Chapter 2

Electric Potential And Capacitance

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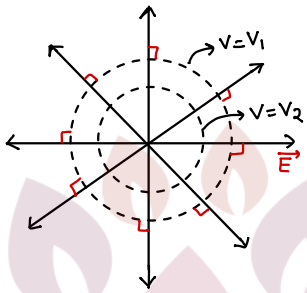
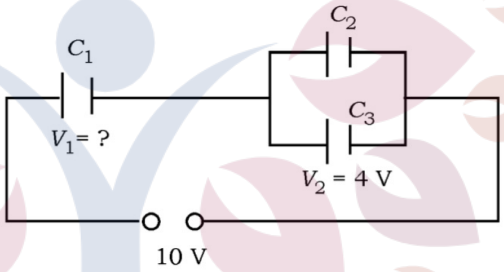
BOARD:- 2013

1. Define Equipotential Surface.

Ans- A surface is called equipotential surface if each point on surface has same potential.



2. (i) Define capacitance.
(ii) Draw a circuit diagram and derive relation of equivalent capacitance of series combination.
(iii) Find value of V_1 in -



Ans- (i) Capacitance- Capacitance of a conductor is a measure of its ability to store charge.

$$\varphi \propto V$$

$$\varphi = CV$$

$$\boxed{C = \frac{\varphi}{V}}$$

If V = 1 volt (increase in potential)

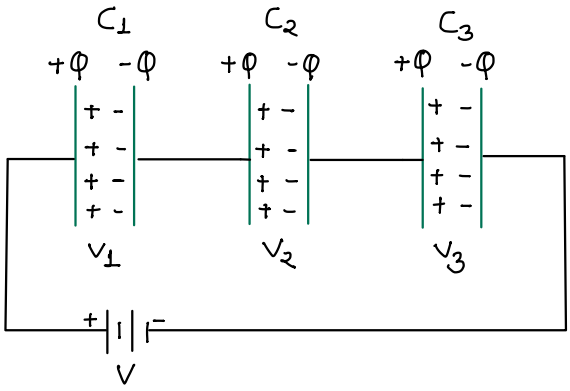
$$\boxed{C = \varphi}$$

Amount of charge given to the conductor which can increase potential of conductor by 1 volt is called capacitance of conductor.

- Scalar quantity
- C/volt or farad

(ii) Series Combination of capacitor-

Suppose these are three capacitor of capacitance C_1, C_2 and C_3 are connected in series combination. Potential across capcitor are V_1, V_2 & V_3 and charge is φ.



Total potential difference –

$$V_S = V_1 + V_2 + V_3 \quad -①$$

W·K·T $\quad Q = CV$

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

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

$$\frac{Q}{C_S} = Q\left[\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right]$$

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

for n capacitor –

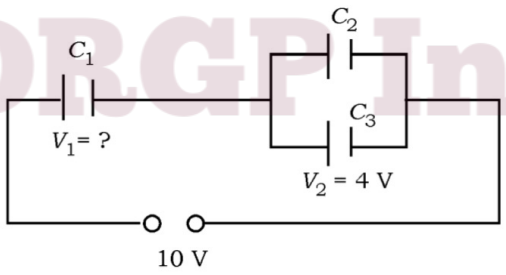
$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{-----} + \frac{1}{C_n}$$

if all have same capacitance –

$$\frac{1}{C_S} = n \times \frac{1}{C} = \frac{n}{C}$$

$$\boxed{C_S = \frac{C}{n}}$$

(iii)



$V_S = V_1 + V_2$

$10 = V_1 + 4$

$\boxed{V_1 = 6\,V}$

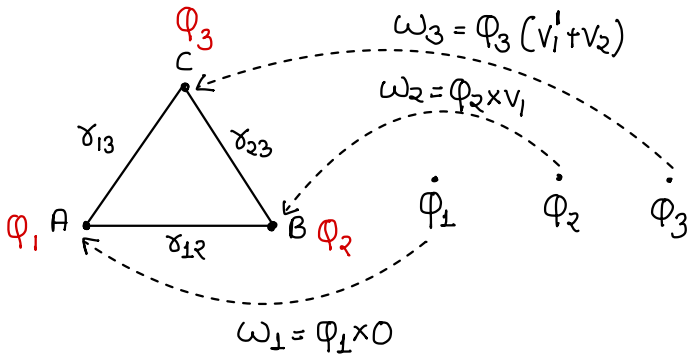
BOARD:- 2013 (Supp)

3. What is value of dielectric strength of air?

Ans- The maximum electric field that a dielectric medium can withstand without breaking of its insulating property is called dielectric strength. For air- 3×10^6 V/m.

4. Find the expression of electric potential energy of a system of three charges.

Ans -



Potential due to φ_1 at point B -

$$V_1 = \frac{K\varphi_1}{\gamma_{12}}$$

Potential due to φ_1 at point C -

$$V_1' = \frac{K\varphi_1}{\gamma_{13}}$$

potential due to φ_2 at point C -

$$V_2 = \frac{K\varphi_2}{\gamma_{23}}$$

Total work done to form system of three charge -

$$W = W_1 + W_2 + W_3$$
$$W = 0 + \varphi_2 V_1 + \varphi_3 (V_1' + V_2)$$
$$W = \varphi_2 \left(\frac{K\varphi_1}{\gamma_{12}}\right) + \varphi_3 \left(\frac{K\varphi_1}{\gamma_{13}}\right) + \varphi_3 \left(\frac{K\varphi_2}{\gamma_{23}}\right)$$
$$W = \frac{K\varphi_1\varphi_2}{\gamma_{12}} + \frac{K\varphi_1\varphi_3}{\gamma_{13}} + \frac{K\varphi_2\varphi_3}{\gamma_{23}}$$

This work done store in form P.E. $\Rightarrow$

$$U = \frac{K\varphi_1\varphi_2}{\gamma_{12}} + \frac{K\varphi_1\varphi_3}{\gamma_{13}} + \frac{K\varphi_2\varphi_3}{\gamma_{23}}$$

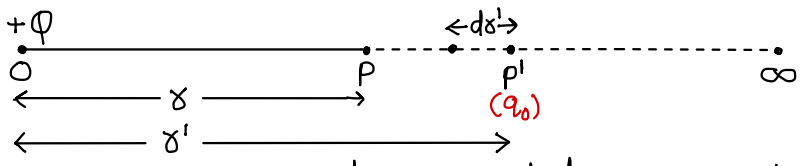
5. Define electrostatic potential. Derive an expression for potential due to a point charge at a γ distance. [1+2 Marks]

Ans - work done to move a test charge from ∞ to a point in a electric field is called electric potential.

$$V = \frac{W}{\varphi}$$

Unit - J/cor volt

Potential Difference due to point charge -



Consider a point charge $+\varphi$ placed at point O. we wish to determine potential at P point, situated at γ

distance. First we calculate work done from ∞ to point P. Φ is positive charge so, it exert a repulsive force at test positive charge q_0. At some intermediate point P' (at r' from O point) repulsive force-

$$F = \frac{K\Phi q_0}{(r')^2}$$

$$F = \frac{K\Phi q_0}{(r')^2} \quad \text{— (1)}$$

work done in moving charge by dr' distance against direction of force-

$$dw = \vec{F} \cdot d\vec{r}'$$

$$dw = F dr' \cos 180^\circ$$

$$dw = -F dr'$$

Total work done in moving charge from ∞ to at r distance-

$$\int dw = \int_\infty^r -F dr'$$

$$w = \int_\infty^r -\frac{K\Phi q_0}{(r')^2} dr'$$

$$w = -K\Phi q_0 \int_\infty^r \frac{1}{(r')^2} dr'$$

$$w = -K\Phi q_0 \left[-\frac{1}{r'}\right]_\infty^r$$

$$w = -K\Phi q_0 \left[-\frac{1}{r} + \frac{1}{\infty}\right]$$

$$w = \frac{K\Phi q_0}{r}$$

By definition of -

$$V = \frac{w}{q_0}$$

$$V = \frac{K\Phi q_0}{r q_0}$$

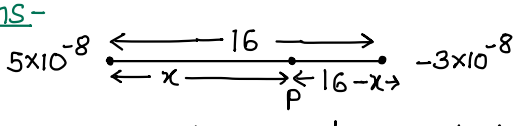
$$\boxed{V = \frac{K\Phi}{r}}$$

↓ potential difference

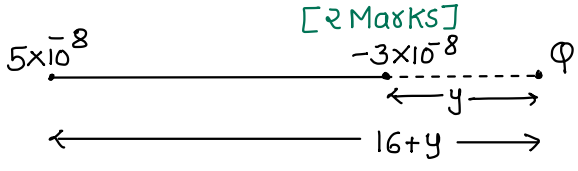
BOARD:- 2014

6. Two point charges 5×10^{-8} C and -3×10^{-8} C are located at 16 cm apart. At what point on the line joining these charges these electric potential will be 0? [2 Marks]

Ans-



Suppose at P point potential is zero.



$$\frac{K(5\times10^{-8})}{x} + \frac{K(-3\times10^{-8})}{(16-x)} = 0$$

$$K\times10^{-8}\left[\frac{5}{x} - \frac{3}{16-x}\right] = 0$$

$$\frac{5(16-x)-3(x)}{x(16-x)} = 0$$

$$80 - 5x - 3x = 0$$

$$80 = 8x$$

$$x = 10\text{cm}$$

(from 5×10^{-8}C)

$$16-x = 6\text{cm}$$

(from -3×10^{-8}C)

$$\frac{K(5\times10^{-8})}{16+y} + \frac{K(-3\times10^{-8})}{y} = 0$$

$$K\times10^{-8}\left[\frac{5}{16+y} - \frac{3}{y}\right] = 0$$

$$\frac{5(y) - 3(16+y)}{y(16+y)} = 0$$

$$5y - 48 - 3y = 0$$

$$2y = 48$$

$$y = 24\text{cm}$$

(from -3×10^{-8}C)

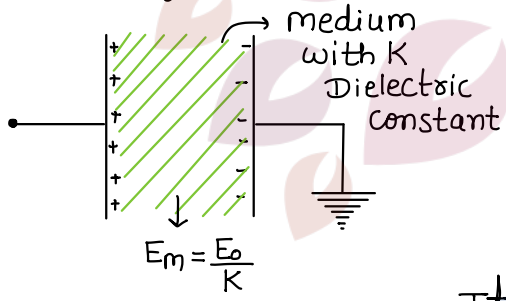
$$16+y = 40\text{cm}$$

(from 5×10^{-8}C)

7. Define electric capacity. Derive an expression for the capacitance of a parallel plate capacitor in which a dielectric medium of dielectric constant K fills the space b/w the plates. Draw the necessary diagram.

[1+2+1 = 4 Marks]

⇒ Suppose we have parallel plate capacitor of two identical metallic plate whose area is A. Both plates are separated by small distance d and in which dielectric medium of dielectric constant K is filled. Capacitance of P.P.C in vaccum is C_o –



$$C_o = \frac{A\varepsilon_o}{d} \quad -(1)$$

A = Area of plate

d = Distance b/w plates

If C_m is capacitance of capacitor after filling medium with K dielectric constant.

$$C_m = \frac{Q}{V_m} \quad -(2)$$

where $V_m = E_m d$ –(3)

$$E_m = \frac{E_o}{K} = \frac{\sigma}{\varepsilon_o K}$$

put in eq^n (3)

$$V_m = \frac{\sigma}{\varepsilon_o K} d$$

put in eq^n (2)

$$C_m = \frac{Q}{\frac{\sigma d}{\varepsilon_o K}} = \frac{Q\varepsilon_o K}{\sigma d}$$

$$\sigma = \frac{Q}{A}$$

$$Q = \sigma A$$

$$C_m = \frac{\sigma A \varepsilon_0 K}{\sigma d}$$

$$\boxed{C_m = \frac{A\varepsilon_0 K}{d}}$$

from eqⁿ ① $C_0 = \frac{A\varepsilon_0}{d}$

$$\boxed{C_m = C_0 K}$$

BOARD:- 2015

8. Calculate the potential at a point due to a charge 4×10^{-9}C located 9×10^{-2}m away from it.

Ans-

$$V = \frac{K\varphi}{\gamma}$$

$$V = \frac{9\times10^{9}\times4\times10^{-9}}{9\times10^{-2}}$$

$$\boxed{V = 4\times10^{2}\ \text{volt}}$$

9. (a) Obtain a relation for equivalent capacitance of the series combination of capacitors. Draw circuit diagrams.
(b) 10 capacitors each of capacity 10μF are joined first in series and then in parallel. Write the value of product of equivalent capacitances.
(c) What will be the value of capacitance of a 4μF capacitor if a dielectric of dielectric constant 2 is inserted fully b/w the plates of parallel plate capacitors. [3+1/2+1/2=4Marks]

Ans- (a) ✓

(b) $C_S = \frac{C}{n} = \frac{10\mu F}{10} = 1\mu F$ $\quad C_p = nC = 10\times10\mu F = 100\,\mu F$

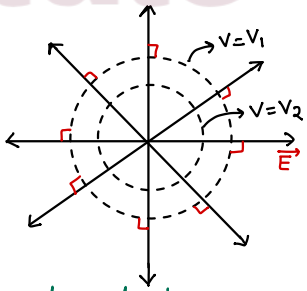
$C_S \cdot C_p = 1\times100 = 100\mu F$

(c) $C_m = C_0K = 4\times2 = 8\mu F$

BOARD:- 2016

10. Draw Equipotienal surface for a single charge.

Ans-

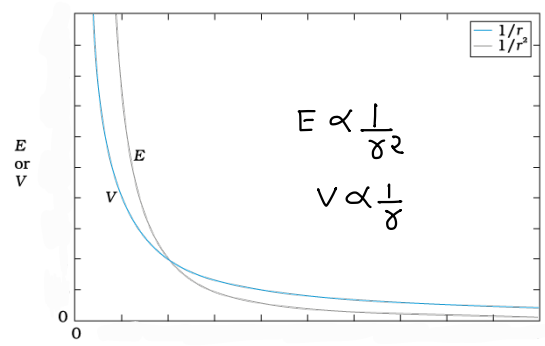


11. (a) Write the definition of electric potential.
(b) Calculate electric potential due to a point charge φ at a distance γ from it.
(c) Draw a graph b/w electrical potential V and distance γ for a point charge φ.

Ans- (a) ✓

(b) ✓

(c) Graph (B/w V & γ)



$E \propto \frac{1}{r^2}$

$V \propto \frac{1}{r}$

$E = \frac{KQ}{r^2}$

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

BOARD- 2017

12. A parallel plate capacitor with air has a capacity of 8PF. Calculate the capacity if the distance b/w the plates is halved and the space b/w them is fully filled a substance of dielectric constant 5.

Ans- Given:- $C_0 = \frac{A\varepsilon_0}{d} = 8\,pF$

$K = 5$

After fill medium and distance reduced to half-

$C_m = \frac{A\varepsilon_0 K}{d/2}$

$C_m = \frac{2A\varepsilon_0 K}{d}$

$C_m = 2K\left(\frac{A\varepsilon_0}{d}\right)$

$C_m = 2 \times 5 \times 8\,pF = 80\,pF$

BOARD- 2017 (Supp.)

13. Explain that -
(i) Inside a conductor electrostatic field is zero.
(ii) Electrostatic potential is constant throughout the volume of the conductor. [1+1 = 2 Marks]

Ans- (i) Because in a conductor, the charges always go and settle on the conductor's surface. So, there is no charge inside and due to it electrostatic field is zero.

(ii) Electric field inside a conductor is zero.

$E = -\frac{dV}{dr}$

if $E = 0$

then $\frac{dV}{dr} = 0$

$V = \text{Constant}$

14. Define capacitor. Derive relation for equivalent capacitance in the series combination of capacitor.

Ans- Capacitor is an arrangement of two identical conductor separated by an insulator or dielectric substance.

BOARD:- 2018

15. Write the name of physical quantity which have unit J/C. Is it vector or scalar quantity. [1 Mark]

Ans- (i) Electric potential
(ii) It is scalar quantity.

16. What do you mean by energy stored in charged capacitor?

Ans- When we move charges from one plate of capacitor to another plate then amount of work done to move charge will be energy stored in charged capacitor.

$$U = \frac{1}{2}CV^2 \text{ or } \frac{1}{2}QV \text{ or } \frac{1}{2}\frac{Q^2}{C}$$

BOARD:- 2018 (Supp.)

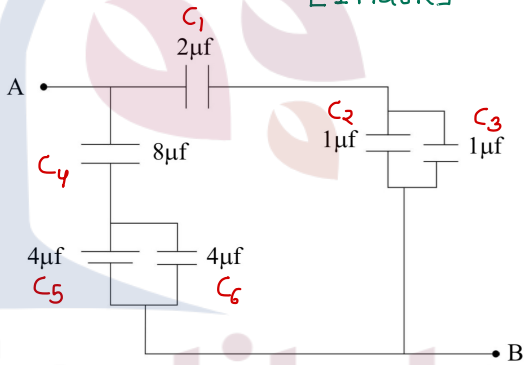
No Questions from current syllabus

BOARD:- 2019

17. Calculate electric potential at a point 1m distance from point charge of 10^{-9} C. [1 Mark]

Ans- $V = \frac{Kq}{r} = \frac{9\times10^{9}\times10^{-9}}{1} = 9$ volt.

18. Find equivalent conductance b/w A & B.

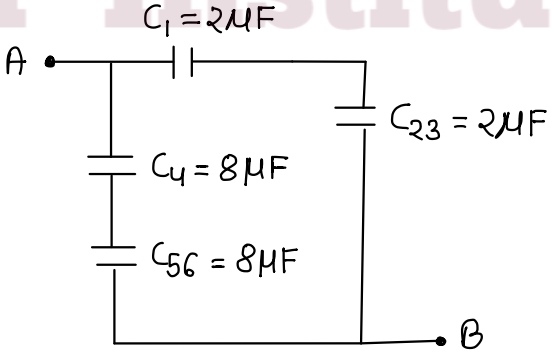


Ans- C_2 & C_3 are in parallel-

$$C_{23} = C_2 + C_3$$
$$C_{23} = 2\,\mu F$$

C_5 & C_6 are in parallel-

$$C_{56} = C_5 + C_6$$
$$C_{56} = 8\,\mu F$$



→ C_1 & C_{23} are in series

$$\frac{1}{C'} = \frac{1}{C_1} + \frac{1}{C_{23}}$$

$$\frac{1}{C'} = \frac{1}{2} + \frac{1}{2}$$

$$C' = 1\,\mu F$$

C_4 & C_{56} are in series $\Rightarrow$ $\frac{1}{C''} = \frac{1}{C_4} + \frac{1}{C_{56}} = \frac{1}{8} + \frac{1}{8}$

$$C'' = 4\,\mu F$$

C' & C'' are in parallel -

$$C = C' + C''$$

$$\boxed{C = 5\,\mu F}$$

BOARD :- 2020

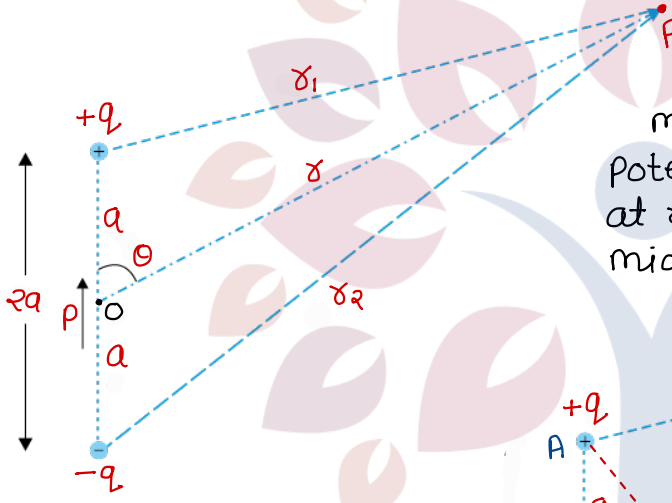
19. Define Dielectric constant of medium. [1 Mark]

Ans. Ratio of permitivity of medium and permitivity of vaccum or free space is known as dielectric constant or relative permitivity.

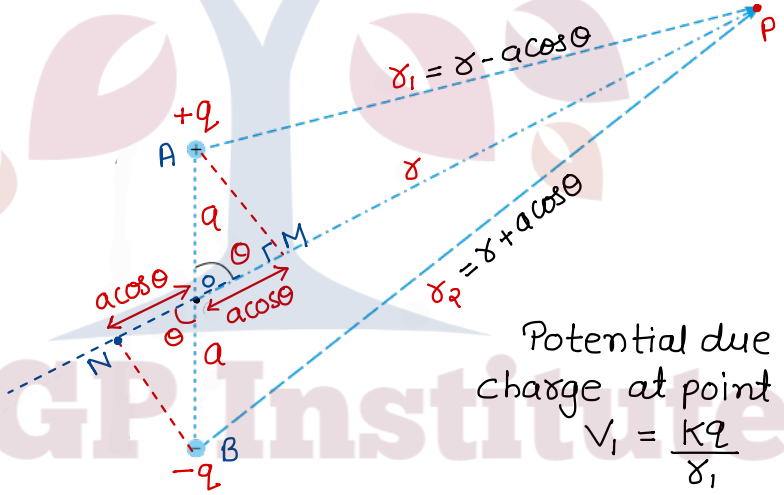
$$\boxed{\varepsilon_r \text{ or } K = \frac{\varepsilon_m}{\varepsilon_0}} \quad \text{Unitless}$$

20. Define electric potential. Obtain an expression of electric potential due to an electric dipole at any point (r, θ). Draw necessary diagram. [1+2+1 = 4 Marks]

Ans -



Suppose a dipole of $\vec{P}$ dipole moment. we have to calculate potential at point P which is situated at r distance and θ angle from mid point O.



Potential due to +q charge at point P -

$$V_1 = \frac{Kq}{r_1}$$

Potential due to -q charge at point P -

$$V_2 = -\frac{Kq}{r_2}$$

Total potential difference - $V = V_1 + V_2$

$$V = \frac{Kq}{r_1} - \frac{Kq}{r_2}$$

$$V = Kq\left[\frac{1}{r_1} - \frac{1}{r_2}\right] = Kq\left[\frac{r_2 - r_1}{r_1 r_2}\right]$$

$$V = Kq\left[\frac{(r + a\cos\theta) - (r - a\cos\theta)}{(r - a\cos\theta)(r + a\cos\theta)}\right]$$

$$V = \frac{Kq\,[r + a\cos\theta - r + a\cos\theta]}{r^2 - a^2\cos^2\theta}$$

$$V = \frac{Kq[2a\cos\theta]}{r^2}$$

$r >> a$

so $r^2 - a^2\cos^2\theta \simeq r^2$

$$\boxed{V = \frac{KP\cos\theta}{r^2}} \quad \{P = q \cdot 2a\}$$

(i) A point on axial line- $\theta = 0^\circ$ $\cos 0^\circ = 1$ $V = \frac{KP}{r^2}$

(ii) A point on equitorial line- $\theta = 90^\circ$ $\cos 90^\circ = 0$ $V = 0$

BOARD:- 2020 (Supp)

21. The diameter of the plates of a parallel plate capacitor is 0.20m. If the distance b/w plates is 0.10m and the medium is air, then calculate the capacitance of capacitor.

Ans. Diameter of plates ⇒ 0.20m

radius ⇒ 0.10m

d ⇒ 0.10m

K ⇒ 1 (for air)

$$C = \frac{A\varepsilon_0 K}{d} = \frac{\pi r^2 \varepsilon_0 K}{d}$$

$$C = \frac{22}{7} \times \frac{0.10 \times 0.10 \times 8.85 \times 10^{-12} \times 1}{1}$$

$C =$

BOARD:- 2021

22. Draw equipotential surface of a point charge.

23. The capacitance of conductor in air is 2μF. If it placed in a medium, then its capacitance becomes 12μF. The dielectric constant of medium will be _____.

Ans- $C_m = C_0 K$

$C_0 = C_a$

$C_m = C_a K$

$K = C_m/C_a = \frac{12}{2} = 6$

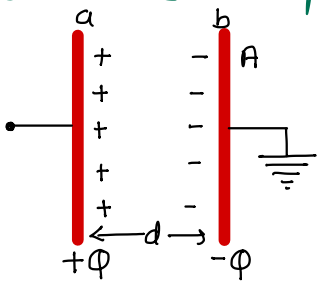
BOARD:- 2022

24. Write the value of electric potential at a distance r from the middle point of the dipole on the axis of the electric dipole of dipole moment P. [1 Mark]

⇒ $V = \frac{KP\cos\theta}{r^2}$ for axis $\theta = 0^\circ$ so, $\boxed{V = \frac{KP}{r^2}}$

25. If the area of each conducting plate of parallel plate capacitor is A & d is the separation blw them, then derive its capacitance formula.

⇒ Suppose we have parallel plate capacitor. Area of both plate is A and distance blw both plate is d. The two plate have +φ & -φ charge.



Electric field blw plates are-

$$E = E_a + E_b$$

$$E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0}$$

$$\boxed{E = \frac{\sigma}{\varepsilon_0}} \quad -①$$

Capacitance

$$C = \frac{\varphi}{V} \quad -②$$

w.k.t $V = E \cdot d$

from eqn ①

$$V = \frac{\sigma d}{\varepsilon_0}$$

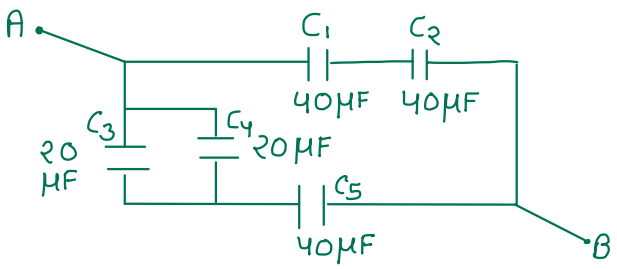
$$V = \frac{\varphi d}{A\varepsilon_0} \quad \left\{\sigma = \frac{\varphi}{A}\right\}$$

put in eqn ②

$$C = \frac{\varphi}{\frac{\varphi d}{A\varepsilon_0}}$$

or $$\boxed{C = \frac{A\varepsilon_0}{d}}$$

26. Find equivalent capacitance –



Solution -

(i) C_3 & C_4 are in parallel -

$$C_{34} = C_3 + C_4$$

$$C_{34} = 40\ \mu F$$

(ii) C_{34} & C_5 are in series -

$$\frac{1}{C'} = \frac{1}{C_{34}} + \frac{1}{C_5}$$

$$\frac{1}{C'} = \frac{1}{40} + \frac{1}{40} = \frac{2}{40}$$

$$C' = 20\ \mu F$$

C_1 & C_2 are Series -

$$\frac{1}{C''} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C'' = 20\ \mu F$$

C' & C'' are in parallel

$$C = C' + C''$$

$$C = 20 + 20$$

$$= 40\mu F$$

BOARD:- 2023

27. Calculate the electric potential at a point due to a charge of 2×10^{-9}C located 9×10^{-4}m away from it. [1.5 Marks]

⇒ $$V = \frac{KQ}{r}$$

$$V = \frac{9\times10^{9} \times 2\times10^{-9}}{9\times10^{-4}}$$

$$V = 2\times10^{4}\ \text{volt}$$

28. Find the expression for electric potential energy of a system of three point charges. [1.5 Marks]

BOARD:- 2024

29. The value of dielectric strength of air -

A. 3×10^{6} V/m B. 3×10^{8} V/m

C. Zero D. ∞

Answer - A

30. Draw equipotential surface for a point charge ($q>0$).

31. Three capacitors of capacitance 6μF are connected in parallel. Calculate equivalent capacitance.

⇒ $$C = C_1 + C_2 + C_3$$

$$C = 6 + 6 + 6$$

$$C = 18\ \mu F$$