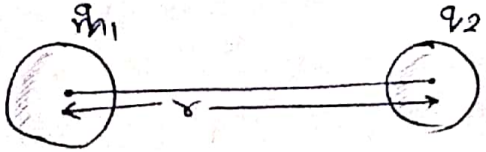
UNIT-II

Electrostatics

Syllabus: 1: Coulomb's law
2: Electric potential and Electric potential Difference
3: Electric field, Electric field intensity, Electric line of force, Electric flux.
4: Gauss's law
5: Application of Gauss's law.
6: Capacitance.
7: Capacitor, types, parallel plate capacitor.
8: Combinations of capacitor.

Coulomb's law: According to Coulomb's law:

"The force between two charge is directly proportional to the multiplication of magnitude of these charge and inversely proportional to the square of distance between these two charges."



Suppose two charges (magnitude q_1 and q_2) are separated by distance r then according to

Coulomb's law: $F \propto q_1 q_2$ ----①

$F \propto \frac{1}{r^2}$ ----②

Combining these two equations

$$F \propto \frac{q_1 q_2}{r^2}$$

$$\Rightarrow \boxed{F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}} \quad \text{.....③}$$

Eq(III) is known as Coulomb's law.

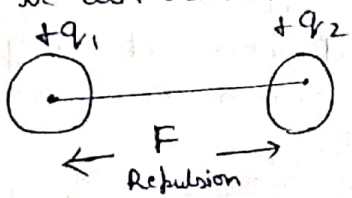
Here $\frac{1}{4\pi\epsilon_0}$ is constant it's value is $9 \times 10^9 \, N m^2/c^2$.

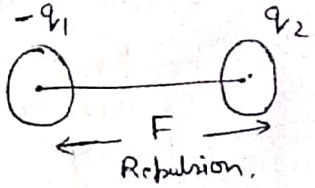
This is known as coulomb's constant i.e.

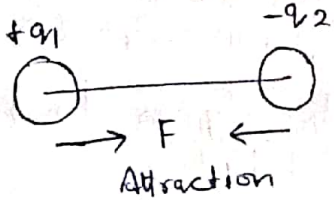
$$K_e = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \, N m^2/c^2$$

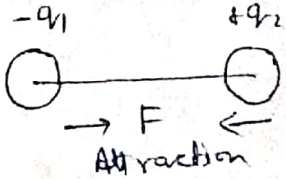
Here ϵ_0 is the permitivity of free space.

The nature of force depends upon the nature of charge. If both have same nature (positive or negative) the force will be repulsive and if the charges are opposite in nature than the force will be attractive.







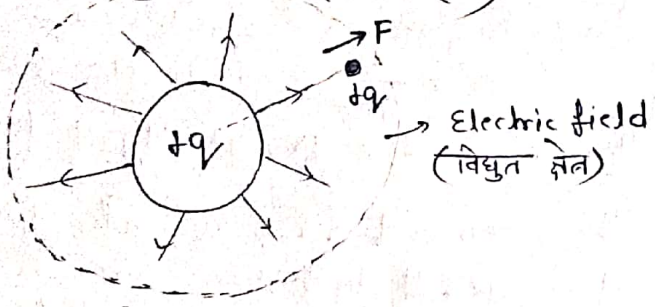


Electric Field (वैद्युत क्षेत्र):

Electric field can be defined as follows:

"The definite space around any charge in which force is exberienced by any other charge is known as electric field."

(किसी आवेश के चारों ओर स्थित वह निश्चित क्षेत्र जिसमें किसी अन्य आवेश द्वारा बल का अनुभव किया जाता है विद्युत क्षेत्र कहलाता है)



Electric field Intensity (वैद्युत क्षेत्र की तीव्रता)

Electric field intensity can be defined as;

"The force exerted ubon unit charge in an electric field is known as electric field intensity"

(इकांक आवेश पर वैद्युत क्षेत्र में लगने वाले बल को वैद्युत क्षेत्र की तीव्रता कहते हैं।)

Electric field intensity is denoted by $\vec{E}$

According to the definition;

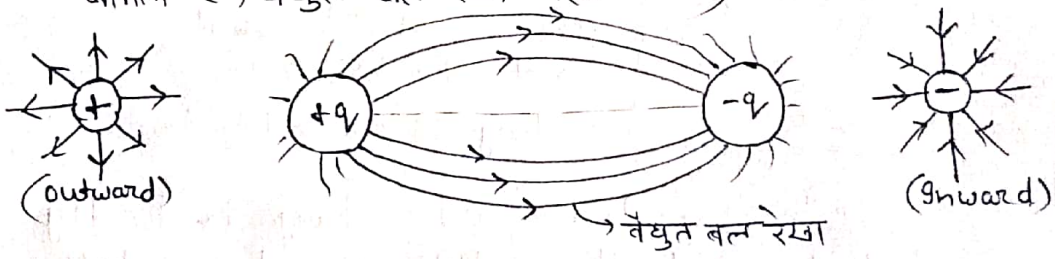
$$\vec{E} = \frac{\vec{F}}{q_0} \quad \text{..... (iv)}$$

Electric line of force (विद्युत बल रेखायें):

Electric lines of force can be defined as;

"A way or path, it may be straight or curved, so that the tangent at any point to it gives the direction of the electric field intensity at that point."

(ऐसा सीधा या वक्राकार मार्ग जिसके किसी बिन्दु पर खींची गयी स्पर्श रेखा उस बिन्दु पर विद्युत क्षेत्र की तीव्रता की दिशा बताता है, वैद्युत बल रेखा कहलाती है)



Electric potential (वैद्युत विभव)

Electric potential can be defined as follows:

"The work done on an unit charge to take it from infinte to any point in an electric field is known as electric potential at that point."

(एकांक आवेश को अनंत से वैद्युत क्षेत्र के भीतर किसी बिन्दु तक लाने में जो कार्य किया जाता है वो उस बिन्दु पर वैद्युत विभव कहलाता है।)

Electric potential is an scalar quantity and is represented by V, i.e.

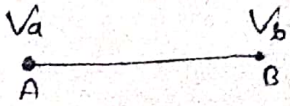
$$V = \frac{W}{q} \quad \text{.....} \quad \text{V}$$

Potential Difference (विभवान्तर)

"Potential difference between two points is the energy needs to take unit charge from one point to other point in an electric field"

(एकांक आवेश को विद्युत क्षेत्र में एक बिन्दु से दूसरे बिन्दु तक ले जाने में किया कार्य उन दो बिन्दुओं के बीच विभवांतर कहलाता है)

$$V_A - V_B = \frac{W}{q} \quad \text{---} \quad \text{VI}$$



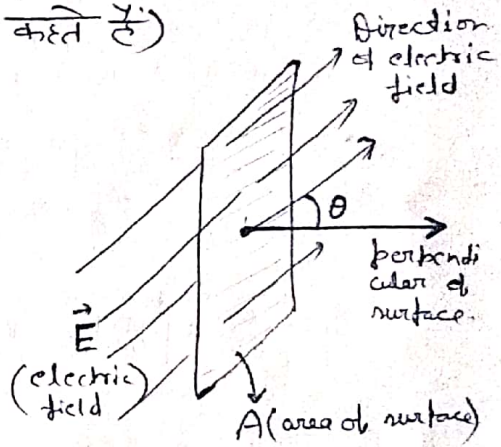
Electric Flux (वैद्युत फ्लक्स)

"The electric flux refers to the electric field lines penetrates a given closed surface."

(किसी बन्द क्षेत्र (पृष्ठ) से गुजरने वाली चुम्बकीय बल रेखाओं की संख्या को ही वैद्युत फ्लक्स कहते हैं)

The electric flux is represented by Φ_E and depends mainly upon three things: (E, A and $\cos\theta$)

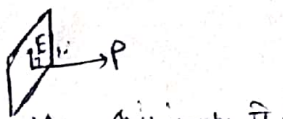
$$\Phi_E = EA\cos\theta \quad \text{---} \quad \text{VII}$$



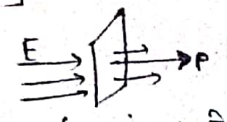
[ध्यान दें: θ कोण विद्युत क्षेत्र की दिशा और पृष्ठ पर डाले गये लम्ब के बीच बना कोण है।]

$(\Phi_E)_{min} = EA\cos 90 = 0$ [जब $\theta = 90$ होगा तो कोई फ्लक्स नहीं गुजरेगा]

$(\Phi_E)_{max} = EA\cos 0 = EA$ [जब $\theta = 0$ होगा तो अधिकतम फ्लक्स गुजरेगा]



Φ_E (minimum की दशा)



(maximum की दशा)

Gauss's Law (गॉस का नियम)

According to the Gauss:

"The electric flux passing through a closed surface is equal to the multiplication of total charged enclosed by that surface and inverse of permitivity of free space i.e.($1/\epsilon_0$)."

(किसी बन्द पृष्ठ से गुजरने वाला वैद्युत फलक्स उस पृष्ठ के अन्दर स्थित सम्पूर्ण आवेश और निर्वात की विद्युतशीलता (ϵ_0) के व्युत्क्रम के गुणनफल के बराबर होता है)

i.e. (अर्थात)

$$\phi_E = \frac{q_{enclosed}}{\epsilon_0}$$

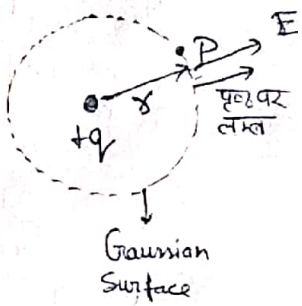
or $$\boxed{\phi_E = \int E.dq = EA\cos\theta = \frac{q}{\epsilon_0}} \quad \text{---------- (VIII)}$$

[ध्यान दें: जो आवेश पृष्ठ के अन्दर होगा वही $q_{enclosed}$ का अर्थ है अर्थात जानश्यम है कि आवेश पृष्ठ से घिरा होना चाहिये।]

Abblication of Gauss's law (गॉस नियम के अनुप्रयोग)

(1) To find Electric field of a point charge:

Suppose we have to find electric field at point P using Gauss's law, so you have to draw a Gaussian surface which goes from that point. Here dotted surface is Gaussian Surface;
गॉस के नियमानुसार



$$\int E.dq = E.A\cos\theta = \frac{q}{\epsilon_0}$$

$$\Rightarrow E.A\cos\theta = \frac{q}{\epsilon_0}$$

[$\because \vec{E}$ और लम्ब दोनों एक ही दिशा में हैं $\therefore \theta = 0$]

$$\Rightarrow EA = \frac{q}{\epsilon_0}$$

$$\Rightarrow E = \frac{1}{4\pi\gamma^2}\frac{q}{\epsilon_0}$$

[A = Gaussian surface का पृष्ठीय क्षे० $= 4\pi\gamma^2$]

$$\Rightarrow \boxed{E_P = \frac{1}{4\pi\epsilon_0}\frac{q}{\gamma^2}} \quad \text{---- (IX)}$$

(2) To find Electric field due to uniform conductor:

Here Dotted cylinder is the Gaussian surface

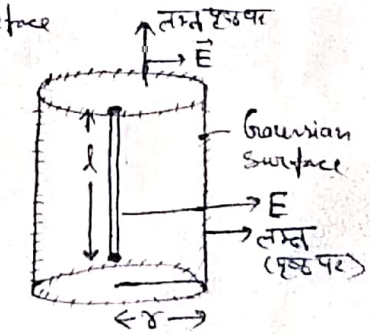
$$EA\cos\theta = \frac{q}{\epsilon_0}$$

$$E(2\pi\gamma\ell)\cos 0 = \frac{\lambda\ell}{\epsilon_0}$$

[λ = लाइन चार्ज डेन्सिटी; $A = 2\pi\gamma l$ = वक्र०]

$$\Rightarrow E = \frac{\lambda}{2\pi\gamma\epsilon_0}$$

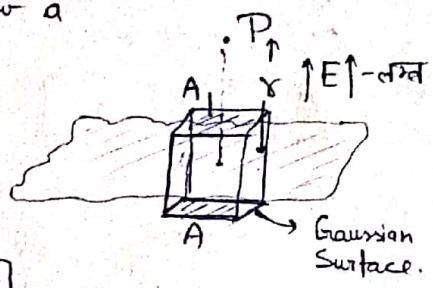
$$\Rightarrow \boxed{E = \frac{1}{4\pi\epsilon_0}\frac{2\lambda}{\gamma}} \quad \text{---------- (X)}$$



[ध्यान दें: ऊपर और नीचे वाले पृष्ठ का फलक्स = 0 क्योंकि $\theta = 90$]

(3) Electric field near an infinite sheet:

We have to find electric field at the point P. We draw a Gaussian surface. Now applying Gauss's law:



ध्यान दें: केवल ऊपर और नीचे वाली surface से flux गुजरेगा क्योंकि इनके लिए $\theta = 0$ अगल-बगल वाली पृष्ठ हेतु $\theta = 90°$

$$\therefore \quad EA\cos\theta = \frac{q}{\epsilon_0}$$

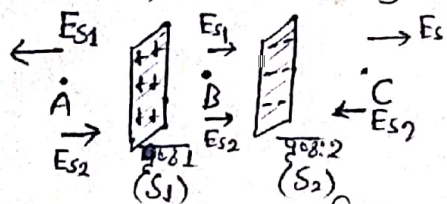
$q = \sigma A$ अगर surface charge density σ हो तो

$$E(2A) = \frac{q}{\epsilon_0} \Rightarrow E = \frac{\sigma A}{2A\epsilon_0}$$

$$\boxed{E = \frac{\sigma}{2\epsilon_0}} \quad \text{---- VI}$$

अतः अनन्त पृष्ठ के नजदीक विद्युत क्षेत्र पृष्ठ से दूरी r पर निर्भर नहीं करता है केवल दिशा महत्वपूर्ण है।

प्रश्न: निम्न में A, B व C पर विद्युत क्षेत्र ज्ञात करो



$$E_{S1} = \frac{\sigma}{2\epsilon_0}$$

$$E_{S2} = \frac{\sigma}{2\epsilon_0}$$

[ध्यान दें: यहाँ दिशा महत्वपूर्ण है A, B, C पर E_{S1} व E_{S2} की दिशा पर ध्यान दें]

$$\begin{cases} E_A = E_{S1} - E_{S2} = E_{S1} - E_{S2} = \frac{\sigma}{2\epsilon_0} - \frac{\sigma}{2\epsilon_0} = 0 \\ E_B = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0} \\ E_C = E_{S1} - E_{S2} = 0 \end{cases}$$

Capacitance (धारिता)

"Capacitance is the ratio of the change in electric charge of a system, to the corresponding change in its electric potential."

(किसी सिस्टम के आवेश में किये गये परिवर्तन (q) और इससे उसके विभवान्तर में उत्पन्न परिवर्तन (V) के अनुपात को उस सिस्टम की धारिता (C) कहते हैं)

Capacitance is represented by 'C', i.e.

$$\boxed{C = \frac{q}{V}}$$ कूलाम्ब/वोल्ट or फैरड ..... (I)

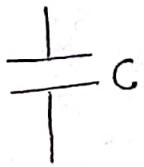
Capacitor (संधारित्र):

"A capacitor is a device that stores electrical energy in an electric field."

("संधारित्र एक ऐसी युक्ति है जो विद्युत ऊर्जा को वैद्युत क्षेत्र में संचित करती है")

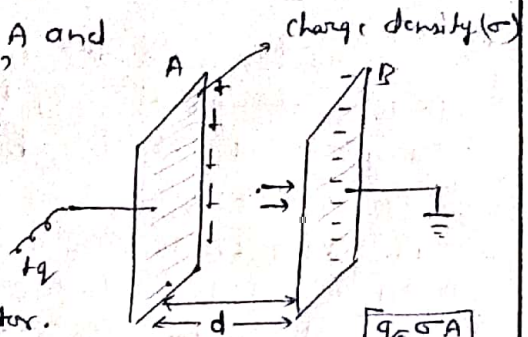
Types (प्रकार): Mainly two types (a) parallel plate capacitor
(b) Spherical capacitor

Notation:



Parallel Plate Capacitor: (समान्तर प्लेट संधारित्र):

When two conductor plates A and B placed at a distance 'd' to each other and B plate is grounded and A is connected to the source of charge. This forms the parallel plate capacitor.



Now Electric field between plates:

$$E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0} \quad \text{---} (a)$$

We know that $V = Ed$

$$\Rightarrow V = \frac{\sigma d}{\epsilon_0} \quad \text{----} (b)$$

Placing eq (b) into the definition of capacitance

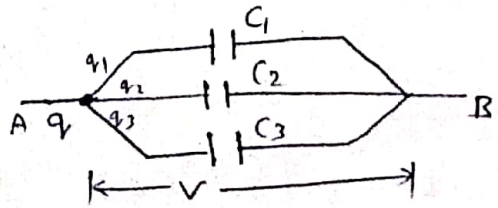
$$C = \frac{q}{V} = \frac{\sigma A}{V} = \frac{\sigma A \epsilon_0}{\sigma d} = \frac{A\epsilon_0}{d}$$

$$\boxed{C = \frac{A\epsilon_0}{d}} \quad \text{-------} \quad \text{XIII}$$

This is formula for the capacitance of a parallel plate capacitor.

Combination Of Capacitor: (संधारित्र का संयोजन:)

[1] सामान्तर संयोजन:



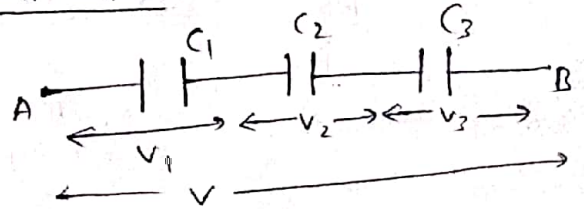
Suppose three capacitor C_1, C_2, C_3 are placed parallelly. At junction point q will divide into q_1, q_2 and q_3

$$\Rightarrow q = q_1 + q_2 + q_3$$

$$\Rightarrow CV = C_1V + C_2V + C_3V$$

$$\Rightarrow \boxed{C = C_1 + C_2 + C_3} \quad \text{----} \quad \text{XIV}$$

[2] श्रेणी-संयोजन:



$V = V_1 + V_2 + V_3$ [V is scalar quantity]

$$\frac{q}{C} = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3}$$

$$\Rightarrow \boxed{\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} \quad \text{----} \quad \text{XV}$$