Ch-02
Electrostatic Potential & Capacitance

Formula Sheet
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① Electric Potential difference $(V_A - V_B) = \boxed{\dfrac{W_{ext\,B \to A}}{q_0}}$; $V \to$ constant
   unit - volt
   Kinetic energy do not change.

② Potential at a point (assuming $V_\infty = 0$) = $V_A - V_\infty = \dfrac{W_{ext\,\infty - A}}{q_0}$

③ $W_{ext} = -W_{electric\,force}$ ($\because \vec{F}_{ext} = -\vec{F}_{electric}$) $\boxed{V_A = \dfrac{W_{ext\,\infty - A}}{q_0}}$

④ Electric potential due to a point charge (at distance r from it) $\boxed{V_P = \dfrac{KQ}{r}}$

⑤ To calculate electric potential due to continuous charge distribution, first calculate dv for a point charge dq. and then integrate dv to calculate V. $Q \to$ with the greater

⑥ Electric potential on the axis of a uniformly charged disc.
   $$V_{axis\,disc} = \dfrac{\sigma}{2\varepsilon_0}\left(\sqrt{R^2 + n^2} - n\right)$$
   at centre = $\boxed{V = \dfrac{\sigma R}{2\varepsilon_0}}$

⑦ Electric potential on the axis of dipole at distance r from centre of dipole
   $\boxed{V_{axis} = \dfrac{KP}{r^2}}$

⑧ On the equitorial line of dipole (at distance r from centre of dipole) $\boxed{V_P = 0}$

⑨ at same general point (r, θ) due to dipole $\boxed{V_n = \dfrac{KP\cos\theta}{r^2}}$

⑩ Electric potential always decrease in the direction of electric field.

⑪ $\Delta v = -\vec{E}\cdot\vec{r}$ (when $\vec{E}$ is uniform)
   $|\Delta v| = \vec{E}\cdot\vec{r}$

⑫ and. $\overset{V_B - V_A =}{\Delta v} = \int dv = \int\limits_A^B -\vec{E}\cdot d\vec{r}$ (when $\vec{E}$ is non uniform)
   $\vec{r} = n\hat{i} + y\hat{j} + z\hat{k}$
   $d\vec{r} = dn\hat{i} + dy\hat{j} + dz\hat{k}$

⑬ $dv = -\vec{E}\cdot d\vec{r}$
   $dv = -(E_n\hat{i} + E_y\hat{j} + E_z\hat{k})\cdot(dn\hat{j} + dy\hat{j} + dz\hat{k}) \Rightarrow d - E_n dn - E_y dy - E_z dz$
   (i) If only n is changing, y & z behaves as constant
   $\boxed{E_n = \dfrac{-dv}{dn}}$

   (ii) Similarly $\boxed{E_y = \dfrac{-dv}{dy}}$ $\dfrac{dv}{dn}$

   (iii) $\boxed{E_z = \dfrac{-dv}{dz}}$ $\left.\begin{array}{l}\dfrac{dv}{dn} \\ \dfrac{dv}{dy} \\ \dfrac{dv}{dz}\end{array}\right\}$ potential gradient

⑭ for equipotential surface, potential difference between any two points is zero. $\because V_A = V_B \Rightarrow \boxed{V_A - V_B = 0}$ and no work is done in moving the charge. $V_A - V_B = 0 \Rightarrow \boxed{W_{ext} = 0}$ ($\because V_A - V_B = \dfrac{W_{ext}}{q}$)

(15) V is constant inside a conductor. $(\because E=0 , \therefore V_A - V_B = 0 , V_A = V_B)$
They have equipotential volumes.

(16) electric potential due to charged conducting sphere (solid/Hallow)
(i) outside $(r>R)$; $V_P = \dfrac{KQ}{r}$ (It seems as charge is at centre)

V_s (at surface) $= \dfrac{KQ}{R}$

(ii) inside $(r<R)$ $\boxed{V_P = \dfrac{KQ}{R}}$

(17) Same results for Hallow Non-Conducting sphere.

(18) Electric potential due to Non-conducting solid sphere (i) outside $(r>R)$
$\boxed{V_P = \dfrac{KQ}{r}}$; at surface $\boxed{V_R = \dfrac{KQ}{R}}$

(ii) inside $(r<R)$ $\boxed{V_P = \dfrac{KQ}{R}\left[\dfrac{3}{2} - \dfrac{1}{2}\dfrac{r^2}{R^2}\right]}$

$\boxed{V \text{ at centre} = \dfrac{3}{2} V_s}$

(19) The conductor which is earthed will have $V=0$ & charge accordingly.

(20) Electrostatic Potential energy $(U_P)=0$ for single charge.

(21) $\Delta U = U_f - U_i = $ W ext agent to bring that charge $(\Delta K.E=0) = -$ W electric

(22) Potential energy of two charges at separation r (assuming $U_\infty = 0$)
$\boxed{U = \dfrac{Kq_1 q_2}{r}}$ $q_1, q_2 \rightarrow$ with sign

(23) Electric potential energy of a system of three charges : $\boxed{U = \dfrac{Kq_1 q_2}{r_1} + \dfrac{Kq_1 q_3}{r_3} + \dfrac{Kq_{23}}{r_2}}$

(24) Potential energy of single charge in an external field $\boxed{U = QV}$
If charge move in ext electric field $\boxed{(\Delta U) = Q\Delta V}$ (q- with sign)

(25) Potential energy of a system of two charges in ext field. $U_{system} = \dfrac{Kq_1 q_2}{r}$

(26) Potential energy of an electric dipole in a uniform electric field
$\Delta U = U_{\theta_2} - U_{\theta_1} = -$ W electric force $= -PE[\cos\theta_2 - \cos\theta_1]$ (dipole is rotated from θ_1 to θ_2)

assumption , $U_{90°} = 0$
and $\theta_1 = 90°$

$\boxed{U_{\theta_2} = -PE\cos\theta_2}$ $\Rightarrow$ $\boxed{U_\theta = -PE\cos\theta}$ $\Rightarrow$ $\boxed{U_\theta = -\vec{P}\cdot\vec{E}}$
$\boxed{U_{max} = +PE}$

$\boxed{U_{min} = -PE}$

(27) Capacitance is ability of a conductor to hold charge or electrical energy
$\boxed{C = \dfrac{Q}{V}}$ ($\because$ C doesn't depend upon Q and V , it depends upon dimension and properties of surrounding medium)
unit - farod

(28) capacitance of a spherical conductor $\boxed{C = 4\pi\varepsilon_0 R}$

energy stored in a spherical Capacitor $\boxed{U = \dfrac{Q^2}{2C} = \dfrac{1}{2}CV^2 = \dfrac{1}{2}QV}$

(30) Capacitance is very law of solid spherical capacitor. because energy is not bounded.

(31) Capacitance for parallel plate Capacitor $= \dfrac{\varepsilon_0 A}{d}$ ($d <<$ area of plates) (area of both plates is same)

(32) energy stored in a parallel plate capacitor $= \boxed{U = \dfrac{Q^2}{2C}} = \boxed{\dfrac{1}{2} CV^2} \boxed{\dfrac{1}{2} QV}$

(These expression of energy is true for cylindrical capacitors as well)

(33) energy density of an electric field $\boxed{Q = \varepsilon_0 AE}$

(34) Force between the plates of a parallel plate capacitor $\boxed{F = \dfrac{Q^2}{2\varepsilon_0 A}}$

(35) In a spherical capacitor the outer shell is earthed and inner shell is given charge $+Q$.

(36) same thing is do applied for cylindrical capacitors.

(37) Capacitance of spherical capacitor $= \boxed{\dfrac{4\pi\varepsilon_0\, ab}{b-a}}$

(38) capacitance of cylindrical capacitor $= \boxed{\dfrac{2\pi\varepsilon_0 L}{\log_e\left(\dfrac{b}{a}\right)}}$

(39) Series Combination of capacitor (Q is same, V-distributed) $\boxed{\dfrac{1}{C_e} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3}}$

(i) for two capacitor $\boxed{C_e = \dfrac{C_1 C_2}{C_1 + C_2}}$

(ii) if n capacitor of equal capacitance $\boxed{C_e = \dfrac{c}{n}}$

(40) Parallel Combination of capacitor (V is same, Q is distributed) $\boxed{C_e = C_1 + C_2 + C_3}$

(i) when n capacitor of equal capacitance $= \boxed{C_e = nc}$

(41) Potential method - if there is no capacitor, resistor or battery etc in the path, the V will be constant.

(42) Infinite ladder problem (i) find repeating unit. (ii) take the equivalent capacitance for these ∞ unit $= n$, (iii) after removing one, eq capacitance of $(\infty - 1)$ unit $= n$ (iv) then solve.

(43) Wheatstone bridge problem : If $\dfrac{rc_1}{c_4} = \dfrac{C_2}{C_3}$ [balanced wheatstone bridge]

then X and Y have same potential $\Rightarrow$ C$_5$ is connected to same potential on both plates $\Rightarrow$ C$_5$ has no role in circuit.

(44) Kirchoff's rule - after inserting dielectric slab - $\boxed{E_{net} = \dfrac{E_0}{K}}$ $\boxed{V' = \dfrac{V_0}{K}}$ $\boxed{C = KC_0}$ where K is dielectric constant (where E_0, V_0, C_0 is without dielectric)

(45) $E_i = E_0\left(1 - \dfrac{1}{K}\right)$; $\sigma_i = \sigma\left(1 - \dfrac{1}{K}\right)$; $Q_i = Q\left(1 - \dfrac{1}{K}\right)$

(dielectric supports plates and prevent attraction between plates)

(46) when battery is disconnected and then dielectric is inserted slowly $Q_i = Q_0$ and $Q_f = Q_0$ | $C_i = C_0$ and $C_f = KC_0$ | $V_i = V_0$ and $V_f = \dfrac{V_0}{K}$

(47) When battery remains connected and dielectric is inserted slowly $V_i = V_0$ and $V_f = V_0$ | $C_i = C_0$ and $C_f = kC_0$ | $Q_i = C_0 V_0$ and $Q_f = kQ_0$

(48) when two plates are connected with each other, V is same in both.