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CAPACITANCE

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CONCEPT OF CAPACITANCE

When a conductor is charged then its potential rises. The increase in potential is directly proportional to the charge given to the conductor. $Q \propto V \Rightarrow Q = CV$

The constant C is known as the capacity of the conductor.

Capacitance is a scalar quantity with dimension $C = \frac{Q}{V} = \frac{Q^2}{W} = \frac{A^2T^2}{M^1L^2T^{-2}} = M^{-1}L^{-2}T^4A^2$

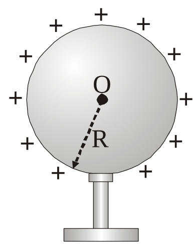
Unit :- farad, coulomb/volt

The capacity of a conductor is independent of the charge given or its potential raised. It is also independent of nature of material and thickness of the conductor. Theoretically infinite amount of charge can be given to a conductor. But practically the electric field becomes so large that it causes ionisation of medium surrounding it. The charge on conductor leaks reducing its potential.

THE CAPACITANCE OF A SPHERICAL CONDUCTOR

When a charge Q is given to a isolated spherical conductor then its potential rises.

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R} \Rightarrow C = \frac{Q}{V} = 4\pi\varepsilon_0 R$$



If conductor is placed in a medium then

$$C_{medium} = 4\pi\varepsilon R = 4\pi\varepsilon_0\varepsilon_r R$$

Capacitance depends upon :

(a) Size and Shape of Conductor

(b) Surrounding medium

(c) Presence of other conductors nearby

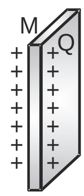
CONDENSER/CAPACITOR

The pair of conductor of opposite charges on which sufficient quantity of charge may be accommodated is defined as condenser.

- **Principle of a Condenser**

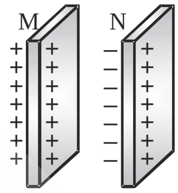
It is based on the fact that capacitance can be increased by reducing potential keeping the charge constant.

Consider a conducting plate M which is given a charge Q such that its potential rises to V then



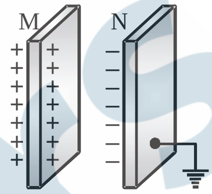
$$C = \frac{Q}{V}$$

Let us place another identical conducting plate N parallel to it such that charge is induced on plate N (as shown in figure). If V_- is the potential at M due to induced negative charge on N and V_+ is the potential at M due to induced positive charge on N, then



$$C' = \frac{Q}{V'} = \frac{Q}{V + V_+ - V_-}$$

Since V' < V (as the induced negative charge lies closer to the plate M in comparison to induced positive charge). $\Rightarrow$ C' > C Further, if N is earthed from the outer side (see figure) then $V'' = V_+ - V_-$ ($\because$ the entire positive charge flows to the earth)



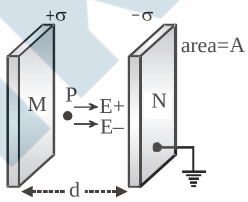
$$C'' = \frac{Q}{V''} = \frac{Q}{V - V_-} \Rightarrow C'' >> C$$

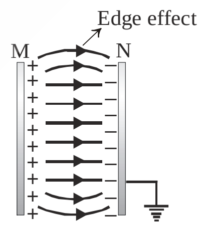
If an identical earthed conductor is placed in the vicinity of a charged conductor then the capacitance of the charged conductor increases appreciable. This is the principle of a parallel plate capacitor.

- **Parallel Plate Capacitor**

(i) Capacitance

It consists of two metallic plates M and N each of area A at separation d. Plate M is positively charged and plate N is earthed. If ε_r is the dielectric constant of the material medium and E is the field at a point P that exists between the two plates, then





I step : Finding electric field $E = E_+ + E_- = \frac{\sigma}{2\varepsilon} + \frac{\sigma}{2\varepsilon} = \frac{\sigma}{\varepsilon} = \frac{\sigma}{\varepsilon_0 \varepsilon_r}$ [$\varepsilon = \varepsilon_0\, \varepsilon_r$]

II step : Finding potential difference $V = Ed = \frac{\sigma}{\varepsilon_0 \varepsilon_r} d = \frac{qd}{A\varepsilon_0 \varepsilon_r}$ $\quad$ ($\because E = \frac{V}{d}$ and $\sigma = \frac{q}{A}$)

III step : Finding capacitance $C = \frac{q}{V} = \frac{\varepsilon_r \varepsilon_0 A}{d}$

(ii) Force between the plates

The two plates of capacitor attract each other because they are oppositely charged.

Electric field due to positive plate $E = \frac{\sigma}{2\varepsilon_0} = \frac{Q}{2\varepsilon_0 A}$

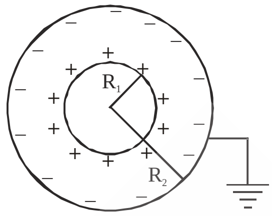
Force on negative charge –Q is $F = -QE = -\frac{Q^2}{2\varepsilon_0 A}$

Magnitude of force $F = \frac{Q^2}{2\varepsilon_0 A} = \frac{1}{2} \varepsilon_0 A E^2$

Force per unit area or energy density or electrostatic pressure $= \frac{F}{A} = u = p = \frac{1}{2} \epsilon_0 E^2$

- **Spherical Capacitor**

Outer sphere is earthed



When a charge Q is given to inner sphere it is uniformly distributed on its surface A charge –Q is induced on inner surface of outer sphere. The charge +Q induced on outer surface of outer sphere flows to earth as it is grounded.

$E = 0$ for $r < R_1$ and $E = 0$ for $r > R_2$

Potential of inner sphere $V_1 = \frac{Q}{4\pi\varepsilon_0 R_1} + \frac{-Q}{4\pi\varepsilon_0 R_2} \Rightarrow \frac{Q}{4\pi\varepsilon_0}\left(\frac{R_2 - R_1}{R_1 R_2}\right)$

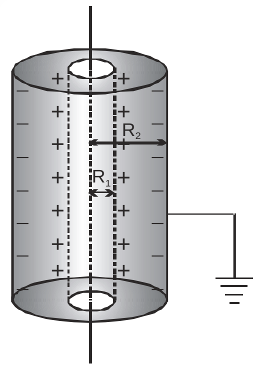
As outer surface is earthed so potential $V_2 = 0$

Potential difference between plates $V = V_1 - V_2 = \frac{Q}{4\pi\varepsilon_0}\frac{(R_2 - R_1)}{R_1 R_2}$

So $C = \frac{Q}{V} = 4\pi\varepsilon_0 \frac{R_1 R_2}{R_2 - R_1}$ (in air or vacuum)

- **Cylindrical Capacitor**

When a charge Q is given to inner cylinder it is uniformly distributed on its surface. A charge –Q is induced on inner surface of outer cylinder. The charge +Q induced on outer surface of outer cylinder flows to earth as it is grounded



Electrical field between cylinders $E = \frac{\lambda}{2\pi\varepsilon_0 r} = \frac{Q/\ell}{2\pi\varepsilon_0 r}$

Potential difference between plates $V = \int_{R_1}^{R_2} \frac{Q}{2\pi\varepsilon_0 r\ell} dr = \frac{Q}{2\pi\varepsilon_0 \ell} \ell n\left(\frac{R_2}{R_1}\right)$

Capacitance $C = \frac{Q}{V} = \frac{2\pi\varepsilon_0 \ell}{\log_e(R_2/R_1)}$

Ex. The stratosphere acts as a conducting layer for the earth. If the stratosphere extends beyond 50 km from the surface of earth, then calculate the capacitance of the spherical capacitor formed between stratosphere and earth's surface. Take radius of earth as 6400 km.

Sol. The capacitance of a spherical capacitor is $C = 4\pi\varepsilon_0\left(\frac{ab}{b-a}\right)$

b = radius of the top of stratosphere layer = 6400 km + 50 km = 6450 km = 6.45×10^6 m

a = radius of earth = 6400 km = 6.4×10^6 m

$\therefore \quad C = \frac{1}{9\times10^9} \times \frac{6.45\times10^6 \times 6.4\times10^6}{6.45\times10^6 - 6.4\times10^6} = 0.092$ F

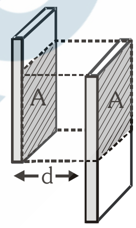
Ex. A cylindrical capacitor has two co-axial cylinders of length 15 cm and radii 1.5 cm and 1.4 cm. The outer cylinder is earthed and the inner cylinder is given a charge of 3.5 μC. Determine the capacitance of the system and the potential of the inner cylinder.

Sol. $\ell = 15\text{ cm} = 15 \times 10^{-2}$ m; $a = 1.4\text{cm} = 1.4 \times 10^{-2}$ m ;
$b = 1.5\text{ cm} = 1.5 \times 10^{-2}$ m; $q = 3.5\ \mu C = 3.5 \times 10^{-6}$ C

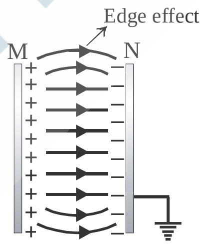
Capacitance $C = \dfrac{2\pi\varepsilon_0\ell}{2.303\log_{10}\left(\dfrac{b}{a}\right)} = \dfrac{2\pi\times 8.854\times10^{-12}\times15\times10^{-2}}{2.303\log_{10}\dfrac{1.5\times10^{-2}}{1.4\times10^{-2}}} = 1.21 \times 10^{-8}$ F

Since the outer cylinder is earthed, the potential of the inner cylinder will be equal to the potential difference between them. Potential of inner cylinder, is $V = \dfrac{q}{C} = \dfrac{3.5\times10^{-6}}{1.2\times10^{-10}} = 2.89\times10^{4}$ V

- If one of the plates of parallel plate capacitor slides relatively than C decrease (As overlapping area decreases).



- If both the plates of parallel plate capacitor are touched each other resultant charge and potential became zero.
- Electric field between the plates of a capacitor is shown in figure. Non-uniformity of electric field at the boundaries of the plates is negligible if the distance between the plates is very small as compared to the length of the plates.

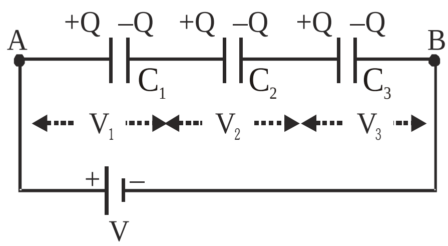


$\vec{E}$ = uniform in the centre

$\vec{E}$ = non-uniform at the edges

COMBINATION OF CAPACITOR

- **Capacitor in series**:
  In this arrangement of capacitors the charge has no alternative path(s) to flow.



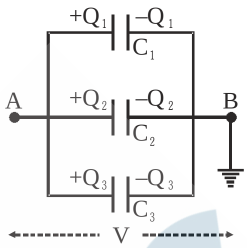
(i) The charges on each capacitor are equal
i.e. $Q = C_1V_1 = C_2V_2 = C_3V_3$

(ii) The total potential difference across AB is shared by the capacitors in the inverse ratio of the capacitances $V = V_1 + V_2 + V_3$
If C_S is the net capacitance of the series combination, then

$$\frac{Q}{C_S} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \Rightarrow \frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

- **Capacitors in parallel**

  In such arrangement of capacitors the charge has an alternative path(s) to flow.



(i) The potential difference across each capacitor is same and equal the total potential applied. i.e. $V = V_1 = V_2 = V_3 \Rightarrow V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2} = \frac{Q_3}{C_3}$

(ii) The total charge Q is shared by each capacitor in the direct ratio of the capacitances. $Q = Q_1 + Q_2 + Q_3$

If C_P is the net capacitance for the parallel combination of capacitors :

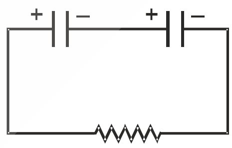
$$C_PV = C_1V + C_2V + C_3V \quad \Rightarrow C_P = C_1 + C_2 + C_3$$

- For a given voltage to store maximum energy capacitors should be connected in parallel.
- If N identical capacitors each having breakdown voltage V are joined in

(i) series then the break down voltage of the combination is equal to NV

(ii) parallel then the breakdown voltage of the combination is equal to V.

- Two capacitors are connected in series with a battery. Now battery is removed and loose wires connected together then final charge on each capacitor is zero.



- If N identical capacitors are connected then $C_{series} = \frac{C}{N}$, $C_{parallel} = NC$

- In DC capacitor's offers infinite resistance in steady state, so there will be no current flows through capacitor branch.

Ex. Capacitor C, 2C, 4C, ... ∞ are connected in parallel, then what will be their effective capacitance ?

Sol. Let the resultant capacitance be $C_{resultant} = C + 2C + 4C + ... \infty = C[1 + 2 + 4 + ... \infty] = C \times \infty = \infty$

Ex. An infinite number of capacitors of capacitance C, 4C, 16C ... ∞ are connected in series then what will be their resultant capacitance ?

Sol. Let the equivalent capacitance of the combination = C_{eq}

$$\frac{1}{C_{eq}} = \frac{1}{C} + \frac{1}{4C} + \frac{1}{16C} + ...\infty = \left[1 + \frac{1}{4} + \frac{1}{16} + ...\infty\right]\frac{1}{C} \text{ (this is G. P.series)}$$

$$\Rightarrow S_\infty = \frac{a}{1-r} \text{ first term } a = 1, \text{ common ratio } r = \frac{1}{4}$$

$$\Rightarrow \frac{1}{C_{eq}} = \frac{1}{1-\frac{1}{4}} \times \frac{1}{C} \Rightarrow C_{eq} = \frac{3}{4}C$$

ENERGY STORED IN A CHARGED CONDUCTOR/CAPACITOR

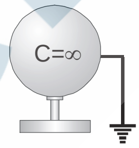
Let C is capacitance of a conductor. On being connected to a battery. It charges to a potential V from zero potential. If q is charge on the conductor at that time then q = CV. Let battery supplies small amount of charge dq to the conductor at constant potential V. Then small amount of work done by the battery against the force exerted by exsiting charge is

$$dW = Vdq = \frac{q}{C}dq \Rightarrow W = \int_0^Q \frac{q}{C}dq = \frac{1}{C}\left[\frac{q^2}{2}\right]_0^Q \Rightarrow W = \frac{Q^2}{2C}$$

where Q is the final charge acquired by the conductor. This work done is stored as potential energy, so

$$U = \frac{Q^2}{2C} = \frac{1}{2}\frac{(CV)^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}\left(\frac{Q}{V}\right)V^2 = \frac{1}{2}QV \quad \therefore \quad U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$

- As the potential of the Earth is assumed to be zero, capacity of earth or a conductor connceted to earth will be infinite $C = \frac{q}{V} = \frac{q}{0} = \infty$



- Actual capacity of the Earth $C = 4\pi\varepsilon_0 R = \frac{1}{9\times10^9}\times 64\times10^5 = 711\,\mu F$
- Work done by battery W_b = (charge given by battery) × (emf) = QV but

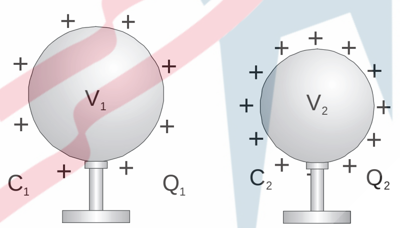
  Energy stored in conductor $= \frac{1}{2}QV$

  so 50% energy supplied by the battery is lost in form of heat.

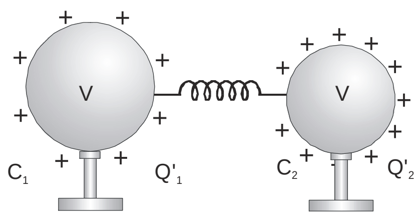
REDISTRIBUTION OF CHARGES AND LOSS OF ENERGY

When two charged conductors are connected by a conducting wire then charge flows from a conductor at higher potential to that at lower potential. This flow of charge stops when the potential of two conductors became equal.

Let the amounts of charges after the conductors are connected are Q_1' and Q_2' respectively and potential is V then



(Before connection)



(After connection)

- **Common potential**

  According to law of Conservation of charge $Q_{\text{before connection}} = Q_{\text{after connection}}$

  $\Rightarrow C_1V_1 + C_2V_2 = C_1V + C_2V$

  Common potential after connection $\boxed{V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}}$

- **Charges after connection**

$$Q_1' = C_1V = C_1\left(\frac{Q_1+Q_2}{C_1+C_2}\right) = \left(\frac{C_1}{C_1+C_2}\right)Q \qquad \text{(Q : Total charge on system)}$$

$$Q_2' = C_2V = C_2\left(\frac{Q_1+Q_2}{C_1+C_2}\right) = \left(\frac{C_2}{C_1+C_2}\right)Q$$

Ratio of the charges after redistribution $\boxed{\frac{Q_1'}{Q_2'} = \frac{C_1V}{C_2V} = \frac{R_1}{R_2} \text{ (in case of spherical conductors)}}$

- **Loss of energy in redistribution**

When charge flows through the conducting wire then **energy is lost mainly on account of Joule effect**, electrical energy is converted into heat energy, so change in energy of this system,

$$\Delta U = U_f - U_i \qquad \Rightarrow \left(\frac{1}{2}C_1V^2 + \frac{1}{2}C_2V^2\right) - \left(\frac{1}{2}C_1V_1^2 + \frac{1}{2}C_2V_2^2\right) \Rightarrow \Delta U = -\frac{1}{2}\left(\frac{C_1C_2}{C_1+C_2}\right)(V_1-V_2)^2$$

Here negative sign indicates that energy of the system decreases in the process.

Ex. The plates of a capacitor are charged to a potential difference of 100 V and then connected across a resister. The potential difference across the capacitor decays exponentially with respect to time. After one second the potential difference between the plates of the capacitor is 80 V. What is the fraction of the stored energy which has been dissipated ?

Sol. Energy losses $\Delta U = \frac{1}{2}CV_0^2 - \frac{1}{2}CV^2$

Fractional energy loss $\frac{\Delta U}{U_0} = \frac{\frac{1}{2}CV_0^2 - \frac{1}{2}CV^2}{\frac{1}{2}CV_0^2} = \frac{V_0^2 - V^2}{V_0^2} = \frac{(100)^2-(80)^2}{(100)^2} = \frac{20\times180}{(100)^2} = \frac{9}{25}$

Ex. Two uniformly charged spherical drops at potential V coalesce to form a larger drop. If capacity of each smaller drop is C then find capacity and potential of larger drop.

Sol. When drops coalesce to form a larger drop then total charge and volume remains conserved. If r is radius and q is charge on smaller drop then $C = 4\pi\varepsilon_0 r$ and $q = CV$

Equating volume we get $\frac{4}{3}\pi R^3 = 2 \times \frac{4}{3}\pi r^3 \Rightarrow R = 2^{1/3} r$

Capacitance of larger drop $C' = 4\pi\varepsilon_0 R = 2^{1/3} C$

Charge on larger drop $Q = 2q = 2CV$

Potential of larger drop $V' = \frac{Q}{C'} = \frac{2CV}{2^{1/3}C} = 2^{2/3} V$

EFFECT OF DIELECTRIC

- The insulators in which microscopic local displacement of charges takes place in presence of electric field are known as **dielectrics**.
- Dielectrics are non conductors upto certain value of field depending on its nature. If the field exceeds this limiting value called **dielectric strength** they lose their insulating property and begin to conduct.

- **Dielectric strength** is defined as the maximum value of electric field that a dielectric can tolerate without breakdown. Unit is volt/metre. Dimensions $M^1L^1T^{-3}A^{-1}$

Polar dielectrics

- In absence of external field the centres of positive and negative charge do not coincide-due to asymmetric shape of molecules.
- Each molecule has permanent dipole moment.
- The dipole are randomly oriented so average dipole moment per unit volume of polar dielectric in absence of external field is nearly zero.
- In presence of external field dipoles tends to align in direction of field.

  Ex. Water, Alcohol, CO_2, $HC\ell$, NH_3

Non polar dielectrics

- In absence of external field the centre of positive and negative charge coincides in these atoms or molecules because they are symmetric.
- The dipole moment is zero in normal state.
- In presence of external field they acquire induced dipole moment.

  Ex. Nitrogen, Oxygen, Benzene, Methane

Polarisation :

The alignment of dipole moments of permanent or induced dipoles in the direction applied electric field is called polarisation.

- **Polarisation vector** $\vec{P}$

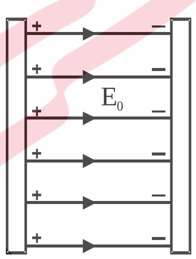
  This is a vector quantity which describes the extent to which molecules of dielectric become polarized by an electric field or oriented in direction of field.

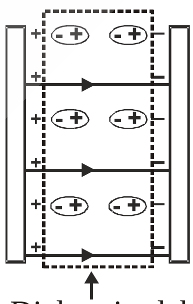
  $\vec{P}$ = the dipole moment per unit volume of dielectric = $n\vec{p}$

  where n is number of atoms per unit volume of dielectric and $\vec{P}$ is dipole moment of an atom or molecule.

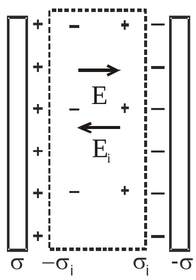
  $\vec{P} = n\vec{p} = \dfrac{q_i d}{Ad} = \left(\dfrac{q_i}{A}\right) = \sigma_i$ = induced surface charge density.

  Unit of $\vec{P}$ is C/m^2 Dimension is $L^{-2}T^1A^1$





Dielectric slab



Let E_0, V_0, C_0 be electric field, potential difference and capacitance in absence of dielectric. Let E, V, C are electric field, potential difference and capacitance in presence of dielectric respectively.

Electric field in absence of dielectric $E_0 = \dfrac{V_0}{d} = \dfrac{\sigma}{\varepsilon_0} = \dfrac{Q}{\varepsilon_0 A}$

Electric field in presence of dielectric $E = E_0 - E_i = \dfrac{\sigma - \sigma_i}{\varepsilon_0} = \dfrac{Q - Q_i}{\varepsilon_0} = \dfrac{V}{d}$

Capacitance in absence of dielectric $C_0 = \dfrac{Q}{V_0}$

Capacitance in presence of dielectric $C = \dfrac{Q - Q_i}{V}$

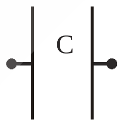
The dielectric constant or relative permittivity K

or $\varepsilon_r = \dfrac{E_0}{E} = \dfrac{V_0}{V} = \dfrac{C}{C_0} = \dfrac{Q}{Q - Q_i} = \dfrac{\sigma}{\sigma - \sigma_i} = \dfrac{\varepsilon}{\varepsilon_0}$

From $K = \dfrac{Q}{Q - Q_i} \Rightarrow Q_i = Q\left(1 - \dfrac{1}{K}\right)$ and $K = \dfrac{\sigma}{\sigma - \sigma_i} \Rightarrow \sigma_i = \sigma\left(1 - \dfrac{1}{K}\right)$

CAPACITY OF DIFFERENT CONFIGURATION

In case of parallel plate capacitor $C = \dfrac{\varepsilon_0 A}{d}$

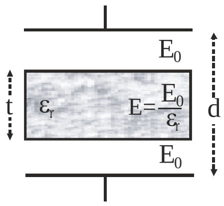


If capacitor is partially filled with dielectric

When the dielectric is filed partially between plates, the thickness of dielatric slab is t(t < d).

If no slab is introduced between the plates of the capacitor, then a field E_0 given by $E_0 = \dfrac{\sigma}{\varepsilon_0}$, exists in a space d.

On inserting the slab of thickness t, a field $E = \dfrac{E_0}{\varepsilon_r}$ exists inside the slab of thickness t and a field E_0 exists in remaining space (d – t). If V is total potential then $V = E_0(d - t) + E\,t$

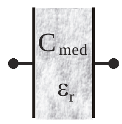


$$\Rightarrow V = E_0\left[d - t + \left(\frac{E}{E_0}\right)t\right] \because \frac{E_0}{E} = \varepsilon_r = \text{Dielectric constant}$$

$$\Rightarrow V = \frac{\sigma}{\varepsilon_0}\left[d - t + \frac{t}{\varepsilon_r}\right] = \frac{q}{A\varepsilon_0}\left[d - t + \frac{t}{\varepsilon_r}\right] \Rightarrow C = \frac{q}{V} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{\varepsilon_r}\right)} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{\varepsilon_r}\right)} \quad \text{...(i)}$$

If medium is fully present between the space.

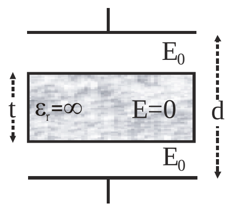
$\because \quad t = d$



Now from equation (i) $C_{medium} = \dfrac{\varepsilon_0 \varepsilon_r A}{d}$

If capacitor is partialy filled by a conducting slab of thickness (t< d).

$\because \quad \varepsilon_r = \infty$ for conductor $C = \dfrac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{\infty}\right)} = \dfrac{\varepsilon_0 A}{(d - t)}$

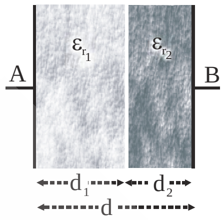


DISTANCE AND AREA DIVISION BY DIELECTRIC

- **Distance Division**

(i) Distance is divided and area remains same.

(ii) Capacitors are in series.



(iii) Individual capacitances are $C_1 = \dfrac{\varepsilon_0 \varepsilon_{r_1} A}{d_1}$, $C_2 = \dfrac{\varepsilon_0 \varepsilon_{r_2} A}{d_2}$

These two are in series $\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} \Rightarrow \dfrac{1}{C} = \dfrac{d_1}{\varepsilon_0 \varepsilon_{r_1} A} + \dfrac{d_2}{\varepsilon_0 \varepsilon_{r_2} A}$

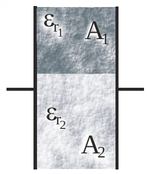
$$\Rightarrow \frac{1}{C} = \frac{1}{\varepsilon_0 A}\left[\frac{d_1 \varepsilon_{r_2} + d_2 \varepsilon_{r_1}}{\varepsilon_{r_1}\varepsilon_{r_2}}\right] \Rightarrow C = \varepsilon_0 A\left[\frac{\varepsilon_{r_1}\varepsilon_{r_2}}{d_1 \varepsilon_{r_2} + d_2 \varepsilon_{r_1}}\right]$$

Special case : If $d_1 = d_2 = \dfrac{d}{2} \Rightarrow C = \dfrac{\varepsilon_0 A}{d}\left[\dfrac{2\varepsilon_{r_1}\varepsilon_{r_2}}{\varepsilon_{r_1} + \varepsilon_{r_2}}\right]$

- **Area Division**

(i) Area is divided and distance remains same.

(ii) Capacitors are in parallel.



(iii) Individual capacitances are $C_1 = \dfrac{\varepsilon_0 \varepsilon_{r_1} A_1}{d}$ $C_2 = \dfrac{\varepsilon_0 \varepsilon_{r_2} A_2}{d}$

These two are in parallel so $C = C_1 + C_2 = \dfrac{\varepsilon_0 \varepsilon_{r_1} A_1}{d} + \dfrac{\varepsilon_0 \varepsilon_{r_2} A_2}{d} = \dfrac{\varepsilon_0}{d}(\varepsilon_{r_1} A_1 + \varepsilon_{r2} A_2)$

Special case : If $A_1 = A_2 = \dfrac{A}{2}$ Then $C = \dfrac{\varepsilon_0 A}{d}\left(\dfrac{\varepsilon_{r_1} + \varepsilon_{r2}}{2}\right)$

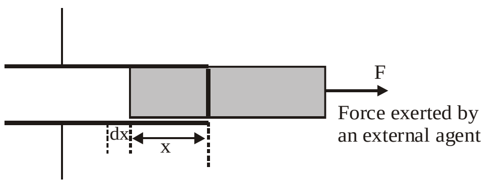
- **Variable Dielectric Constant :**

If the dielectric constant is variable, then equivalent capacitance can be obtained by selecting an element as per the given condition and then integrating.

(i) If different elements are in parallel, then $C = \int dC$, where dC = capacitance of selected differential element.

(ii) If different element are in series, then $\dfrac{1}{C} = \int d\left(\dfrac{1}{C}\right)$ is solved to get equivalent capacitance C.

FORCE ON A DIELECTRIC IN A CAPACITOR



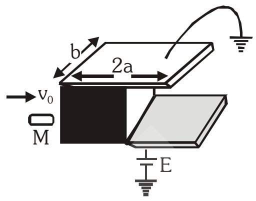
Consider a differential displacement dx of the dielectric as shown in figure always keeping the net force on it zero so that the dielectric moves slowly without acceleration. Then, $W_{Electrostatic} + W_F = 0$, where W_F denotes the work done by external agent in displacement dx

$W_F = -W_{Electrostatic}$ $W_F = \Delta U$

$$\Rightarrow -F.dx = \frac{Q^2}{2} d\left[\frac{1}{C}\right] \left[U = \frac{Q^2}{2C}\right] \Rightarrow -F.dx = \frac{-Q^2}{2C^2} dC \Rightarrow F = \frac{Q^2}{2C^2}\left(\frac{dC}{dx}\right)$$

This is also true for the force between the plates of the capacitor. If the capacitor has battery connected to it, then as the p.d. across the plates is maintained constant. $V = \dfrac{Q}{C} \Rightarrow F = \dfrac{1}{2}V^2 \dfrac{dC}{dx}$.

Ex. A parallel plate capacitor is half filled with a dielectric (K) of mass M. Capacitor is attached with a cell of emf E. Plates are held fixed on smooth insulating horizontal surface. A bullet of mass M hits the dielectric elastically and its found that dielectric just leaves out the capacitor. Find speed of bullet and the current as a function of time.



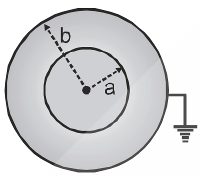
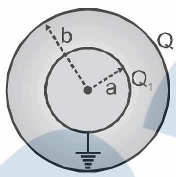
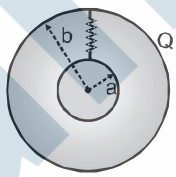
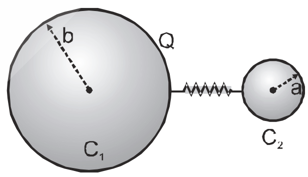
Sol. Since collision is elastic $\therefore$ Velocity of dielectric after collision is v_0.
Dielectric will move and when it is coming out of capacitor a force is applied on it by the capacitor $F=\frac{-dU}{dx}=\frac{-E^2\varepsilon_0 b(K-1)}{2d}$

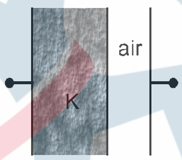
Which decreases its speed to zero, till it comes out it travels a distance a.

$$\frac{1}{2}Mv_0^2=\frac{E^2\varepsilon_0 b(K-1)a}{2d}\Rightarrow v_0=E\left[\frac{\varepsilon_0 ab(K-1)}{Md}\right]^{1/2}$$

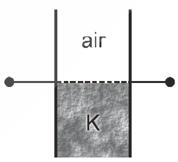
$$i=vE.\frac{dC}{dx}\left[\text{Since, } i=\frac{dq}{dt}=\frac{d}{dt}(EC)=E\frac{dC}{dt}=\frac{EdC}{dx}\frac{dx}{dt}\right]$$

$$i=\left(v_0-\frac{F}{M}t\right)E\varepsilon_0 b\frac{(K-1)}{d}\quad \text{for } t_0<t<\left(t_0+\frac{v_0M}{F}\right)\ (\text{where, } t_0=\frac{a}{v_0})$$

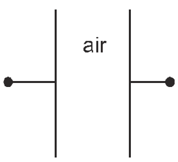
Spherical capacitor outer is earthed	Inner is earthed and outer is given a charge	Connected and outer is given a charge	Connected spheres
			
$C=\frac{4\pi\varepsilon_0 ab}{b-a}$ (b > a)	$C=\frac{4\pi\varepsilon_0 b^2}{b-a}$ (b > a)	$C=4\pi\varepsilon_0 b$	$C=C_1+C_2$ $C=4\pi\varepsilon_0(a+b)$



$C_1=\left[\frac{2K}{K+1}\right]C$



$C_2=\left[\frac{K+1}{2}\right]C$



$C_3=C$
when no dielectric is used

$$\boxed{C_2>C_1>C_3}$$

Ex. A capacitor has two circular plates whose radius are 8cm and distance between them is 1mm. When mica (dielectric constant = 6) is placed between the plates, calculate the capacitance of this capacitor and the energy stored when it is given potential of 150 volt.

Sol. Area of plate $\pi r^2=\pi\times(8\times 10^{-2})^2=0.0201\ m^2$ and $d=1mm=1\times 10^{-3}\ m$

Capacity of capacitor $C=\frac{\varepsilon_0\varepsilon_r A}{d}=\frac{8.85\times 10^{-12}\times 6\times 0.0201}{1\times 10^{-3}}=1.068\times 10^{-9}\ F$

Potential difference $V = 150$ volt

Energy stored $U = \frac{1}{2}CV^2 = \frac{1}{2}\times(1.068\times10^{-9})\times(150)^2 = 1.2\times10^{-5}$ J

Ex. A parallel-plate capacitor is formed by two plates, each of area 100 cm^2, separated by a distance of 1mm. A dielectric of dielectric constant 5.0 and dielectric strength 1.9×10^7 V/m is filled between the plates. Find the maximum charge that can be stored on the capacitor without causing any dielectric breakdown.

Sol. If the charge on the capacitor = Q

the surface charge density $\sigma = \frac{Q}{A}$ and the electric field = $\frac{Q}{KA\varepsilon_0}$.

This electric field should not exceed the dielectric strength 1.9×10^7 V/m.

$\therefore$ if the maximum charge which can be given is Q

then $\frac{Q}{KA\varepsilon_0} = 1.9\times10^7$ V/m, $\because$ A = 100 cm^2 = 10^{-2} m^2

$\Rightarrow$ Q = $(5.0)\times(10^{-2})\times(8.85\times10^{-12})\times(1.9\times10^7) = 8.4\times10^{-6}$ C.

Ex. The distance between the plates of a parallel-plate capacitor is 0.05 m. A field of 3×10^4 V/m is established between the plates of capacitor by connecting with battery. Now capacitor is disconnected from the battery and an uncharged metal plate of thickness 0.01 m is inserted between the plates of capacitor. Calculate new potential difference between the plates of capacitor.What would be the potential difference if a plate of same thickness and dielectric constant K = 2 is introduced in place of metal plate ?

Sol. (i) In case of a capacitor as E = (V/d), the potential difference between the plates before the introduction of metal plate

$$V = E\times d = 3\times10^4\times0.05 = 1.5 \text{ kV}$$

(ii) Now as after charging battery is removed , capacitor is isolated so q = constant. If C' and V' are the capacity and potential after the introduction of plate q = CV = C'V' i.e., $V' = \frac{C}{C'}V$

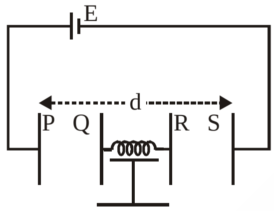
And as $C = \frac{\varepsilon_0 A}{d}$ and $C' = \frac{\varepsilon_0 A}{(d-t)+(t/K)}$, $V' = \frac{(d-t)+(t/K)}{d}\times V$

So in case of metal plate as K = ∞, $V_M = \left[\frac{d-t}{d}\right]\times V = \left[\frac{0.05-0.01}{0.05}\right]\times1.5 = 1.2$ kV

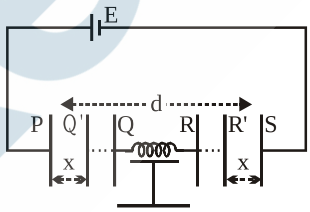
And if instead of metal plate, dielectric with K = 2 is introduced

$$V_D = \left[\frac{(0.05-0.01)+(0.01/2)}{0.05}\right]\times1.5 = 1.35 \text{ kV}$$

Ex. Two parallel plate capacitors with area A are connected through a conducting spring of natural length ℓ in series as shown. Plates P and S have fixed positions at separation d. Now the plates are connected by a battery of emf E as shown. If the extension in the spring in equilibrium is equal to the separation between the plates, find the spring constant k.



Sol. At any time distance between plates P and Q, R and S is same because force acting on them is same. Let charge on capacitors be q and separation between plates P and Q, R and S be x



Capacitance of capacitor PQ, $C_1 = \dfrac{\varepsilon_0 A}{x}$

Capacitance of capacitor RS, $C_2 = \dfrac{\varepsilon_0 A}{x}$ From KVL $\dfrac{q}{C_1} + \dfrac{q}{C_2} = E \Rightarrow q = \dfrac{\varepsilon_0 AE}{2x}$

At this moment extension in spring, $y = d - 2x - \ell$.

Force on plate Q towards P, $F_1 = \dfrac{q^2}{2A\varepsilon_0} = \dfrac{\varepsilon_0^2 A^2 E^2}{8Ax^2\varepsilon_0} = \dfrac{A\varepsilon_0 E^2}{8x^2}$

Spring force on plate Q due to extension in spring, $F_2 = ky$

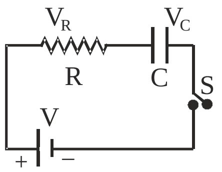
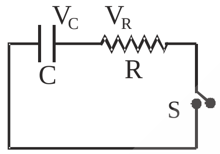
At equilibrium, separation between plates = extension in spring

Thus $x = y = d - 2x - \ell \Rightarrow x = \dfrac{d-\ell}{3}$ ...(i) and $F_1 = F_2$ ...(ii)

From eq. (i) and (ii), $\dfrac{A\varepsilon_0 E^2}{8x^2} = ky = kx \Rightarrow x = \left(\dfrac{A\varepsilon_0 E^2}{8k}\right)^{1/3}$ ...(iii)

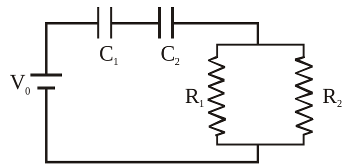
From eq. (i) and (iii), $\left(\dfrac{d-\ell}{3}\right) = \dfrac{A\varepsilon_0 E^2}{8k} \Rightarrow k = \dfrac{A\varepsilon_0 E^2 27}{8(d-\ell)^3}$

CHARGING & DISCHARGING OF A CAPACITOR

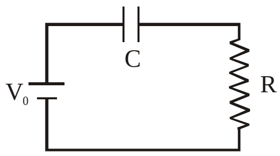
Charging	Discharging
• When a capacitor, resistance, battery, and key is conected in series and key is closed, then  • **Charge at any instant** $V = V_C + V_R = \frac{Q}{C} + IR = \frac{Q}{C} + \frac{dQ}{dt}R$ $Q = CV\left[1-e^{-t/RC}\right] = Q_0\left[1-e^{-t/RC}\right]$ At $t = \tau = RC$ = time constant $Q = Q_0[1-e^{-1}] = 0.632\ Q_0$ So, in charging, charge increases to 63.2% of charge in the time equal to τ. • **Current at any instant** $i = dQ/dt = i_0e^{-t/RC}$ $\{i_0 = Q_0/RC\}$ • **Potential at any instant** $V = V_0(1-e^{-t/RC})$	• When a charged capacitor, resistance and keys is conected in series and key is closed. Then energy stored in capacitor is used to circulate current in the circuit.  • **Charge at any instant** $V_C + V_R = 0$ $Q=Q_0e^{-t/RC}$ At $t = \tau = RC$ = time constant $Q = Q_0e^{-1} = 0.368\ Q_0$ So, in discharging, charge decreases to 36.8% of the initial charge in the time equal to τ. • **Current at any instant** $i = dQ/dt = -i_0e^{-t/RC}$ $\{i_0 = Q_0/RC\}$ • **Potential at any instant** $V = V_0\ e^{-t/RC}$

Ex. Find the time constant for given circuit if

$R_1 = 4\Omega$, $R_2 = 12\Omega$, $C_1 = 3\mu F$ and $C_2 = 6\mu F$.



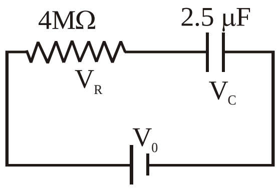
Sol. Given circuit can be reduced to :



$$C = \frac{C_1C_2}{C_1+C_2} = \frac{3\times6}{3+6} = 2\mu F,\quad R = \frac{R_1R_2}{R_1+R_2} = \frac{4\times12}{4+12} = 3\Omega$$

Time constant = RC = (3) (2×10^{-6}) = $6\mu s$

Ex. A capacitor of 2.5 μF is charged through a series resistor of $4M\Omega$. In what time the potential drop across the the capacitor will become 3 times that of the resistor. (Given : $\ell n2 = 0.693$)



Sol. $V_C = V_0(1 - e^{-t/RC})$ $\because V_C = 3V_R$ $\therefore V_0 = V_C + \frac{V_C}{3} \Rightarrow V_C = \frac{3}{4}V_0$

$$\Rightarrow \frac{3}{4}V_0 = V_0(1 - e^{-t/RC}) \Rightarrow \frac{3}{4} = 1-e^{-t/RC} \Rightarrow \frac{1}{4} = e^{-t/RC} \Rightarrow 4 = e^{t/RC}$$

$$\Rightarrow \frac{t}{RC} = \ell n4 \Rightarrow t = RC\ell n4 = 2RC\ \ell n2 = 2 \times 4 \times 10^6 \times 2.5 \times 10^{-6} \times 0.693 = 13.86\ s$$

EXERCISE (S-1)

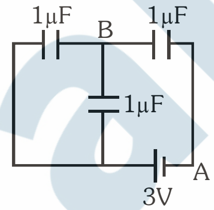
Capacitance

1. Two large parallel conducting plates are 34 mm apart and carry equal but opposite charges on their facing surfaces. An electron placed midway between the plates experiences a force of 3.2×10^{-16} N. What is the potential difference (in volts) between the plates?

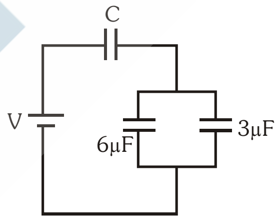
2. 2 conducting objects one with charge of +Q and another with –Q are kept on x-axis at x = 0 and x = 1 respectively. The electric field on the x-axis is given by $3Q\left(x^2 + \frac{4}{3}\right)$. If the capacitance of this configuration of objects is C. Then fill $\frac{1}{C}$ (in F^{-1}) in OMR sheet.

Capacitor Circuits

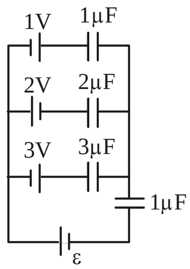
3. If potential of A is 5V, then potential of B in volt is



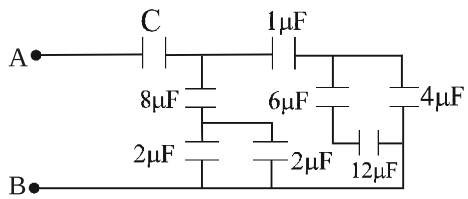
4. If charge on 3μF capacitor is 3μC. Find the charge on capacitor of capacitance C in μC.



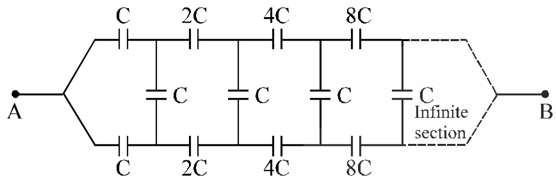
5. In the figure shown, find the e.m.f. ε for which charge on 2μF capacitor is 4 μC.



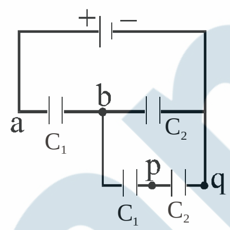
6. In the following circuit, the resultant capacitance between A and B is 1 μF. Find the value of C.



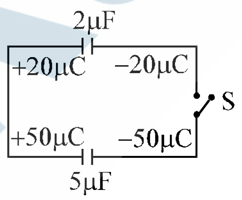
7. Find the equivalent capacitance of the circuit between point A and B.



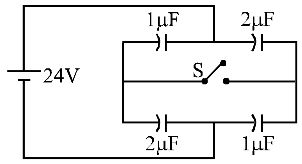
8. In the given network if potential difference between p and q is 2V and $C_2 = 3C_1$. Then find the potential difference between a & b.



9. Find heat produced in the circuit shown in figure on closing the switch S.



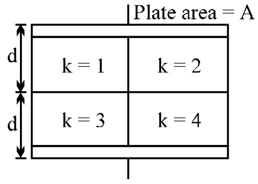
10. The connections shown in figure are established with the switch S open. How much charge will flow through the switch if it is closed ?



11. The plates of a parallel plate capacitor are given charges +4Q and –2Q. The capacitor is then connected across an uncharged capacitor of same capacitance as first one (= C). Find the final potential difference between the plates of the first capacitor.

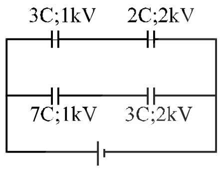
Dielectrics

12. Find the capacitance of the system shown in figure.



13. The plates of a parallel plate capacitor are charged upto 100 volt. A 2 mm thick plate is inserted between the plates, then to maintain the same potential difference, the distance between the capacitor plates is increased by 1.6 mm. Find the dielectric constant of the plate.

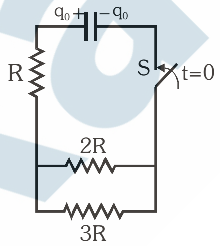
14. The diagram shows four capacitors with capacitances and break down voltages as mentioned. What should be the maximum value of the external emf source such that no capacitor breaks down?



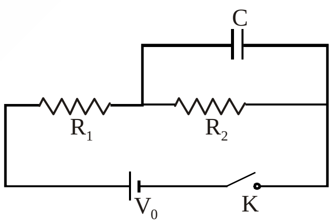
15. Two square metallic plates of 1 m side are kept 0.01 m apart, like a parallel plate capacitor, in air in such a way that one of their edges is perpendicular, to an oil surface in a tank filled with an insulating oil. The plates are connected to a battery of e.m.f. 500 volt . The plates are then lowered vertically into the oil at a speed of 0.001 m/s. Calculate the current drawn from the battery during the process. [di-electric constant of oil = 11, $\in_0 = 8.85 \times 10^{-12}$ $C^2/N^2 m^2$]

R-C Circuits

16. At t = 0 charge on capacitor is q_0. Now switch S is closed. Heat loss in 3R is $x \times 10^{-6}$ J. Then find the value of x. [Given q_0= 15μC, C = 6/55 μF]



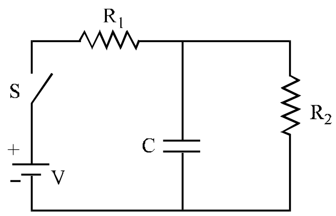
17. In the connection shown in the *figure* the switch K is open and the capacitor is uncharged. Then we close the switch and let the capacitor charge up to the maximum and open the switch again. Then (Use the following data : V_0=30 V, R_1=10 kΩ, R_2=5 kΩ.)



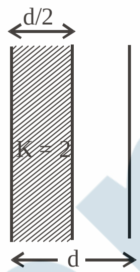
(i) the current through R_1 be I_1 immediately after closing the switch
(ii) the current through R_2 be I_2 a long time after the switch was closed
(iii) the current through R_2 be I_3 immediately after reopening the switch

Find the value of $\dfrac{I_1}{I_2 I_3}$ (in ampere^{-1}).

18. In the given circuit, the switch S is closed at time t = 0. The charge Q on the capacitor at any instant t is given by $Q(t) = Q_0(1-e^{-\alpha t})$. Find the value of Q_0 and α in terms of given parameters shown in the circuit.
[IIT-JEE 2005]



19. A certain series RC circuit is formed using a resistance R, a capacitor without dielectric having a capacitance C = 2F and a battery of emf E = 3V. The circuit is completed and it is allowed to attain the steady state. After this, at t = 0, half the thickness of the capacitor is filled with a dielectric of constant K = 2 as shown in the figure. The system is again allowed to attain a steady state. What will be the heat generated (in joule) in the circuit between t = 0 and t = ∞ ?



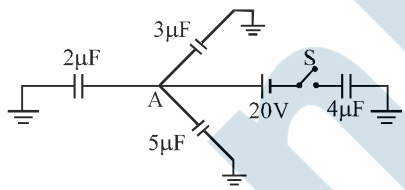
20. A capacitor filled with dielectric of permittivity ε = 2.1 loses half the charge acquired during a time interval τ = 3.0 min. Assuming the charge to leak only through the dielectric filler, calculate its resistivity.

EXERCISE (S-2)

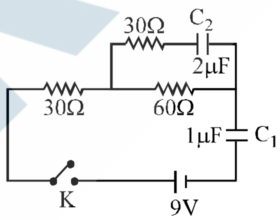
1. Three capacitors of 2μF, 3μF and 5μF are independently charged with batteries of emf's 5V, 20V and 10V respectively. After disconnecting from the voltage sources. These capacitors are connected as shown in figure with their positive polarity plates are connected to A and negative polarity is earthed. Now a battery of 20V and an uncharged capacitor of 4μF capacitance are connected to the junction A as shown with a switch S. When switch is closed, find :

(a) the potential of the junction A.

(b) final charges on all four capacitors.



2. For the arrangement shown in the figure, the key is closed at t = 0. C_2 is initially uncharged while C_1 has a charge of 2μC.



(a) Find the current coming out of the battery just after switch is closed.

(b) Find the charge on the capacitors in the steady state condition.

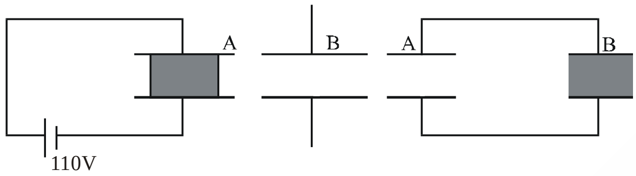
3. A potential difference of 300 V is applied between the plates of a parallel plate capacitor spaced 1 cm apart. A plane parallel glass plate with a thickness of 0.5 cm and a plane parallel paraffin plate with a thickness of 0.5 cm are placed in the space between the capacitor plates find :

(i) Intensity of electric field in each layer.

(ii) The drop of potential in each layer.

(iii) Surface charge density on the capacitor. Given that : $k_{glass} = 6$, $k_{paraffin} = 2$

4. Two parallel plate capacitors A & B have the same separation $d = 8.85 \times 10^{-4}$ m between the plates. The plate areas of A & B are 0.04 m^2 & 0.02 m^2 respectively. A slab of di-electric constant (relative permittivity) K=9 has dimensions such that it can exactly fill the space between the plates of capacitor B.



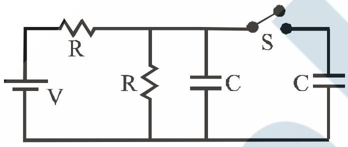
(a) (b) (c)

(i) The di-electric slab is placed inside A as shown in the figure (a) A is then charged to a potential difference of 110 volt. Calculate the capacitance of A and the energy stored in it.

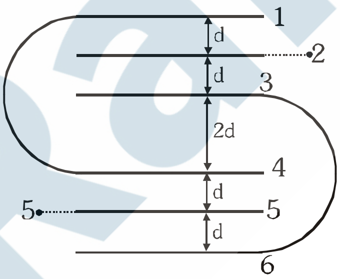
(ii) The battery is disconnected & then the di-electric slab is removed from A . Find the work done by the external agency in removing the slab from A .

(iii) The same di-electric slab is now placed inside B, filling it completely. The two capacitors A & B are then connected as shown in figure (c). Calculate the energy stored in the system.

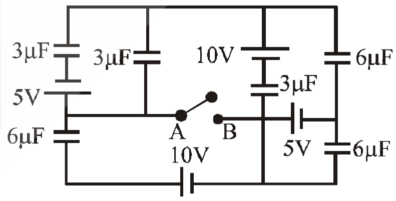
5. In the figure shown initially switch is open for a long time. Now the switch is closed at t = 0. Find the charge on the rightmost capacitor as a function of time given that it was intially uncharged.



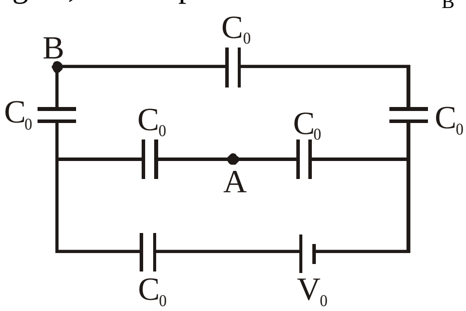
6. There are six plates of equal area A and separation between the plates is d (d<<A) are arranged as shown in figure. The equivalent capacitance between points 2 and 5, is $\alpha \frac{\epsilon_0 A}{d}$. Then find the value of α.



7. Find the charge flown through the switch from A to B when it is closed.



8. In the arrangement shown in figure, find the potential difference $V_B - V_A$ (in Volt). (Take $V_0 = 55$ V)



EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

Capacitance

1. A parallel plate capacitor has d = 1mm and C = 1 F with no medium inside will have :-

(A) Area = $36\,\pi \times 10^6$
(B) Area = $4\,\pi \times 10^6$
(C) Area = $6\,\pi \times 10^6$
(D) Area = $\pi \times 10^6$

2. A capacitor connected with battery is kept in a box so :-

(A) Net flux will come out from the box
(B) Net flux will get in the box
(C) Net flux is zero
(D) Net flux depends on polarity of battery

3. Choose the CORRECT statement :-

(A) C will increase on increasing Q
(B) C will increase on decreasing Q
(C) C will increase on decreasing V
(D) C doesnot depend on Q & V

4. The plate areas and plate separations of parallel plate capacitors are

Capacitor 1 : area A_0, separation d_0
Capacitor 2 : area $2A_0$, separation $2d_0$
Capacitor 3 : area $2A_0$, separation $d_0/2$
Capacitor 4 : area $A_0/2$, separation $2d_0$
Capacitor 5 : area A_0, separation $d_0/2$

Rank these according to their capacitances, least to greatest

(A) 1, 2, 3, 4, 5
(B) 5, 4, 3, 2, 1
(C) 5, 3 and 4 tie ; then 1, 2
(D) 4, 1 and 2 tie ; then 5, 3

Capacitor circuits

5. A 2-μF and a 1-μF capacitor are connected in parallel and a potential difference is applied across the combination. The 2-μF capacitor has :

(A) Twice the charge of the 1-μF capacitor
(B) Half the charge of the 1-μF capacitor
(C) Twice the potential difference of the 1-μF
(D) Half the potential difference of the 1-μF capacitor

6. A 2-μF and a 1-μF capacitor are connected in series and a potential difference is applied across the combination. The 2-μF capacitor has :

(A) Twice the charge of the 1-μF capacitor
(B) Half the charge of the 1-μF capacitor
(C) Twice the potential difference of the 1-μF
(D) Half the potential difference of the 1-μF capacitor

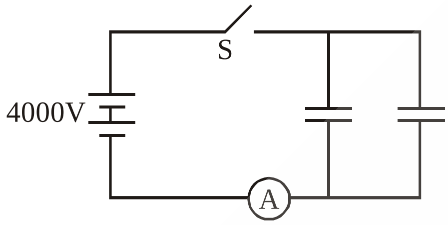
7. Capacitor C_1 and C_2 are connected in parallel and a potential difference is applied to the combination. If the capacitor that is equivalent to the combination has the same potential difference, then the charge on the equivalent capacitor is the same as :

(A) The charge on C_1
(B) The sum of the charges on C_1 and C_2
(C) The difference of the charges on C_1 and C_2
(D) The product of the charges on C_1 and C_2

8. A 2-μF and a 1-μF capacitor are connected in series and charged from a battery. They store charges P and Q, respectively. When disconnected and charged separately using the same battery, they have charges R and S, respectively. Then :

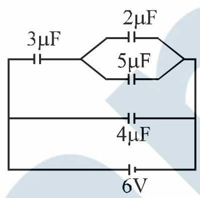
(A) R > S > Q = P (B) P > Q > R = S (C) R > P = Q > S (D) R = P > S = Q

9. Each of the two 25-μF capacitors shown is initially unchanged. How many coulombs of charge pass through the ammeter A after the switch S is closed ?



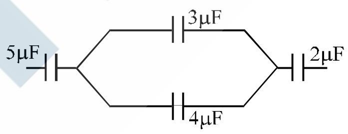
(A) 0.10 (B) 0.20 (C) 10 (D) 0.05

10. In the circuit shown in figure, the ratio of charges on 5μF and 4μF capacitor is :-



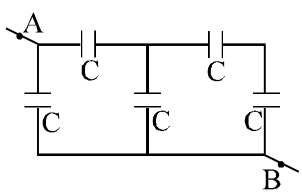
(A) 4/5 (B) 3/5 (C) 3/8 (D) 1/2

11. If charge on left plate of the 5μF capacitor in the circuit segment shown in the figure is –20μC, the charge on the right plate of 3μF capacitor is :-



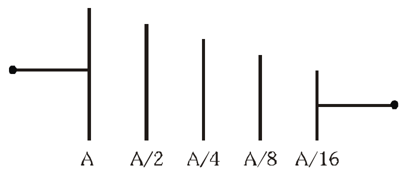
(A) +8.57 μC (B) –8.57 μC (C) +11.42 μC (D) –11.42 μC

12. What is the equivalent capacitance of the system of capacitors between A & B as shown in the figure.



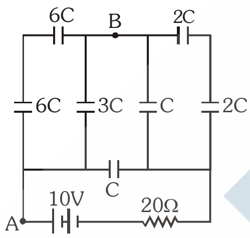
(A) $\frac{7}{6}$C (B) 1.6 C (C) C (D) None

13. 5 Conducting plates each are placed face to face & equi-spaced at distance d. Area of each plate is half the previous plate. If area of first plate is A. Then the equivalent capacitance of the system shown is :-



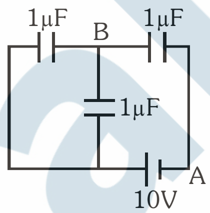
(A) $\frac{\varepsilon_0 A}{d}$ (B) $\frac{\varepsilon_0 A}{10d}$ (C) $\frac{\varepsilon_0 A}{20d}$ (D) $\frac{\varepsilon_0 A}{30d}$

14. For the circuit shown here, the potential difference between points A and B is :-



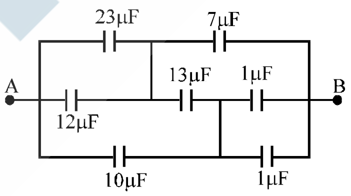
(A) 2.5 V (B) 7.5 V (C) 10 V (D) Zero

15. If potential of A is 10V, then potential of B is :-



(A) 25/3 V (B) 50/3 V (C) 100/3 V (D) 50 V

16. Find the equivalent capacitance across A & B :-



(A) $\frac{28}{3}$ μf (B) $\frac{15}{2}$ μF (C) 15 μF (D) none

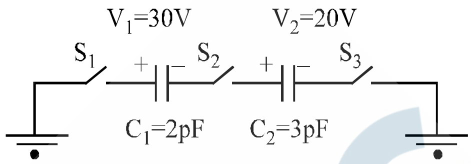
17. A capacitor of capacitance C is charged to a potential difference V from a cell and then disconnected from it. A charge +Q is now given to its positive plate. The potential difference across the capacitor is now :-

(A) V (B) $V + \frac{Q}{C}$ (C) $V + \frac{Q}{2C}$ (D) $V - \frac{Q}{C}$, if $V < CV$

18. A parallel plate capacitor is made by stacking n equally spaced plates connected alternatively. If the capacitance between any two adjacent plates is C, then the resultant capacitance is :-**[AIEEE-2005]**

(A) (n–1)C (B) (n+1)C (C) C (D) nC

19. For the circuit shown, which of the following statements is true ? **[IIT-JEE 1999]**



(A) with S_1 closed, V_1 = 15 V, V_2 = 20 V

(B) with S_3 closed, $V_1 = V_2$ = 25 V

(C) with S_1 & S_2 closed, $V_1 = V_2$ = 0

(D) with S_1 & S_2 closed, V_1 = 30 V, V_2 = 20 V

Force & energy

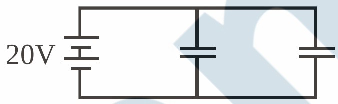
20. A 2-μF and a 1-μF capacitor are connected in series and charged by a battery. They store energies P and Q, respectively. When disconnected and charged separately using the same battery, they store energies R and S, respectively. Then

(A) R > P > S > Q (B) P > Q > R > S (C) R > P > Q > S (D) R > S > Q > P

21. Capacitors A and B are identical. Capacitor A is charged so it stores 4J of energy and capacitor B is uncharged. The capacitor are then connected in parallel. The total stored energy in the capacitors is now:

(A) 16 J (B) 8 J (C) 4 J (D) 2 J

22. To store a total of 4×10^{-4} J of energy in the two identical capacitors shown, each should have a capacitance of :



(A) 0.10 μF (B) 0.50 μF, 0.10 μF (C)1.0 μF (D) 1.5 μF

23. A battery is used to charged a parallel-plate capacitor, after which it is disconnected. Then the plates are pulled apart to twice their original separation. This process will doubled the :

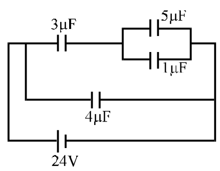
(A) capacitance (B) surface charge density on each plate

(C) stored energy (D) electric field between the two places

24. A parallel-plate capacitor has a plate area of 0.3 m^2 and a plate separation of 0.1 mm. If the charge on each plate has a magnitude of 5×10^{-6} C then the force exerted by one plate on the other has a magnitude of about :

(A) 0 (B) 5 N (C) 1×10^4 N (D) 9×10^5 N

25. In the circuit shown, the energy stored in 1μF capacitor is :-



(A) 40 μJ (B) 64 μJ (C) 32 μJ (D) none

26. A parallel plate capacitor has an electric field of 10^5V/m between the plates. If the charge on the capacitor plate is 1μC, then the force on each capacitor plate is :-

(A) 0.1N (B) 0.05N (C) 0.02N (D) 0.01N

27. Consider a capacitor connected with a battery, capacitor is in steady state. Now plates of capacitor are drawn apart so as to double the separation in two cases.

Case :

(i) Battery remains connected

(ii) Battery is disconnected

Mark the **CORRECT** statement.

(A) In case (i) energy of capacitor increases

(B) In case (i) work done by battery is positive

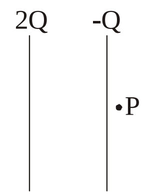
(C) In case (ii) energy of capacitor increases

(D) In case (ii) potential difference across capacitor decreases

28. Two identical capacitors, have the same capacitance C. One of them is charged to potential V_1 and the other to V_2. The negative ends of the capacitors are connected together. When the positive ends are also connected, the decrease in energy of the combined system is :- **[IIT-JEE 2002 (Scr)]**

(A) $\frac{1}{4}C\left(V_1^2 - V_2^2\right)$ (B) $\frac{1}{4}C\left(V_1^2 + V_2^2\right)$ (C) $\frac{1}{4}C\left(V_1 - V_2\right)^2$ (D) $\frac{1}{4}C\left(V_1 + V_2\right)^2$

29. In the figure shown the plates of a parallel plate capacitor have unequal charges. Its capacitance is 'C'. P is a point outside the capacitor and close to the plate of charge–Q. The distance between the plates is 'd' then which statement is wrong :-



(A) A point charge at point 'P' will experience electric force due to capacitor

(B) The potential difference between the plates will be $\frac{3Q}{2C}$

(C) The energy stored in the electric field in the region between the plates is $\frac{9Q^2}{8C}$

(D) The force on one plate due to the other plate is $\frac{Q^2}{2\pi \in_0 d^2}$

Dielectrics

30. A dielectric slab is slowly inserted between the plates of a parallel plate capacitor, while the potential difference between the plates is held constant by a battery. As it is being inserted :

(A) the capacitance, the potential difference between the plates, and the charge on the positive plate all increase

(B) the capacitance, the potential difference between the plates, and the charge on the positive plate all decrease

(C) the potential difference between the plates increases, the charge on the positive plate decreases, and the capacitance remains the same

(D) the capacitance and the charge on the positive plate increase but the potential difference between the plates remains the same

31. An air-filled parallel-plate capacitor has a capacitance of 1 pF. The plate separation is then doubled and a wax dielectric is inserted, completely filling the space between the plates. As a result, the capacitance becomes 2 pF. The dielectric of the wax is

(A) 0.25 (B) 0.5 (C) 2.0 (D) 4.0

32. One of materials listed below is to be placed between two identical metal sheets, with no, air gap, to form a parallel-plate capacitor. Which produces the greatest capacitance ?

(A) material of thickness 0.1 mm and dielectric constant 2
(B) material of thickness 0.2 mm and dielectric constant 3
(C) material of thickness 0.3 mm and dielectric constant 2
(D) material of thickness 0.4 mm and dielectric constant 8

33. Two parallel-plate capacitors with the same plate area but different capacitance are connected in parallel to a battery. Both capacitors are filled with air. The quantity that is the same for both capacitors when they are fully charged is :

(A) potential difference (B) energy density
(C) electric field between the plates (D) charge on the positive plate

34. A capacitor stores 60μC charge when connected across a battery. When the gap between the plates is filled with a dielectric, a charge of 120μC flows through the battery. The dielectric constant of the material inserted is :

(A) 1 (B) 2 (C) 3 (D) none

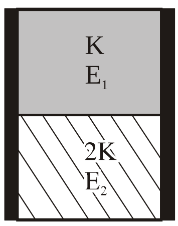
35. Condenser A has a capacity of 15 μF when it is filled with a medium of dielectric constant 15. Another condenser B has a capacity 1 μF with air between the plates. Both are charged separately by a battery of 100V . After charging, both are connected in parallel without the battery and the dielectric material being removed. The common potential now is :-

(A) 400V (B) 800V (C) 1200V (D) 1600V

36. Three capacitors 2 μF, 3 μF and 5 μF can withstand voltages to 3V, 2V and 1V respectively. Their series combination can withstand a maximum voltage equal to :-

(A) 5 Volts (B) (31/6) Volts (C) (26/5) Volts (D) None

37. A parallel plate capacitor is connected from a cell and then isolated from it. Two dielectric slabs of dielectric constant K and 2K are now introduce in the region between upper half and lower half of the plate (as shown in figure). The electric field intensity in upper half of dielectric is E_1 and lower half is E_2 then



(A) $E_1 = 2E_2$

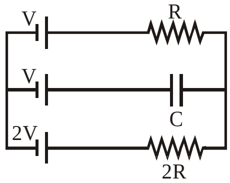
(B) Electrostatic potential energy of upper half is less than that of lower half
(C) Induced charges on both slabs are same
(D) Charge distribution on the plates remains same after insertion of dielectric

38. Two point charges exert a force F_0 on each other when placed in vacuum. Now the charges are increased to four times, separation between them is doubled and the system is placed is an insulating medium. Now they experience the same force. What should be the dielectric constant of the medium?

(A) 3 (B) 4 (C) 2 (D) 5

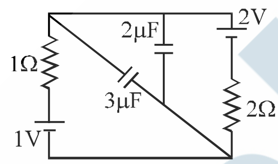
R-C Circuits

39. In the given circuit, with steady current the potential drop across the capacitor must be :-



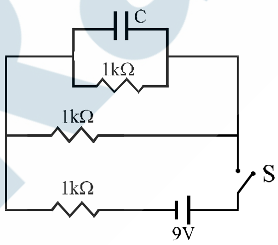
(A) V (B) $\frac{V}{2}$ (C) $\frac{V}{3}$ (D) $\frac{2V}{3}$

40. In the circuit shown, the charge on the 3μF capacitor at steady state will be



(A) 6 μC (B) 4 μC (C) $\frac{2}{3}$ μC (D) 3 μC

41. A capacitor C = 100 μF is connected to three resistor each of resistance 1 kΩ and a battery of emf 9V. The switch S has been closed for long time so as to charge the capacitor. When switch S is opened, the capacitor discharges with time constant :-



(A) 33 ms (B) 5 ms (C) 3.3 ms (D) 50 ms

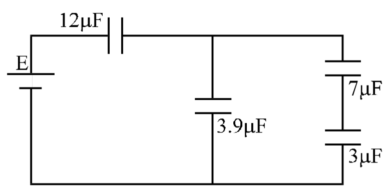
42. An uncharged capacitor of capacitance 4μF, a battery of emf 12 volt and a resistor of 2.5 MΩ are connected in series. The time after which $v_c = 3v_R$ is (take $ln2 = 0.693$) **[IIT-JEE' 2005 (Scr)]**

(A) 6.93 sec. (B) 13.86 sec. (C) 20.52 sec. (D) none of these

MULTIPLE CORRECT TYPE QUESTIONS

Capacitor Circuits

43. Four capacitors and a battery are connected as shown. The potential drop across the 7 μF capacitor is 6 V. Then the :



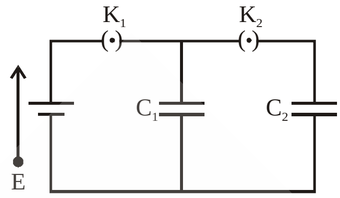
(A) potential difference across the 3 μF capacitor is 10 V

(B) charge on the 3 μF capacitor is 42 μC

(C) e.m.f. of the battery is 30 V

(D) potential difference across the 12 μF capacitor is 10 V.

44. In the circuit shown in figure initially key K_1 is closed and key K_2 is open. Then K_1 is opened and K_2 is closed (order is important). [Take Q'_1 and Q'_2 as charges on C_1 and C_2 and V_1 and V_2 as voltage respectively. Then



(A) charge on C_1 gets redistributed such that $V_1 = V_2$
(B) charge on C_1 gets redistributed such that $Q'_1 = Q'_2$
(C) charge on C_1 gets redistributed such that $C_1V_1 + C_2V_2 = C_1 E$
(D) charge on C_1 gets redistributed such that $Q'_1 + Q'_2 = Q$

45. A circuit shown in the figure consists of a battery of emf 10 V and two capacitance C_1 and C_2 of capacitances 1.0 μF and 2.0 μF respectively. The potential difference $V_A - V_B$ is 5V

(A) charge on capacitor C_1 is equal to charge on capacitor C_2
(B) Voltage across capacitor C_1 is 5V.
(C) Voltage across capacitor C_2 is 10 V
(D) Energy stored in capacitor C_1 is two times the energy stored in capacitor C_2.

Dielectrics

46. A parallel plate capacitor has a parallel slab of copper inserted between and parallel to the two plates, without touching the plates. The capacity of the capacitor after the introduction of the copper sheet is:
(A) minimum when the copper slab touches one of the plates.
(B) maximum when the copper slab touches one of the plates.
(C) invariant for all positions of the slab between the plates.
(D) greater than that before introducing the slab.

47. A parallel plate air-core capacitor is connected across a source of constant potential difference. When a dielectric plate is introduced between the two plates then :
(A) some charge from the capacitor will flow back into the source.
(B) some extra charge from the source will flow back into the capacitor.
(C) the electric field intensity between the two plate does not change.
(D) the electric field intensity between the two plates will decrease.

48. A parallel plate capacitor of plate area A and plate seperation d is charged to potential difference V and then the battery is disconnected. A slab of dielectric constant K is then inserted between the plates of the capacitor so as to fill the space between the plates. If Q, E and W denote, the magnitude of charge on each plate, the electric field between the plates (after the slab is inserted) and the work done on the system respectively in question, then in the process of inserting the slab

(A) $Q = \dfrac{\varepsilon_0 AV}{d}$ (B) $Q = \dfrac{\varepsilon_0 KAV}{d}$ (C) $E = \dfrac{V}{Kd}$ (D) $W = -\dfrac{\varepsilon_0 AV^2}{2d}\left(1-\dfrac{1}{K}\right)$

49. The capacitance of a parallel plate capacitor is C when the region between the plate has air. This region is now filled with a dielectric slab of dielectric constant k. The capacitor is connected to a cell of emf E, and the slab is taken out
(A) charge $CE(k-1)$ flows through the cell
(B) energy $E^2C(k-1)$ is absorbed by the cell.
(C) the energy stored in the capacitor is reduced by $E^2C(k-1)$
(D) the external agent has to do $\dfrac{1}{2}E^2C(k-1)$ amount of work to take the slab out.

50. A capacitor of capacity C_0 is connected to a battery of emf V_0. When steady state is attained a dielectric slab of dielectric constant K is slowly introduced in the capacitor. Mark the Correct statement(s), in final steady state :-

(A) Magnitude of induced charge on the each surface of slab is C_0V_0 (K – 1)

(B) Net electric force due to induced charges on the plate is zero.

(C) Force of attraction between plates of capacitor is $\dfrac{K\left(C_0V_0\right)^2}{2\in_0 A}$

(D) Net field due to induced charges in dielectric slab is $\dfrac{8V_0\left(k-1\right)^2}{K\in_0 A}$

R-C Circuits

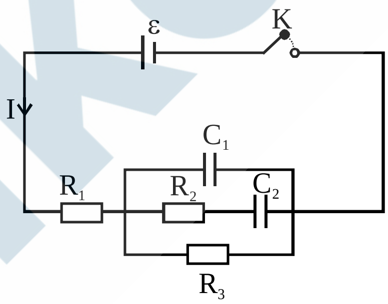
51. Mark the **CORRECT** statement(s) regarding the current I through the battery in the circuit shown in figure.

(A) Immediately after the key K is closed, $I = \dfrac{\varepsilon}{R_1}$

(B) Immediately after the key K is closed, $I = \dfrac{\varepsilon}{R_1+R_3}$

(C) Long time after key K is closed, $I = \dfrac{\varepsilon}{R_1+R_3}$

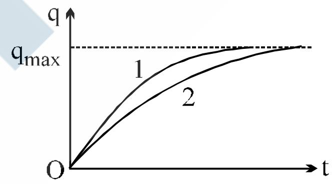
(D) Long time after key K is closed, $I = \dfrac{\varepsilon}{R_1+R_2}$



COMPREHENSION TYPE QUESTIONS

Paragraph for Question No. 52 & 53

The charge across the capacitor in two different RC circuits 1 and 2 are plotted as shown in figure.



52. Choose the correct statement(s) related to the two circuits.

(A) Both the capacitors are charged to the same charge.

(B) The emf's of cells in both the circuit are equal.

(C) The emf's of the cells may be different.

(D) The emf E_1 is more than E_2

53. Identify the correct statement(s) related to the R_1, R_2, C_1 and C_2 of the two RC circuits.

(A) $R_1 > R_2$ if $E_1 = E_2$
(B) $C_1 < C_2$ if $E_1 = E_2$

(C) $R_1C_1 > R_2C_2$
(D) $\dfrac{R_1}{R_2} < \dfrac{C_2}{C_1}$

MATRIX MATCH TYPE QUESTION

54.

Column-I	**Column-II**
(A) Plates of an isolated, charged, parallel plate, air core capacitor are slowly pulled apart.	(P) Electric energy stored inside capacitor increases in the process.
(B) A dielectric is slowly inserted inside an isolated and charged parallel plate air cored capacitor to completely fill the space between plates.	(Q) Force between the two plates of the capacitor remain unchanged.
(C) Plates of a parallel plate capacitor connected across a battery are slowly pulled apart.	(R) Electric field in the region between plates remain unchanged.
(D) A dielectric slab is slowly inserted inside a parallel plate capacitor connected across a battery to completely fill the space between plates.	(S) Total electric energy stored inside capacitor decreases in the process.
	(T) Electric field in the region decreases.

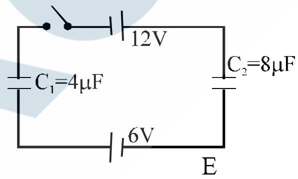
EXERCISE (O-2)

SINGLE CORRECT TYPE QUESTIONS

1. Three long concentric conducting cylindrical shells have radii R, 2R and $2\sqrt{2}$ R. Inner and outer shells are connected to each other. The capacitance across middle and inner shells per unit length is:

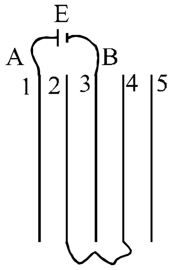
(A) $\dfrac{\frac{1}{3}\in_0}{\ell n\,2}$ (B) $\dfrac{6\pi\in_0}{\ell n\,2}$ (C) $\dfrac{\pi\in_0}{2\ell n\,2}$ (D) None

2. In the circuit shown initially C_1 & C_2 are uncharged. After closing the switch



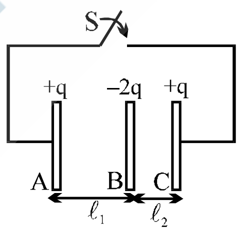
(A) The charge on C_2 is greater that on C_1
(B) The charge on C_1 and C_2 are the same
(C) The potential drops across C_1 and C_2 are the same
(D) The potential drops across C_2 is greater than that across C_1

3. Five conducting parallel plates having area A and separation between them d, are placed as shown in the figure. Plate number 2 and 4 are connected wire and between point A and B, a cell of emf E is connected. The charge flown through the cell is :-



(A) $\dfrac{3}{4}\dfrac{\varepsilon_0 AE}{d}$ (B) $\dfrac{2}{3}\dfrac{\varepsilon_0 AE}{d}$ (C) $\dfrac{4\varepsilon_0 AE}{d}$ (D) $\dfrac{\varepsilon_0 AE}{2d}$

4. Three long conducting plate A, B & C having charges +q, –2q & +q as shown in figure. Here plate A and C are fixed. If the switch S is closed. The middle plate (B) will start moving in



(here $\ell_1 > \ell_2$)

(A) Leftward direction (B) Rightward direction
(C) will not move (D) First move leftward & then rightward

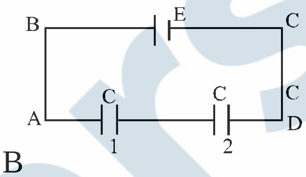
5. A capacitor of capacitance C is initially charged to a potential difference of V volt. Now it is connected to a battery of 2V Volt with opposite polarity. The ratio of heat generated to the final energy stored in the capacitor will be :-

(A) 1.75 (B) 2.25 (C) 2.5 (D) 1/2

6. A conducting body 1 has some initial charge Q, and its capacitance is C. There are two other conducting bodies, 2 and 3, having capacitances : $C_2 = 2C$ and $C_3 \to \infty$. Bodies 2 and 3 are initially uncharged. "Body 2 is touched with body 1. Then, body 2 is removed from body 1 and touched with body 3, and then removed." This process is repeated N times. Then, the charge on body 1 at the end must be

(A) $Q/3^N$ (B) $Q/3^{N-1}$ (C) Q/N^3 (D) None

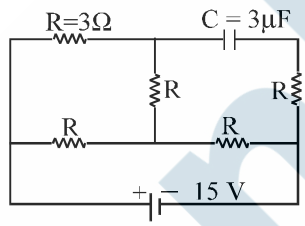
7. In the adjoining figure, capacitor (1) and (2) have a capacitance 'C' each. When the dielectric of dielectric constant K is inserted between the plates of one of the capacitor, the total charge flowing through battery is :-



(A) $\frac{KCE}{K+1}$ from B to C (B) $\frac{KCE}{K+1}$ from C to B

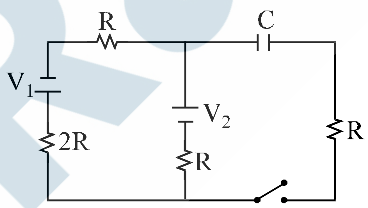
(C) $\frac{(K-1)CE}{2(K+1)}$ from B to C (D) $\frac{(K-1)CE}{2(K+1)}$ from C to B

8. In the circuit shown, the cell is ideal, with emf = 15 V. Each resistance is of 3Ω. The potential difference across the capacitor is :-



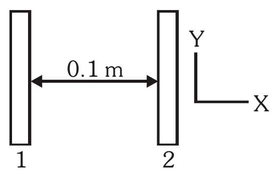
(A) zero (B) 9 V (C) 12 V (D) 15 V

9. In the transient circuit shown the time constant of the circuit is :



(A) $\frac{5}{3}RC$ (B) $\frac{5}{2}RC$ (C) $\frac{7}{4}RC$ (D) $\frac{7}{3}RC$

10. Two insulating plates are both uniformly charged in such a way that the potential difference between them is $V_2 - V_1 = 20$ V. (i.e., plate 2 is at a higher potential). The plates are separated by d = 0.1 m and can be treated as infinitely large. An electron is released from rest on the inner surface of plate 1. What is its speed when it hits plate 2 ? ($e = 1.6 \times 10^{-19}$ C, $m_0 = 9.11 \times 10^{-31}$ kg) **[AIEEE-2006]**



(A) 2.65×10^6 m/s (B) 7.02×10^{12} m/s (C) 1.87×10^6 m/s (D) 32×10^{-19} m/s

11. A battery is used to charge a parallel plate capacitor till the potential difference between the plates becomes equal to the electromotive force of the battery. The ratio of the energy stored in the capacitor and the work done by the battery will be- **[AIEEE-2007]**

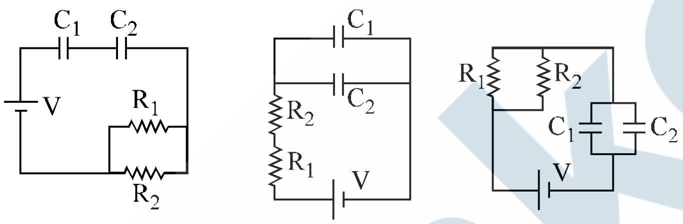
(A) 1 (B) 2 (C) 1/4 (D) 1/2

12. A parallel plate condenser with a dielectric of dielectric constant K between the plates has a capacity C and is charged to a potential V volts. The dielectric slab is slowly removed from between the plates and then re-inserted. The net work done by the system in this process is- **[AIEEE-2007]**

(A) $\frac{1}{2}(K-1)CV^2$ (B) $CV^2(K-1)/K$ (C) $(K-1)CV^2$ (D) zero

13. Given : $R_1 = 1\Omega$, $R_2 = 2\Omega$, $C_1 = 2\mu F$, $C_2 = 4\mu F$ **[IIT-JEE 2006]**

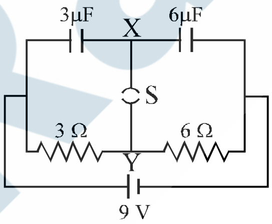
The time constants (in μS) for the circuits I, II, III are respectively



(I) (II) (III)

(A) 18, 8/9, 4 (B) 18, 4, 8/9 (C) 4, 8/9, 18 (D) 8/9, 18, 4

14. A circuit is connected as shown in the figure with the switch S open. When the switch is closed, the total amount of charge that flows from Y to X is :- **[IIT-JEE 2007]**



(A) 0 (B) 54 μC (C) 27 μC (D) 81 μC

MULTIPLE CORRECT TYPE QUESTIONS

15. A parallel-plate capacitor is connected to a cell. Its positive plate A and its negative plate B have charges +Q and –Q respectively. A third plate C, identical to A and B, with charge +Q, is now introduced midway between A and B, parallel to them. Which of the following are correct?

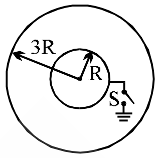
(A) The charge on the inner face of B is now $-\frac{3Q}{2}$

(B) There is no change in the potential difference between A and B.

(C) The potential difference between A and C is one-third of the potential difference between B and C.

(D) The charge on the inner face of A is now $Q/2$.

16. Two thin conducting shells of radii R and 3R are shown in the figure. The outer shell carries a charge +Q and the inner shell is neutral. The inner shell is earthed with the help of a switch S.



(A) With the switch S open, the potential of the inner sphere is equal to that of the outer.

(B) When the switch S is closed, the potential of the inner sphere becomes zero.

(C) With the switch S closed, the charge attained by the inner sphere is – Q/3.

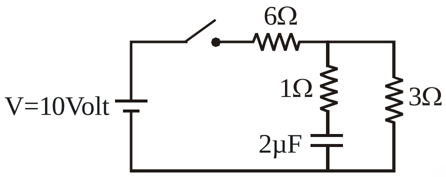
(D) By closing the switch the capacitance of the system increases.

MATRIX MATCH TYPE QUESTION

17. Match the following. In each of the cases shown below, find the time constant of the circuit (in μs) after switch is closed.

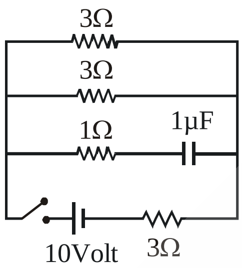
List-I | **List-II**

(P)



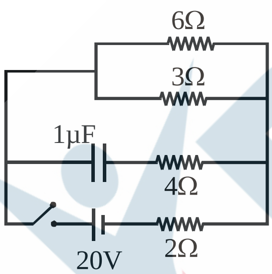
(1) 6

(Q)



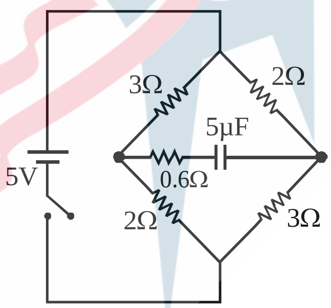
(2) 2

(R)



(3) 5

(S)



(4) 15

Codes :

	P	Q	R	S
(A)	1	2	1	4
(B)	3	1	4	2
(C)	1	2	3	4
(D)	2	4	1	3

EXERCISE (J-M)

1. Let C be the capacitance of a capacitor discharging through a resistor R. Suppose t_1 is the time taken for the energy stored in the capacitor to reduce to half its initial value and t_2 is the time taken for the charge to reduce to one-fourth its initial value. Then the ratio t_1/t_2 will be : **[AIEEE-2010]**

(1) 2 (2) 1 (3) 1/2 (4) 1/4

2. Two identical charged spheres are suspended by strings of equal lengths. The strings make an angle of 30° with each other. When suspended in a liquid of density 0.8 g cm^{-3}, the angle remains the same. If density of the material of the sphere is 1.6 g cm^{-3}, the dielectric constant of the liquid is : **[AIEEE - 2010]**

(1) 1 (2) 4 (3) 3 (4) 2

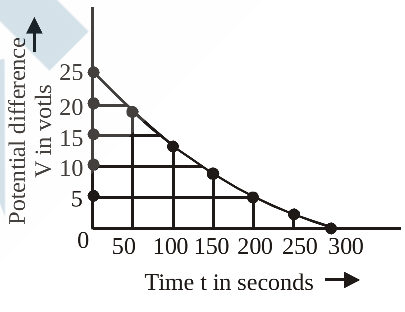
3. A resistor 'R' and 2μF capacitor in series is connected through a switch to 200 V direct supply. Across the capacitor is a neon bulb that lights up at 120 V. Calculate the value of R to make the bulb light up 5s after the switch has been closed. ($\log_{10} 2.5 = 0.4$) **[AIEEE-2011]**

(1) $2.7 \times 10^6\ \Omega$ (2) $3.3 \times 10^7\ \Omega$ (3) $1.3 \times 10^4\ \Omega$ (4) $1.7 \times 10^5\ \Omega$

4. Combination of two identical capacitors, a resistor R and a dc voltage source of voltage 6V is used in an experiment on (C–R) circuit. It is found that for a parallel combination of the capacitor the time in which the voltage of the fully charged combination reduces to half its original voltage is 10 second. For series combination the time needed for reducing the voltage of the fully charged series combination by half is :- **[AIEEE-2011]**

(1) 20 second (2) 10 second (3) 5 second (4) 2.5 second

5. The figure shows an experimental plot for discharging of a capacitor in an R–C circuit. The time constant τ of this circuit lies between :-



(1) 100 sec and 150 sec (2) 150 sec and 200 sec
(3) 0 and 50 sec (4) 50 sec and 100 sec

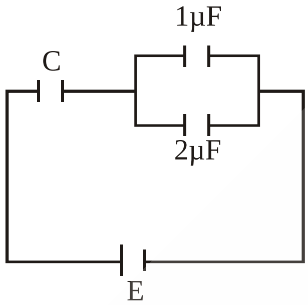
6. Two capacitors C_1 and C_2 are charged to 120V and 200V respectively. It is found that by connecting them together the potential on each one can be made zero. Then : **[JEE-Main-2013]**

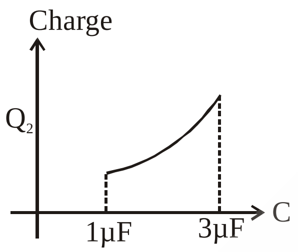
(1) $5C_1 = 3C_2$ (2) $3C_1 = 5C_2$ (3) $3C_1 + 5C_2 = 0$ (4) $9C_1 = 4C_2$

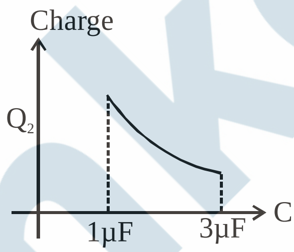
7. A parallel plate capacitor is made of two circular plates separated by a distance of 5 mm and with a dielectric of dielectric constant 2.2 between them. When the electric field in the dielectric is 3×10^4 V/m, the charge density of the positive plate will be close to : **[JEE-Main-2014]**

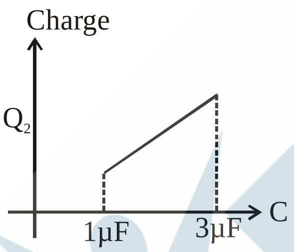
(1) 3×10^4 C/m^2 (2) 6×10^4 C/m^2 (3) 6×10^{-7} C/m^2 (4) 3×10^{-7} C/m^2

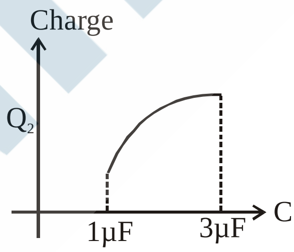
8. In the given circuit, charge Q_2 on the 2μF capacitor changes as C is varied from 1μF to 3μF. Q_2 as a function of 'C' is given properly by : (figures are drawn schematically and are not to scale) :- **[JEE-Main-2015]**



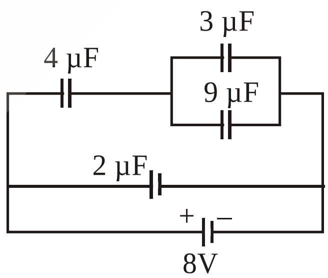
(1)


(2)


(3)


(4)


9. 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 μF and 9 μF capacitors), at a point 30 m from it , would equal: **[JEE-Main-2016]**



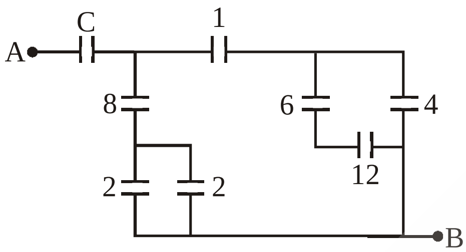
(1) 480 N/C (2) 240 N/C (3) 360 N/C (4) 420 N/C

10. Three capacitors each of 4 μF are to be connected in such a way that the effective capacitance is 6 μF. This can be done by connecting them : **[JEE-Main online-2016]**

(1) two in parallel and one in series (2) all in parallel

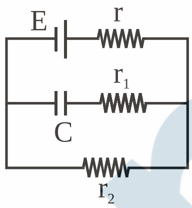
(3) two in series and one in parallel (4) all in series

11. 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 μF is :- **[JEE-Main online-2016]**



(1) $\frac{33}{23}\mu F$ (2) $\frac{34}{23}\mu F$ (3) $\frac{31}{23}\mu F$ (4) $\frac{32}{23}\mu F$

12. In the given circuit diagram when the current reaches steady state in the circuit, the charge on the capacitor of capacitance C will be : **[JEE-Main-2017]**



(1) $CE\frac{r_2}{(r+r_2)}$ (2) $CE\frac{r_1}{(r_1+r)}$ (3) CE (4) $CE\frac{r_1}{(r_2+r)}$

13. A capacitance of 2 μF is required in an electrical circuit across a potential difference of 1.0 kV. A large number of 1 μF 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 : **[JEE-Main-2017]**

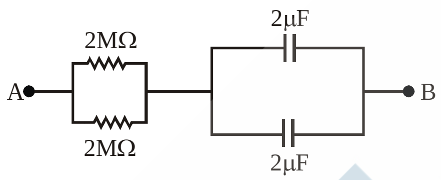
(1) 24 (2) 32 (3) 2 (4) 16

14. A parallel plate capacitor of capacitance 90 pF is connected to a battery of emf 20V. If a dielectric material of dielectric constant $K = \frac{5}{3}$ is inserted between the plates, the magnitude of the induced charge will be :- **[JEE-Main-2018]**

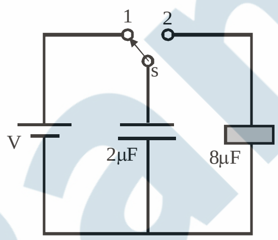
(1) 0.3 n C (2) 2.4 n C (3) 0.9 n C (4) 1.2 n C

EXERCISE (J-A)

1. At time t=0, a battery of 10V is connected across points A and B in the given circuit. If the capacitors have no charge initially, at what time (in seconds) does the voltage across them become 4V?
[Take : $\ell n\ 5 = 1.6$, $\ell n 3 = 1.1$] **[IIT-JEE 2010]**

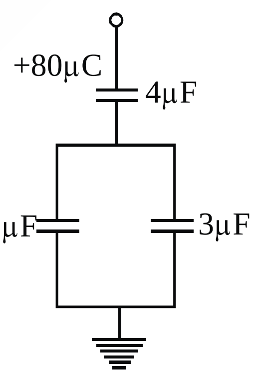


2. A 2 μF capacitor is charged as shown in figure. The percentage of its stored energy dissipated after the switch S is turned to position 2 is :- **[IIT-JEE 2011]**



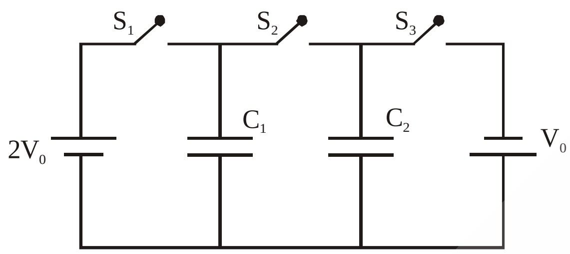
(A) 0% (B) 20% (C) 75% (D) 80%

3. In the given circuit, a charge of +80 μC is given to the upper plate of the 4μF capacitor. Then in the steady state, the charge on the upper plate of the 3μF capacitor is :- **[IIT-JEE 2012]**



(A) + 32 μC (B) + 40μC (C) +48μC (D) + 80μC

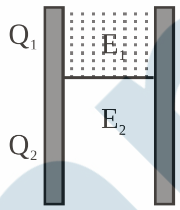
4. In the circuit shown in the figure, there are two parallel plate capacitors each of the capacitance C. The switch S_1 is pressed first to fully charge the capacitor C_1 and then released. The switch S_2 is then pressed to charge the capacitor C_2. After some time, S_2 is released and then S_3 is pressed, After some time, **[IIT-JEE 2013]**



(A) the charge on the upper plate of C_1 is $2CV_0$ (B) the charge on the upper plate of C_1 is CV_0

(C) the charge on the upper plate of C_2 is 0. (D) the charge on the upper plate of C_2 is $-CV_0$

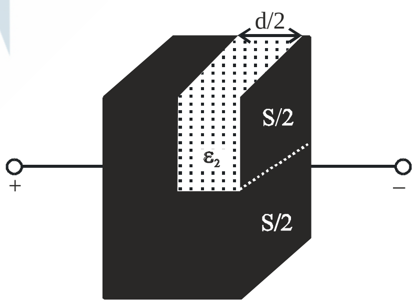
5. A parallel plate capacitor has a dielectric slab of dielectric constant K between its plates that covers 1/3 of the area of its plates, as shown in the figure. The total capacitance of the capacitor is C while that of the portion with dielectric in between is C_1. When the capacitor is charged, the plate area covered by the dielectric gets charge Q_1 and the rest of the area gets charge Q_2. The electric field in the dielectric is E_1 and that in the other portion is E_2. Choose the correct option/options, ignoring edge effects. **[JEE-Advance 2014]**



(A) $\frac{E_1}{E_2} = 1$ (B) $\frac{E_1}{E_2} = \frac{1}{K}$ (C) $\frac{Q_1}{Q_2} = \frac{3}{K}$ (D) $\frac{C}{C_1} = \frac{2+K}{K}$

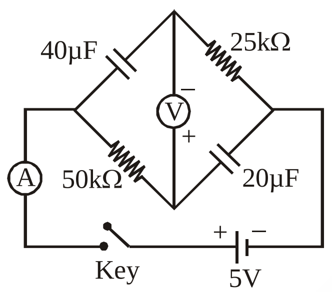
6. A parallel plate capacitor having plates of area S and plate separation d, has capacitance C_1 in air. When two dielectrics of different relative permittivities ($\varepsilon_1 = 2$ and $\varepsilon_2 = 4$) are introduced between the two plates as shown in the figure, the capacitance becomes C_2. The ratio $\frac{C_2}{C_1}$ is :-

[JEE-Advance 2015]



(A) $\frac{6}{5}$ (B) $\frac{5}{3}$ (C) $\frac{7}{5}$ (D) $\frac{7}{3}$

7. In the circuit shown below, the key is pressed at time t = 0. Which of the following statement(s) is(are) true? **[JEE-Advance 2016]**



(A) The voltmeter displays –5V as soon as the key is pressed, and displays +5V after a long time

(B) The voltmeter will display 0 V at time t = ln 2 seconds

(C) The current in the ammeter becomes 1/e of the initial value after 1 second

(D) The current in the ammeter becomes zero after a long time

PARAGRAPH–1

Consider a simple RC circuit as shown in figure 1.

Process 1 : In the circuit the switch S is closed at t = 0 and the capacitor is fully charged to voltage V_0 (i.e., charging continues for time T >> RC). In the process some dissipation (E_D) occurs across the resistance R. The amount of energy finally stored in the fully charged capacitor is E_C.

Process 2 : In a different process the voltage is first set to $\frac{V_0}{3}$ and maintained for a charging time T >> RC. Then the voltage is raised to $\frac{2V_0}{3}$ without discharging the capacitor and again maintained for a time T >> RC. The process is repeated one more time by raising the voltage to V_0 and the capacitor is charged to the same final voltage V_0 as in Process 1.

These two processes are depicted in Figure 2. **[JEE-Advance 2017]**

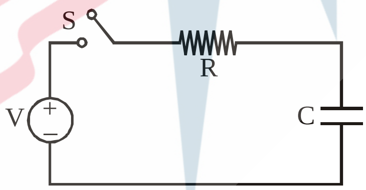


Figure 1

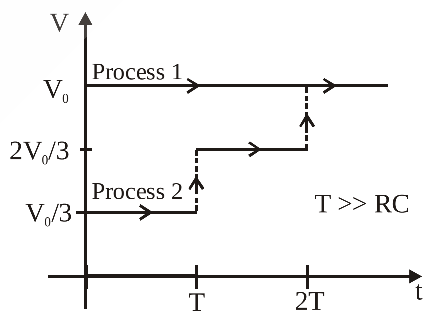


Figure 2

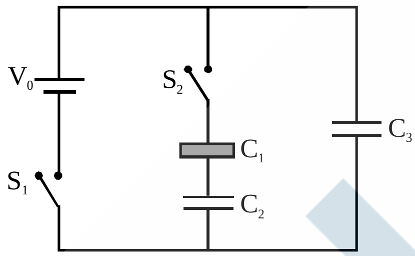
8. In Process 1, the energy stored in the capacitor E_C and heat dissipated across resistance E_D are related by :-

(A) $E_C = E_D$ (B) $E_C = 2E_D$ (C) $E_C = \frac{1}{2}E_D$ (D) $E_C = E_D \ln 2$

9. In Process 2, total energy dissipated across the resistance E_D is :-

(A) $E_D = \frac{1}{3}\left(\frac{1}{2}CV_0^2\right)$ (B) $E_D = 3\left(\frac{1}{2}CV_0^2\right)$ (C) $E_D = \frac{1}{2}CV_0^2$ (D) $E_D = 3CV_0^{\ 2}$

10. Three identical capacitors C_1, C_2 and C_3 have a capacitance of 1.0 μF each and they are uncharged initially. They are connected in a circuit as shown in the figure and C_1 is then filled completely with a dielectric material of relative permittivity $\in_r$. The cell electromotive force (emf) V_0 = 8V. First the switch S_1 is closed while the switch S_2 is kept open. When the capacitor C_3 is fully charged, S_1 is opened and S_2 is closed simultaneously. When all the capacitors reach equilibrium, the charge on C_3 is found to be 5μC. The value of $\in_r$. **[JEE-Advance 2018]**



CAPACITANCE

(CBSE Previous Year's Questions)

1. A parallel capacitor is to be designed with a voltage rating 1 kV using a material of dielectric constant 3 and dielectric strength about 10^7 Vm^{-1}. For safety we would like the field 'never to exceed say, 10% of the dipole strength. What minimum area of the plats is required to have a capacitance of 50 PF?

[2; CBSE-2005]

2. A 4μF capacitor is charged by a 200 V supply. The supply is then disconnected and the charged capacitor is connected to another uncharged 2 μF capacitor. How much electrostatic energy of the first capacitor is lost in the process of attaining the steady situation? **[2; CBSE-2005]**

3. Two capacitors of capacitance of 6μF and 12μF are connected in series with a battery. The voltage across the 6μF capacitor is 2 V. Compute the total battery voltage. **[2; CBSE-2006]**

4. A parallel plate capacitor with air between the plates has a capacitance of 8 pF. The separation between the pates is now reduced by half and the space between them is filled with a medium of dielectric constant 5. Calculate the value of capacitance of the capacitor in the second case.

[2; CBSE-2006]

5. The equivalent capacitance of the combination between A and B in the given figure is 4μF.

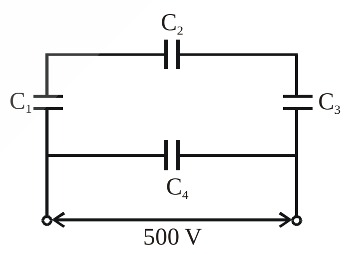
(i) Calculate capacitance of the capacitor C.

(ii) Calculate charge on each capacitor if a 12 V battery is connected across tem1inalsAand B.

(iii) What will be the potential drop across each capacitor ? **[3; CBSE-2009]**

6. A network of four capacitors each of 12μF capacitance is connected to a 500 V supply as shown in the figure. Determine (a) equivalent capacitance of the network and (b) charge on each capacitor.

[3; CBSE-2010]



7. A parallel plate capacitor is being charged by a time varying current. Explain briefly how Ampere's circuital law is generalized to incorporate the effect due to the displacement current. **[2; CBSE-2011]**

8. Net capacitance of three identical capacitor in series is 1μF. What will be their net capacitance if connected in parallel ? Find the ratio of energy stored in the two configurations if they are both connected to the same source. **[2; CBSE-2011]**

9. A capacitor of capacitance 'C' is being charged by connecting it across a dc source along with an ammeter. Will the ammeter show a momentary deflection during the process of charging? If so, how would you explain this momentary deflection and the resulting continuity of current in the circuit? Write the expression for the current inside the capacitor. **[2; CBSE-2012]**

10. Deduce the expression for the electrostatic energy stored in a capacitor ofcapacitance 'C' and having charge'Q'.
How will the (i) energy stored and (ii) the electric field inside the capacitor be affected when it is completely filled with a dielectric material of dielectric constant K? **[3; CBSE-2012]**

11. A slab of material of dielectric constant K has the same area as that of the plates of a parallel plate capacitor but bas the thickness d/2, where d is the separation between the plates. Find out the expression for its capacitance when the slab is inserted between the plates of the capacitor. **[CBSE-2013]**

12. A parallel plate capacitor of capacitance C is charged to a potential V. It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor. **[CBSE-2014]**

13. Define dielectric constant of a medium. What is its S.I. unit ? **[1; CBSE-2015]**

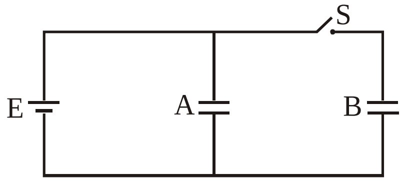
14. Three circuits, each consisting of a switch 'S' and two capacitors, are initially charged, as shown in the figure. After the switch has been closed, in which circuit will the charge on the left-hand capacitor (i) increase, (ii) decrease and (iii) remain same ? Given reasons. **[3; CBSE-2015]**

15. (a) Distinguish, with the help of a suitable diagram, the difference in the behaviour of a conductor and a dielectric plaed in an external electric field. How does polarised dielectric modify the original external field ? **[5; CBSE-2016]**

(b) A capacitor of capacitance C is charged fully by connecting it to a battery of emf E. It is then disconnected from the battery. If the separation between the plates of the capacitor is now doubled, how will the following change ?

(i) charge stored by the capacitor.
(ii) field strength between the plates.
(iii) energy stored by the capacitor.
Justify your answer in each case.

16. Two identical parallel plate capacitors A and B are connected to a battery of V volts with the switch S closed. The switch is now opened and the free space between the plates of the capacitors is filled with a dielectric of dielectric constant K. Find the ratio of the total electrostatic energy stored in both capacitors before and after the introduction of the dielectric. **[3; CBSE-2017]**



ANSWER KEY

EXERCISE (S-1)

1. Ans. 068 2. Ans. 5 3. Ans. 7 4. Ans. 9 5. Ans. 6V, 34V

6. Ans. $\frac{32}{23}$ μF 7. Ans. (C) 8. Ans. 30 V 9. Ans. 0 10. Ans. 12μC

11. Ans. 3Q/2C 12. Ans. $\frac{25}{24}\frac{\varepsilon_0 A}{d}$ 13. Ans. 5 14. Ans. 2.5 kV 15. Ans. 4.425×10^{-9} Ampere

16. Ans. 225 17. Ans. 750 18. Ans. $Q_0 = \frac{CVR_2}{R_1+R_2}$ and $\alpha = \frac{R_1+R_2}{CR_1R_2}$

19. Ans. $\frac{3}{4}$J 20. Ans. $\rho = \tau/\varepsilon_0\varepsilon \ln 2 = 1.4 \times 10^{13}$ Ω.m.

EXERCISE (S-2)

1. Ans. (a) $\frac{100}{7}$ volts; (b) 28.56 μC, 42.84 μC, 71.4 μC, 22.88 μC

2. Ans. (a) $\frac{7}{50}$A or $\frac{11}{50}$A, (b) $Q_1 = 9\mu C$, $Q_2 = 0$

3. Ans. (i) 1.5×10^4 V/m, 4.5×10^4 V/m, (ii) 75 V, 225 V, (iii) 8×10^{-7} C/m^2

4. Ans. (i) 0.2×10^{-8} F, 1.2×10^{-5} J ; (ii) 4.84×10^{-5} J ; (iii) 1.1×10^{-5} J

5. Ans. $q = \frac{CV}{2}\left(1-\frac{1}{2}e^{-t/RC}\right)$ 6. Ans. 1 7. Ans. 69 mC 8. Ans. 5

EXERCISE (O-1)

SINGLE CORRECT TYPE QUESTIONS

1. Ans. (A)	2. Ans. (C)	3. Ans. (D)	4. Ans. (D)	5. Ans. (A)
6. Ans. (D)	7. Ans. (B)	8. Ans. (A)	9. Ans. (B)	10. Ans. (C)
11. Ans. (A)	12. Ans. (B)	13. Ans. (D)	14. Ans. (A)	15. Ans. (B)
16. Ans. (B)	17. Ans. (C)	18. Ans. (A)	19. Ans. (D)	20. Ans. (D)
21. Ans. (D)	22. Ans. (C)	23. Ans. (C)	24. Ans. (B)	25. Ans. (C)
26. Ans. (B)	27. Ans. (C)	28. Ans. (C)	29. Ans. (D)	30. Ans. (D)
31. Ans. (D)	32. Ans. (A,D)	33. Ans. (A)	34. Ans. (C)	35. Ans. (B)
36. Ans. (B)	37. Ans. (B)	38. Ans. (B)	39. Ans. (C)	40. Ans. (B)
41. Ans. (D)	42. Ans. (B)	43. Ans. (B, C, D)	44. Ans. (A,C,D)	45. Ans. (A, D)
46. Ans. (C, D)	47. Ans. (B, C)	48. Ans. (A, C, D)	49. Ans. (A, B, D)	50. Ans. (A, B)
51. Ans. (A, C)				

COMPREHENSION TYPE QUESTIONS

52. Ans. (A, C) 53. Ans. (D)

MATRIX MATCH TYPE QUESTION

54. Ans. (A) $\rightarrow$(PQR); (B) $\rightarrow$(QST); (C) $\rightarrow$(ST); (D) $\rightarrow$(PR)

EXERCISE (O-2)

SINGLE CORRECT TYPE QUESTIONS

1. Ans. (B)	2. Ans. (B)	3. Ans. (B)	4. Ans. (B)	5. Ans. (B)
6. Ans. (A)	7. Ans. (D)	8. Ans. (C)	9. Ans. (C)	10. Ans. (A)
11. Ans. (D)	12. Ans. (D)	13. Ans. (D)	14. Ans. (C)	

MULTIPLE CORRECT TYPE QUESTIONS

15. Ans. (A,B,C,D) 16. Ans. (A,B,C,D)

MATRIX MATCH TYPE QUESTION

17. Ans. (C)

EXERCISE (JM)

1. Ans. (3)	2. Ans. (4)	3. Ans. (2)	4. Ans. (4)	5. Ans. (1)
6. Ans. (2)	7. Ans. (3)	8. Ans. (4)	9. Ans. (4)	10. Ans. (3)
11. Ans. (4)	12. Ans. (1)	13. Ans. (2)	14. Ans. (4)	

EXERCISE (JA)

1. Ans. 2	2. Ans. (D)	3. Ans. (C)	4. Ans. (B,D)	5. Ans. (A,D)
6. Ans. (D)	7. Ans. (A,B,C,D)	8. Ans. (A)	9. Ans. (A)	10. Ans. 1.50