Electrostatics : Capacitors, Kirchhoff's Law & Magnetic Property of matter

1. ***Define electric capacity. Give its unit & dimension. Describe Parallel plate capacitor.***

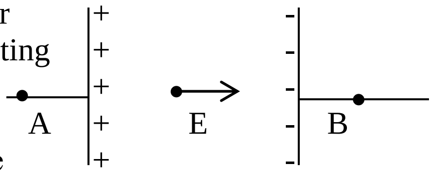
Ans: The ability of electrostatics system to exchange charge with minimum change in its electric potential is called electric capacity. It is defined as

$$C = dQ/dV$$

Its unit is Coulomb/Volt or Farad. Its dimensional formula is $[M^{-1}L^{-2}T^{4}I^{2}]$

Parallel Plate Capacitor:

Parallel Plate Capacitor consists of two conducting sheets of area 'A' kept parallel to each other at a separation 'd'. The two plates supports equal amount of opposite uniform areal charge distribution. One of the plate is called collecting plate and other is called condensing plate. The charge distribution creates uniform parallel electric field in the gap and potential difference across the plates.



Areal charge density $\sigma = Q/A$ c/m^2

Electric field in the gap $E = \sigma/\in_0$

Potential difference across the plates

$V = Ed = \sigma d/\in_0$

Amount of charge exchanged = Q

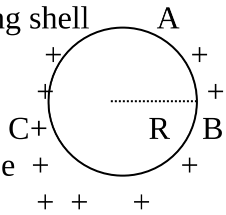
From definition of electric capacity

$C = Q/V = \in_0 A/d$

The electric capacity of parallel plate capacitor is independent of amount of charge on the plate and level of potential difference.

2. ***Describe isolated spherical conductor as condenser.***

Ans: ABC is spherical conducting shell of radius R. When charge is given it spread uniformly on its outer surface establishing non uniform radial electric field from the surface to infinity. The infinity acts as condensing plate.



$\triangle Q = Q-0$ $\triangle V = V-0$

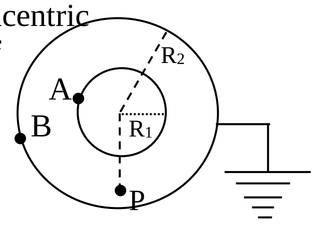
Capacity $C = \triangle Q/\triangle V = Q/V$

Potential on its outer surface $V = (1/4\pi\in_0)\, Q/R$

Electric Capacity $C = Q\times 4\pi\in_0 R/Q = 4\pi\in_0 R$

3. ***Describe Spherical condenser.***

Ans: It consists of two concentric spherical conducting shell of radia R_1 and R_2. The outer shell is kept earthed while inner shell is given charge Q. The inner shell acts as collecting plate while outer shell acts as condensing plate.



The gap between two shells has non uniform radial electric field. 'P' is a point between the two shells where electric field is

$E = (1/4\pi\in_0)Q/r^2$ $(R_1 < r < R_2)$

Then, $dV = -Edr = -(Q/4\pi\in_0)dr/r^2$

$$\int_0^{V_A} dV = -(Q/4\pi\in_0)\int_{R_2}^{R_1} dr/r^2$$

$$V_A = -(Q/4\pi\in_0)[-1/r]_{R_2}^{R_1} = Q/4\pi\in_0(-1/R_1 - 1/R_2)$$

$$= Q(R_2 - R_1)/4\pi\in_0 R_1.R_2$$

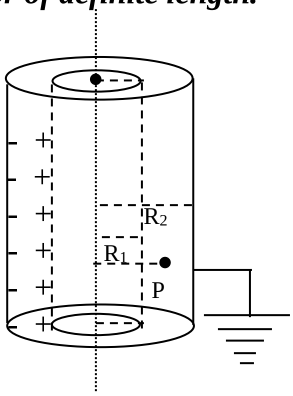
From definition of electric capacity

$C = Q/V = 4\pi\in_0 R_1.R_2/R_2 - R_1$

The capacitance is independent of amount of charge and electric potential.

4. ***Describe Cylindrical Capacitor of definite length.***

Ans: A cylindrical capacitor consists of two coaxial cylindrical conducting tubes of different radii. The outer tube is kept is earthed while inner tube is given charge.



Linear charge density = λc/m

Electric Field at point P

$E = \lambda 2\pi\in_0 r$

Where r is radial distance.

$V = -Edr = -(\lambda 2\pi\in_0)dr/r$

$$\int_0^{V} dV = -(\lambda 2\pi\in_0)\int_{R_2}^{R_1} dr/r$$

$V = -(\lambda 2\pi\in_0)\log_e R_1/R_2 = (\lambda 2\pi\in_0)\log R_2/R_1$

Amount of charge on the capacitor $Q = \lambda l$

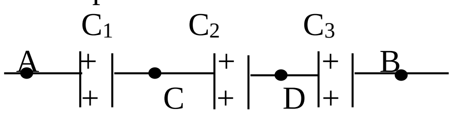
From the definition of electric capacity

$C = Q/V = \lambda l \times 2\pi\in_0/\lambda \log_e R_2/R_1$

$= 2\pi\in_0 l/\log_e R_2/R_1$

5. ***How Capacitors can be joined in series and parallel combination.***

Ans: Two or more capacitors are said to be in series combination across two points if they divide the potential difference across the terminals between no. of potential steps and charge which enters at one terminal emerges out of other terminal without being distributed or contributed.



$V_A - V_C = Q/C_1$ ------ (1)

$V_C - V_D = Q/C_2$ ------ (2)

$V_D - V_B = Q/C_3$ ------ (3)

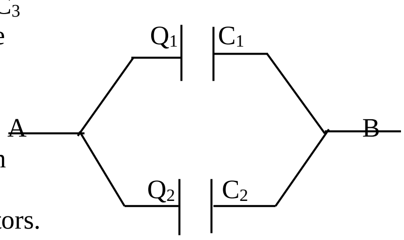
$V_A - V_B = Q/C_{eq}$ ------ (4)

Adding equation (1), (2), (3) and then comparing with equation (4).

$Q/C_{eq} = Q/C_1 + Q/C_2 + Q/C_3$

$1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3$

Two or more capacitors are said to be in parallel combination if they are connected across the same terminals and charge which enters at one terminal gets distributed over the capacitors.



$Q_1 = (V_A - V_B)C_1$ ------ (1)

$Q_2 = (V_A - V_B)C_2$ ------ (2)

$Q = (V_A - V_B)C_{eq}$ ------ (3)

From the conservation of charge

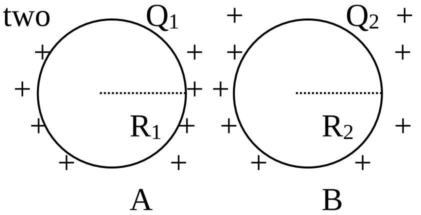
$Q = Q_1 + Q_2$

Putting the values from equation (1), (2) & (3)

$C_{eq} = C_1 + C_2$

6. ***Prove that there is loss of energy when two shells of different radii charged to different level are electrically connected.***

Ans: A and B are two conducting shells of radii R_1 and R_2 charged to electric potential V_1 and V_2



Where

$V_1 = (1/4\pi\in_0)\, Q_1/R_1$ & $V_2 = (1/4\pi\in_0)\, Q_2/R_2$

Potential energy of the spheres before connecting

$U_i = (Q_1^2/8\pi\in_0R_1) + (Q_2^2/8\pi\in_0R_2)$

When they are electrically joined they exchange charge till their electric potential becomes equal.

$Q_1 - q/4\pi\in_0R_1 + Q_2 + q/4\pi\in_0R_2$

After connecting potential energy of the system.

$U_f = (Q_1 - q)^2/8\pi\in_0R_1 + (Q_2 + q)^2/8\pi\in_0R_2$

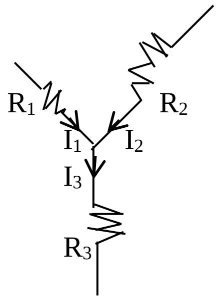
Since $U_f - U_i \neq 0$ and $U_f < U_i$ there is less of energy during electrically connecting them

7. ***State and explain Kirchhoff's Law of electric circuit. Describe Wheat Stone Bridge.***

Ans: Kirchhoff's current law: Algebraic sum of incoming and outgoing current at any junction of the circuit
is always zero.

$I_1 + I_2 - I_3 = 0$

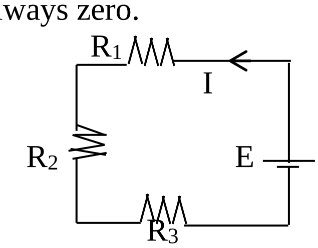
It is law of conservation of charged applied to electric circuit.



Kirchhoff's voltage law: Algebraic sum of potential difference across different elements along any closed path of the circuit is always zero.

$E - IR_1 - IR_2 - IR_3 = 0$

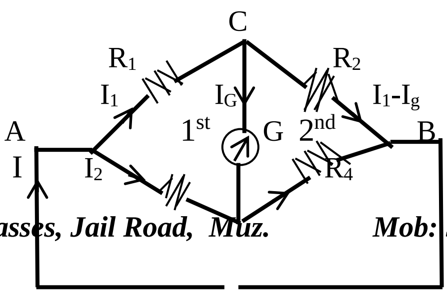
It is law of conservation of energy applied to electric circuit.



The two Kirchhoff's laws are used to determine current in the circuit and potential difference.

Wheat Stone Bridge: It is combination resistances used to compare resistances.

It consist of four resistance $R_1, R_2, R_3,$ & R_4. R_g is



resistance R_3 D I_2+I of galvanometer.

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Applying Kirchhoff's law in 1st and 2nd loop.

$I_1R_1 – I_gR_g – I_2R_2 = 0$ ------ (1)

$-(I_1– I_g)R_2 + (I_2 + I_g)R_4 + I_gR_g = 0$ ----- (2)

When potential difference across points C & D is zero.

i.e $V_C = V_D$,$I_g = 0$, $I_1R_1 = I_2R_2$, $I_2R_2 = I_2R_4$ **,$R_1/R_2 = R_3/R_4$**

Under this condition the Wheat Stone Bridge is said to be balanced.

8. ***(Additional)What do mean by intensity of magnetization magnetic susceptibility & magnetic permeability. Describe modern theory of magnetism.***

Ans: When a magnetizing field is applied on a magnetic material the randomly oriented magnetic dipoles experience torque and try to align themselves in the direction of the magnetic moment.

The magnetic moment developed in the material per unit volume is called intensity of magnetization.

$I = M/V = 2.l.m/2l.A$

Where M = magnetic moment.
V = Volume.
m = Pole strength.
A = Cross sectional area.

Magnetic Susceptibility :

The amount of intensity of magnetization dev eloped per unit application of magnetizing field is called Magnetic Susceptibility.

$k = I/H$

If k = -ve the material is called diamagnetic.
k = +ve the material is called paramagnetic.

Magnetic Permeability :

The ratio of magnetic induction inside t5he magnetic material to the magnetizing field is called Permeability.

$\mu = B/H$

If $\mu > 1$ the material is paramagnetic or ferromagnetic.
If $\mu < 1$ the material is diamagnetic.

According to modern theory of magnetism, the electric orbits are micro magnets. Depending upon the no of electronic orbit, direction of revolution of electrons in the orbit the molecules and atoms have magnetic moment. These magnetic dipoles remains in random orientation in the absence of applied magnetizing field. When external field is applied in the direction of field to generates a strong resultant magnetic moment. Then the material gets magnetized.

1. **(a) Why does the electric field inside a dielectric decreases when it is placed in an external electric field?**
(b) Define the term dielectric constant of a medium in terms of capacitance.

Ans : (a) When a dielectric material is exposed to electric filed the randomly distributed dipoles align themselves in the direction field called polarization. After polarization the dipoles create an induced electric field opposite to applied field which reduces the resultant field.

$E_{\text{in the absence of dielectric}} = E_o$,

$E_{\text{in the presence of dielectric}} = E - E_{\text{induced}}$

(b) Capacity of a parallel plate capacitor containing air is defined as

$C_o = \in_0.A/d$

Capacity of a parallel plate capacitor field with dielectric material

$C_o = k\in_0.A/d$

$C/C_o = k$ = Dielectric constant

2. Derive expression for energy stored in a parallel plate capacitor with air between the plates. How does the stored energy changes if air is replaced by a medium of dielectric constant k.

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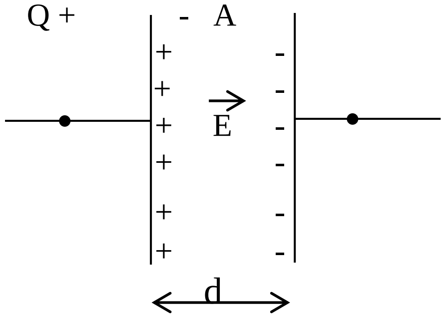
Ans : When a parallel plate capacitor is connected with voltage source, equal and opposite charge appears on the two plates. The charge appearing on the plates create electric field in the capacitor gap and potential difference across the plates.



Q is amount of charge at any moment on the plates

when Potential difference $V = Q/C_o$

Potential change of capacitor $dU = VdQ = 1/C_o.QdQ$

$$U = 1/C_0.\int^{Q} QdQ = Q^2/2C_o$$

Or, $U = 1/2C_oV_o^2$

When air gap is filled with dielectric material capacity increases k times. If voltage source is kept connected potential energy increases $U = 1/2kC_oV_o^2$

If the voltage source is disconnected charge becomes and potential energy decreases k times.

$$U = Q^2/2kC_o$$

3. A parallel plate capacitor is charged to a potential difference V by a d.c source. The capacitor is then disconnected from the source. If the distance between the plates is doubled state reason how the following will change. (i) Electric field between the plates.
(ii) Capacitance
(iii) Energy stored in the capacitor.

Ans : When the e.m.f. source is removed after charging a capacitor the amount of charge on the capacitor becomes constant. If the separation between the plates is doubled capacity becomes half and potential difference gets doubled. $E = V/d$

But electric field remains constant.

Potential energy of capacitor $U = Q^2/2C$

Becomes double as capacity becomes half.

4. What is capacitance of spherical condenser whose outer shell is kept earthed. What is change in capacity if the gap is filled with dielectric material. How capacitance changes if inner shell is earthed instead of outer shell.

Ans : The space between inner shell and outer shell is the capeacitative space. When inner shell is given charge Q field at any point P. $E = (1/4\pi\epsilon_0)\, Q/R^2$

$$dV = -Edr$$

$$V = -Q/4\pi\epsilon_0 \int_{R_2}^{R_1} dr/r^2 = -Q/4\pi\epsilon_0 [-1/r]_{R_2}^{R_1} = -Q/4\pi\epsilon_0 [1/R_1 - 1/R_2]$$

$$= Q(R_2-R_1)/4\pi\epsilon_0.R_1R_2$$

The capacitance $C = Q/V = 4\pi\epsilon_0.R_1R_2/R_2-R_1$

When the gap between two shells is filled with dielectric capacity increases k times.

$$C = 4\pi k\epsilon_0.R_1R_2/R_2-R_1$$

If inner shell is earthed instead of outer shell charge appears on outer surface of outer shell also. Then there exists capacitative space one in between two shells and other outside the shell.

Both capacities are in parallel combination. $C = C_1 + C_2 = 4\pi\epsilon_0.R_1R_2/R_2-R_1 + 4\pi\epsilon_0R_2$

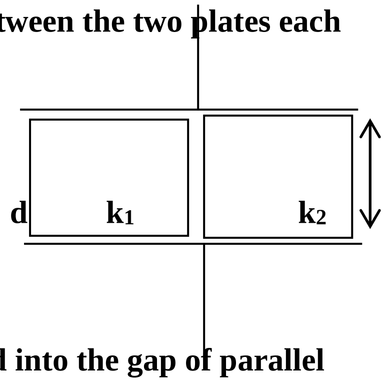
5. **(a) Two dielectric slabs of dielectric constant k_1 and k_2 are filled in between the two plates each of area A_1 a parallel plate capacitor. Find net capacitance.**

Ans : $C_1 = \in_0.k_1A_1/d$

$C_2 = \in_0.k_2A_2/d$

The two capacitance are in parallel combination across the terminals

$C = C_1 + C_2 = \in_0(k_1A_1 + k_2A_2)/d$



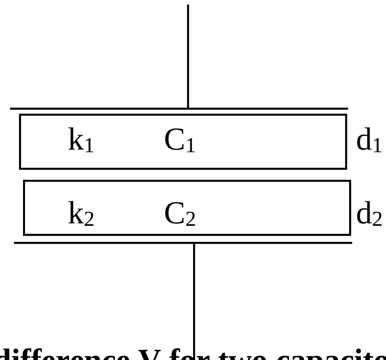
(b) Two dielectric slabs of same area but different thickness d_1 and d_2 inserted into the gap of parallel plate capacitor. Find net capacitance.

Ans: The capacitor may be considered to be made two capacitor in series combination across the terminals

$C_1 = \in_0.k_1A/d_1$

$C_2 = \in_0.k_2A/d_2$

$C = C_1C_2 / C_1 + C_2$



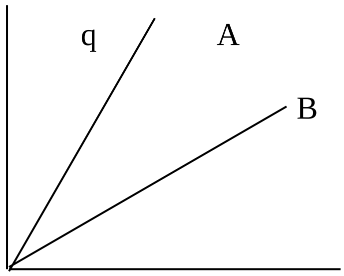
6. **The given graph shows the variation of charge q verses potential difference V for two capacitors have same plate separation plate area of C_2 is double than that C_1. Which of the line4s of the graph correspond to C_1 and C_2 and why.**

Ans : Since plate area of is C_2 twice of that C_1.

$C_2 > C_1$

As $C = dQ/dV$ = slope of q-V graph.

There fore line A represents C_2.



V

Questions On Electricity

1. Derive expression for induced emf in a coil rotating uniform magnetic field. Or, Describe principle of A.C generator.

2. Define (a) R.M.S. value of Alternating current and voltage.

3. Defined impedance of A.C. circuit containing
   (a) Resistance and Capacitance in series.
   (b) Resistance and Inductance in series.
   (c) Resistance, Capacitance and Inductance in series.

4. Define electric capacity. Give its unit & dimension. Describe Parallel plate capacitor.
5. Describe isolated spherical conductor as condenser.
6. Describe Spherical condenser.
7 Describe Cylindrical Capacitor of definite length.
8. How Capacitors can be joined in series and parallel combination.

9. Prove that there is loss of energy when two shells of different radii charged to different level are electrically connected.
10. State and explain Kirchhoff's Law of electric circuit. Describe Wheat Stone Bridge.
11. State Faraday's Law of Electromagnetic Induction. Prove that law of conservation of energy is valid in the Electromagnetic Induction.
12. What is self - induction. Derive expression for self – inductance of a circular coil.

13. Define mutual inductance. Derive expression for mutual inductance of two circular coils wound on same core.
14. State Coulomb's law. Define electric intensity and potential due to a point charge.

15. Define electric dipole moment. Derive expression for electric potential and field intensity at any point due to an electric dipole.

16. State and prove Gauss Theorem. Derive expression for electric field near uniform areal charge distribution. Or,
    Derive expression for electric field due to long uniform linear charge distribution.
17. Derive expression for electric field at any point due to a point charge using Gauss theorem.
18. What is Biot – Savart law. Find an expression for magnetic field at a point due to long straight current carrying condenser. Or, Derive expression for magnetic field at the center of the circular coil.
19. Derive expression for magnetic field at the axial point of a circular coil carrying current.
20. Derive expression for magnetic field at the axial point of a solenoid.
21. Derive expression for magnetic force experienced by two parallel current carrying wire. Define ampere as unit of current.
22. Derive expression for torque experienced by a current conducting loop in uniform magnetic field. Derive magnetic moment of the coil.

23. Describe principal and construction of moving coil Galvanometer.

24. What do mean by intensity of magnetization magnetic susceptibility & magnetic permeability. Describe modern theory of magnetism.

25. Find expression for capacity of parallel plate condenser.
(a) When there is a single dielectric slab completely fills the gap between the plates.
(b) Compound dielectric parallel plate capacitor.

26. What is Magnetic moment of a magnet. Derive expression for potential energy of a magnet in uniform magnetic field.
27. Derive expression for magnetic potential and intensity due to a permanent magnet in (a) End on position (b) Broad side on position.
28. Find expression for magnetic potential and magnetic force field at a point due to magnetic dipole or short magnet.
29. State Tangent law. Describe comparison of magnetic moments of two magnet using tangent law.
30. Derive expression for period of oscillation of a permanent magnet in uniform magnetic field.
31. Describe P-N junction semiconductor rectifier.
32. **
33. State Joule's law of heating. Describe experiment for verification of Joule's law of heating.
34. What is Seebeck effect.
35. What is Peltier effect.
36. Describe principal and construction of potentiometer. How it is used for determination of e.m.f. of a cell.
37. What are Faraday's law of electrolysis. Describe experimental verification of Faraday's law.

ADVISORY :-- ***Students are advised to study from Standard books and understand the topics in detail for success in exam.The above Questions& Answers may be helpful but can never be Substitute to deep understandings &detailed study.***