^2/Nm^2$)

   (+4, −1)

   a. 3.8

   b. 4.5

   c. 6.2

   d. 8.5

3. In the figure shown below, the charge on the left plate of the $10\,\mu F$ capacitor is $-30\,\mu C$. The charge on the right plate of the $6\,\mu F$ capacitor is :

   (+4, −1)

   a. $-18\,\mu C$

   b. $-12\,\mu C$

   c. $+12\,\mu C$

   d. $+18\,\mu C$

4. In the figure shown, after the switch $'S'$ is turned from position $'A'$ to position $'B'$, the energy dissipated in the circuit in terms of capacitance $'C'$ and total charge $'Q'$ is: **(+4, −1)**

a. $\frac{3}{8}\frac{Q^2}{C}$

b. $\frac{4}{3}\frac{Q^2}{C}$

c. $\frac{1}{8}\frac{Q^2}{C}$

d. $\frac{5}{8}\frac{Q^2}{C}$

5. In the circuit shown, find C if the effective capacitance of the whole circuit is to be $0.5\mu F$. All values in the circuit are in μF. **(+4, −1)**

a. $\frac{7}{10}\mu F$

b. $\frac{7}{11}\mu F$

c. $\frac{6}{5}\mu F$

d. $4\mu F$

6. In the following figure is shown a system of four capacitors connected across a $10\,V$ battery. Charge that will flow from switch S when it is closed is **(+4, −1)**

a. 5 μC from b to a

b. 20 μC from a to b

c. 5 μC from a to b

d. $zero$

7. Assume that an electric field $\vec{E} = 30x^2\hat{i}$ exists in space. Then the potential difference $V_A - V_{O'}$ where V_O is the potential at the origin and V_A the potential at $x = 2\,m$ is **(+4, −1)**

a. 120 J

b. -120 J

c. -80 J

d. 80 J

---

8. A uniformly charged solid sphere of radius R has potential V_0 9 measured with respect to ∞) on its surface. For this sphere the equipotential surfaces with potentials $\frac{3V_0}{2}, \frac{5V_0}{4}, \frac{3V_0}{4}$ and $\frac{V_0}{4}$ have radius R_1, R_2, R_3 and R_4 respectively. Then   (+4, -1)

   a. $R_1 \neq 0$ and $(R_2 - R_1) > (R_4 - R_3)$

   b. $R_1 = 0$ and $R_2 > (R_4 - R_3)$

   c. $2R < R_4$

   d. $R_1 = 0$ and $R_2 < (R_4 - R_3)$

---

9. A uniform electric field $\vec{E}$ exists between the plates of a charged condenser. A charged particle enters the space between the plates and perpendicular to $\vec{E}$. The path of the particle between the plates is a :   (+4, -1)

   a. straight line

   b. hyperbola

   c. parabola

   d. circle

---

10. A solid conducting sphere, having a charge Q, is surrounded by an uncharged conducting hollow spherical shell. Let the potential difference between the surface of the solid sphere and that of the outer surface o f the hollow shell be V. If the shell is now given a charge of $-4Q$, the new potential difference between the same two surfaces is :   (+4, -1)

   a. V

b. 2V

c. -2V

d. 4V

---

11. A plane electromagnetic wave of frequency $50\,MHz$ travels in free space along the positive x-direction. At a particular point in space and time, $\vec{E} = 6.3\hat{j}V/m$. The corresponding magnetic field $\vec{B}$, at that point will be: **(+4, −1)**

a. $18.9 \times 10^{-8}\hat{k}T$

b. $6.3 \times 10^{-8}\hat{k}T$

c. $2.1 \times 10^{-8}\hat{k}T$

d. $18.9 \times 10^{8}\hat{k}T$

---

12. A parallel plate capacitor of capacitance $90\,pF$ is connected to a battery of emf $20\,V$. If a dielectric material of dielectric constant $K = \frac{5}{3}$ is inserted between the plates, the magnitude of the induced charge will be : **(+4, −1)**

a. 1.2 n C

b. 0.3 n C

c. 2.4 n C

d. 0.9 n C

---

13. A parallel plate capacitor is made of two circular plates separated by a distance of 5 mm and with a dielectric of dielectric constant 2.2 between them. When the electric field in the dielectric is $3 \times 10^4\,V/m$, the charge density of the positive plate will be close to **(+4, −1)**

a. $6 \times 10^{-7}C/m^2$

b. $3 \times 10^{-7}C/m^2$

c. $3 \times 10^4 \, C/m^2$

d. $6 \times 10^4 \, C/m^2$

---

14. A charge Q is uniformly distributed over a long rod AB of length L as shown in the figure. The electric potential at the point O lying at distance L from the end A is

(+4, −1)

a. $\frac{Q}{8p\varepsilon_0 L}$

b. $\frac{3Q}{4p\varepsilon_0 L}$

c. $\frac{Q}{4p\varepsilon_0 L \, In \, 2}$

d. $\frac{Q \, In \, 2}{4p\varepsilon_0 L}$

---

15. A capacitor is made of two square plates each of side $'a'$ making a very small angle a between them, as shown in figure. The capacitance will be close to :

(+4, −1)

a. $\frac{\epsilon_0 a^2}{d} \left(1 - \frac{\alpha a}{4d}\right)$

b. $\frac{\epsilon_0 a^2}{d} \left(1 + \frac{\alpha a}{d}\right)$

c. $\frac{\epsilon_0 a^2}{d} \left(1 - \frac{\alpha a}{2d}\right)$

d. $\frac{\epsilon_0 a^2}{d} \left(1 - \frac{3\alpha a}{2d}\right)$

---

16. A capacitor C is fully charged with voltage V_0. After disconnecting the voltage source, it is connected in parallel with another uncharged capacitor of capacitance $\frac{C}{2}$. The energy loss in the process after the charge is distributed between the two capacitors is :

(+4, −1)

a. $\frac{1}{6}CV_0^2$

b. $\frac{1}{2}CV_0^2$

**c.** $\frac{1}{3}CV_0^2$

d. $\frac{1}{4}CV_0^2$

---

17. A capacitance of $2\,\mu F$ is required in an electrical circuit across a potential difference of $1.0\,kV$. A large number of $1\,\mu F$ capacitors are available which can withstand a potential difference of not more than $300\,V$. The minimum number of capacitors required to achieve this is : **(+4, −1)**

a. 2

b. 16

c. 24

d. 32

---

18. A combination of capacitors is set up as shown in the figure. The magnitude of the electric field, due to a point charge Q (having a charge equal to the sum of the charges on the $4\,\mu F$ and $9\,\mu F$ capacitors), at a point distant $30\,m$ from it, would equal : **(+4, −1)**

a. 240 N/C
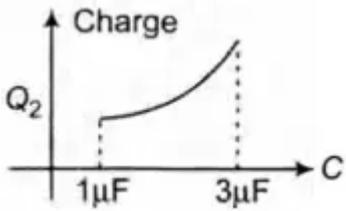
b. 360 N/C

c. 420 N/C

d. 480 N/C

---

19. In the given circuit, charge Q_2 on the $2\mu F$ capacitor changes as C is varied from $1\mu F$ to $3\mu F$. Q_2 as a function of $'C'$ is given properly by (figures are drawn schematically and are not to scale) **(+4, −1)**
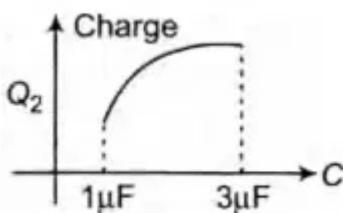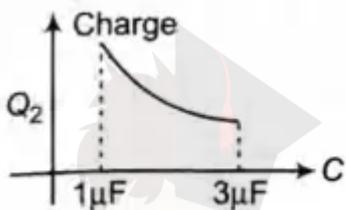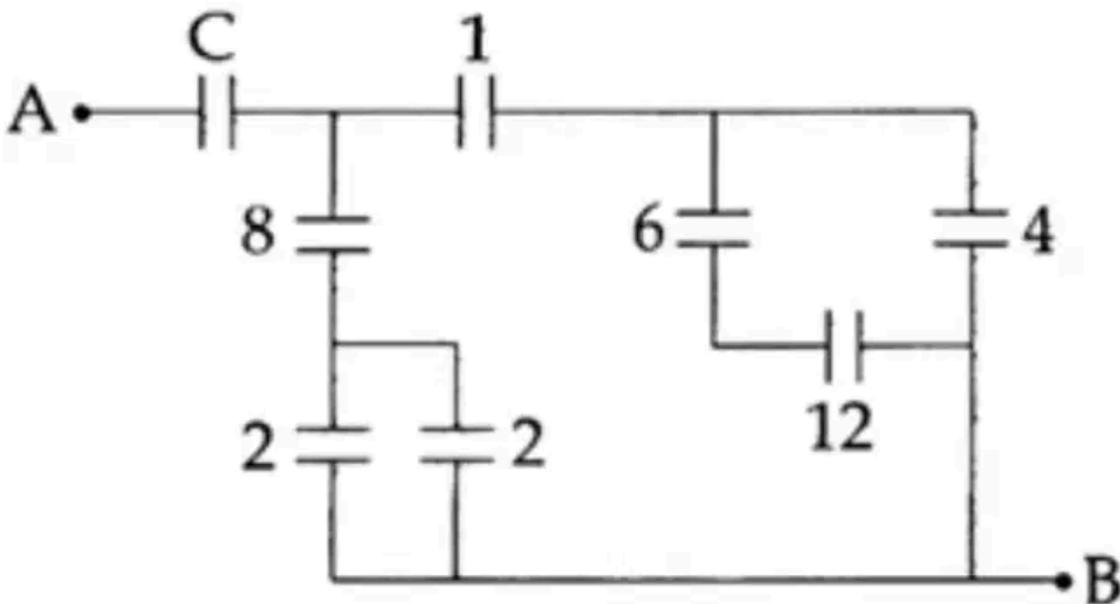
a.
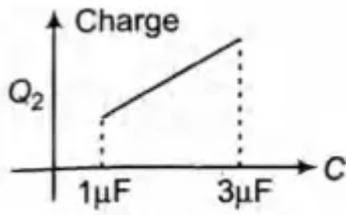
b.

c.

d.

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20. Figure shows a network of capacitors where the numbers indicates capacitances in micro Farad. The value of capacitance C if the equivalent capacitance between point A and B is to be $1\,\mu F$ is :   (+4, −1)

a. $\frac{31}{23}\mu F$

b. $\frac{32}{23}\mu F$

c. $\frac{33}{23}\mu F$

d. $\frac{34}{23}\mu F$

Answers

1. **Answer: a**

Explanation:

Electric field intensity at the centre of the disc. $E = \frac{\sigma}{2\epsilon_0}$ (given)

Electric field along the axis at any distance x from the centre of the disc $E' = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{x}{\sqrt{x^2+R^2}}\right)$

From question, x=R (radius of disc)

$\therefore E' = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{R}{\sqrt{R^2+R^2}}\right) = \frac{\sigma}{2\epsilon_0}\left(\frac{\sqrt{2}R-R}{\sqrt{2}R}\right) = \frac{4}{14}E$

$\therefore$ % reduction in the value of electric field $= \frac{\left(E - \frac{4}{14}E\right)\times 100}{E} = \frac{1000}{14}\% \approx 70.7\%$

Hence, The correct answer is option (A): reduces by 70.7%

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".

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

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---

2. **Answer: d**

Explanation:

$$A = 10^{-4}m^2$$
$$E_{max} = 10^6 V/m$$
$$C = 15\mu F$$
$$C = \frac{k\varepsilon_0 A}{d}$$
$$\frac{Cd}{\varepsilon_0 A} = k$$
$$k = \frac{15 \times 10^{-12} \times 500 \times 10^{-6}}{8.86 \times 10^{-12} \times 10^4}$$
$$= \frac{15 \times 5}{8.86} = 8.465$$
$$k \approx 8.5$$

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3. Answer: d

Explanation:

$6\mu F$ & $4\mu F$ are in parallel & total charge on this combination is $30\ \mu C$

$\therefore$ Charge on $6\mu F$ capacitor $= \frac{6}{6+4} \times 30$

$= 18\ \mu C$

Since charge is asked on right plate therefore is $+18\mu C$

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---

4. Answer: a

Explanation:

$$V_i = \frac{1}{2}CE^2$$
$$V_f = \frac{(CE)^2}{2 \times 4c} = \frac{1}{2}\frac{CE^2}{4}$$

$$\Delta E = \tfrac{1}{2}CE^2 \times \tfrac{3}{4} = \tfrac{3}{8}CE^2$$

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5. **Answer: b**

Explanation:

From equs.

$$\frac{\frac{7C}{3}}{\frac{7}{3}+C} = \frac{1}{2}$$

$$\Rightarrow \ 14C = 7 + 3C$$

$$\Rightarrow \ C = \frac{7}{11}$$

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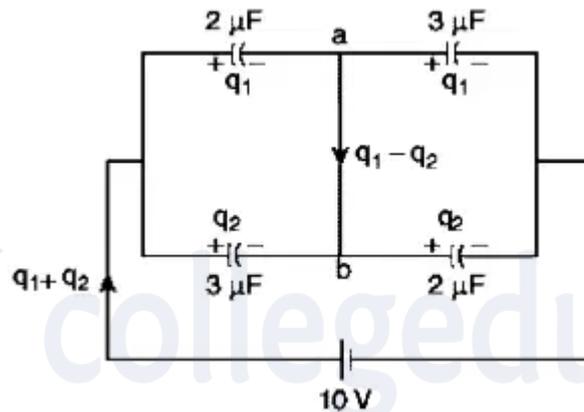
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6. **Answer: a**

Explanation:

Concepts:

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7. **Answer: c**

Explanation:

$$dV = -\vec{E} \cdot \overline{dx}$$
$$\int_{V_0}^{V_A} dV = -\int_0^2 30x^2 dx$$
$$V_A - V_O = -\left[10x^3\right]_0^2 = -80\,J$$

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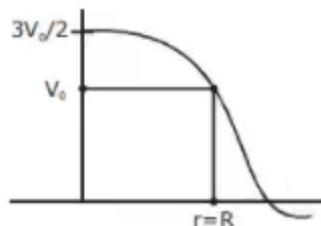
$R_1 = \frac{3V_0}{2}; R_2 = \frac{5V_0}{4}; R_3 \frac{3V_0}{4}; R_4 = \frac{V_0}{4}$

$\therefore r < R \quad V = \frac{KQ}{2R^3}\left(3R^2 - r^2\right)$

$v = \frac{3V_0}{2}, R_1 = 0$

$\frac{5V_0}{4} = \frac{KQ}{2R^3}\left(3R^2 - R_2^2\right)$

$\therefore R_2 = \frac{R}{\sqrt{2}}$

$r > R$

$\frac{3V_0}{4} = \frac{KQ}{R_3}$

$R_3 = \frac{4KQ}{3V_0} = \frac{KQ \times R}{3 \times KQ} = \frac{R}{3}$

$\frac{V_0}{4} = \frac{KQ}{R_4}$

$\therefore R_4 = \frac{4KQ}{V_0} = \frac{4KQ}{KQ} \times R = 4R$

On comparing we get

$(1) \& (2)$

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9. **Answer: c**

Explanation:

When charged particle enters perpendicularly in an electric field, it describes a parabolic path
$$y = \tfrac{1}{2}\left(\frac{QE}{m}\right)\left(\frac{x}{4}\right)^2$$
This is the equation of parabola.

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10. **Answer: a**

Explanation:

As given in the first condition :
Both conducting spheres are shown.
$V_{in} - V_{out} = \left(\frac{kQ}{r_1}\right) - \left(\frac{kQ}{r_2}\right)$
$= kQ\left(\frac{1}{r_1} - \frac{1}{r_2}\right) = V$
$V_{in} - V_{out} = \left(\frac{kQ}{r_1} - \frac{4kQ}{r_2}\right) - \left(\frac{kQ}{r_2} - \frac{4kQ}{r_2}\right)$
$= \frac{kQ}{r_1} - \frac{kQ}{r_2}$
$= kQ\left(\frac{1}{r_1} - \frac{1}{r_2}\right) = V$

Hence, we also obtain that potential difference does not depend on charge of outer sphere.
$\therefore$ P.d. remains same

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11. **Answer: c**

Explanation:

$|B| = \frac{|E|}{C} = \frac{6.3}{3 \times 10^8} = 2.1 \times 10^{-8} T$
and $\hat{E} \times \hat{B} = \hat{C}$
$\hat{j} \times \hat{B} = \hat{i}$
$\hat{B} = \hat{k}$
$\vec{B} = |B|\hat{B} = 2.1 \times 10^8 \hat{k} T$

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12. **Answer: a**

Explanation:

$C' = KC_0$

$Q = KC_0V$

$$Q_{\text{induced}} = Q\left(1 - \frac{1}{K}\right)$$
$$= \frac{5}{3} \times 90 \times 10^{-12} \times 20\left(1 - \frac{3}{5}\right)$$
$$= 1.2\,nC$$

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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;

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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.

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13. Answer: a

Explanation:

$E = \frac{\sigma}{K\varepsilon_0}$

$\sigma = K\varepsilon_0 E$

$= 2.2 \times 8.85 \times 10^{-12} \times 3 \times 10^4 \approx 6 \times 10^{-7}\, C/m^2$

Concepts:

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---

14. Answer: d

Explanation:

$$V = \int_L^{2L} \frac{k dQ}{x} = \int_L^{2L} \frac{k\left(\frac{Q}{L}\right) dx}{x} = \frac{Q}{4p\varepsilon_0 L} \int_L^{2L} \left(\frac{1}{x}\right) dx$$

$$\hspace{15mm} = \frac{Q}{4p\varepsilon_0 L} [\log_e\, x]^{2L}_L$$

$$\hspace{15mm} = \frac{Q}{4p\varepsilon_0 L} [\log_e\, 2L - \log_e L] = \frac{Q}{4p\varepsilon_0 L} \ln\, (2)$$

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---

15. **Answer: c**

Explanation:

Assume small element dx at a distance x from left end
Capacitance for small element dx is

$dC = \frac{\varepsilon_0 a\, dx}{d + x\, \alpha}$

$C = \int\limits_0^a \frac{\varepsilon_0 a\, dx}{d + x\, \alpha}$

$= \frac{\varepsilon_0\, a}{\alpha} In\left(\frac{1+\alpha a}{d}\right) \big|_0^a \quad \left(In\left(1+x\right) \approx x - \frac{x^2}{2}\right)$

$= \frac{\varepsilon_0 a^2}{d}\left(1 - \frac{\alpha a}{2d}\right)$

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---

16. **Answer: a**

Explanation:
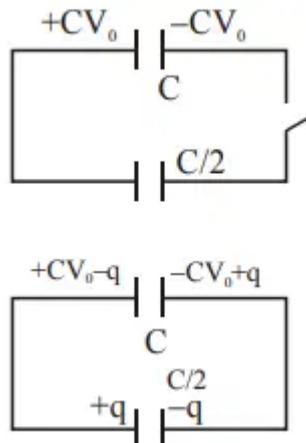
$$\frac{CV_0 - q}{C} = \frac{q}{C/2} = \frac{2q}{C}$$

$V_0 = \frac{3q}{C} \quad \Rightarrow q = \frac{CV_0}{3}$

$U_i = \frac{1}{2}CV_0^2$

$U_f = \frac{\left(\frac{2CV_0}{3}\right)^2}{2C} + \frac{\left(\frac{CV_0}{3}\right)^2}{2\left(\frac{C}{2}\right)}$

$= \frac{1}{2}CV_0^2 \left[\frac{4}{9} + \frac{2}{9}\right] = \frac{1}{2}CV_0^2 \left(\frac{2}{3}\right)$

Heat loss $= \frac{1}{2}CV_0^2 - \left(\frac{2}{3}\right)\left(\frac{1}{2}CV_0^2\right)$

$= \frac{1}{6}CV_0^2$

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---

17. **Answer: d**

Explanation:

Following arrangement will do the needful :
8 capacitors of $1\,\mu F$ in parallel with four such branches in series.

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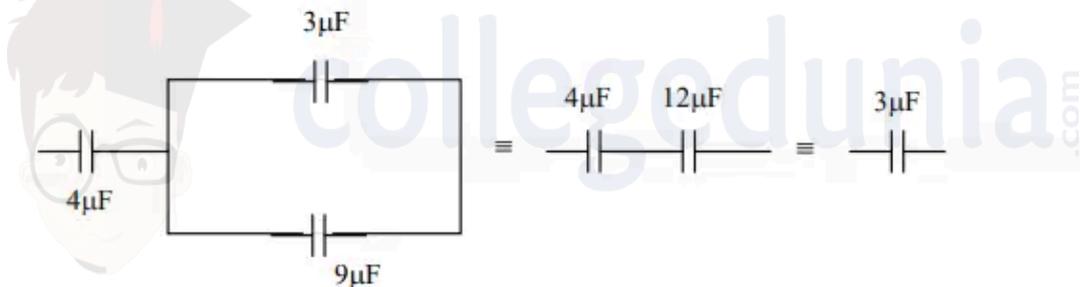
one of the capacitor's capacitance.

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---

18. **Answer: c**

Explanation:

The equivalent capacitance of the above branch will be $\frac{4(9+3)}{4+9+3} = 3\mu F$
The total charge in the above branch will be Q=CV=24 μF
Now voltage across $12\mu F$ V= gives the combination of capacitors$\frac{Q}{C} = \frac{24}{12} = 2\,V$
This is the same as the voltage across $9\mu F$ capacitor.
Hence, the charge on 9 μF capacitor is =24+18=42μC
Now by Coulomb's law,
$E = \frac{kQ}{r^2}$
$E = \frac{9\times10^9\times42\times10^{-6}}{30^2}$ =420 N/C

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---

19. Answer: a

Explanation:

$q = \left(\frac{3C}{C+3}\right) E$

$q = CV$

$q \propto C$

$q_2 = \left(\frac{3C}{C+3}\right) E \left(\frac{2}{3}\right)$

$q_2 = \left(\frac{2C}{C+3}\right) E$

$q_2 = \left(\frac{2c}{1+\frac{3}{C}}\right) E \quad q = CV$

$C \uparrow q_2 \uparrow$

If $C \to \infty, q =$ constant value.

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---

20. **Answer: b**

Explanation:

$\frac{8 \times 12}{18} = 4\,\mu F$

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