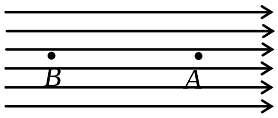
Chapter Overview

Potential:

1. **Nature of electrostatic force: Conservative**.
2. **Potential:** Work done by bringing a unit charge from infinity to a point by an external force (equal and opposite to electrostatic force) is **potential** at that point.
   Or, negative of the work done by an electric force in bringing a unit charge from infinity to a point is the potential at that point.
3. Potential (and the field also) is not defined at the location of the point charge. In the expression $U = qV$, V is due to the charges other than q.
4. Potential decreases in the direction of the electric field.



$V_A < V_B$

   Energy of positive charge decreases as it moves down the electric field while that of the negative charge increases.
5. Potential and potential energy are arbitrary quantities. Taking value of potential at infinity to be zero, potential at a point with position vector $\vec{r}$ with respect to the point-charge q is $V(r) = \dfrac{q}{4\pi\varepsilon_0 r}$.
6. **Equipotential surface:** A surface at every point of which potential is the same.
   Properties:
   (i) No work is done if a charge is displaced on the equipotential surface.
   (ii) Electric field is always perpendicular to the equipotential surface.
   (iii) Equipotential surfaces never intersect.
7. Potential energy of a charge q at a point where potential is V is $U = qV$.

Dipole:

8. Potential at a point at position $\vec{r}$ with respect to the location of the dipole is $V(r) = \dfrac{\vec{P}\cdot\vec{r}}{4\pi\varepsilon_0 r^3} = \dfrac{P\cos\theta}{4\pi\varepsilon_0 r^2}$.
   θ is the angle between $\vec{P}$ and $\vec{r}$.
9. Potential energy of a dipole at point where electric field is E is $U = -\vec{p}\cdot\vec{E}$.
10. Work done by external agent in rotating a dipole: $W_{ext} = PE[\cos\theta_1 - \cos\theta_2]$.

Potential energy of a system of charges:

11. **Superposition Principle**: Potential at a point P due several charges is $V_P = \sum_{i=1}^{i=n} \dfrac{q_i}{4\pi\varepsilon_0 r_i}$, r_i is the distance of q_i from P.
12. Potential energy of two charge system: $U = \dfrac{q_1 q_2}{4\pi\varepsilon_0 r_{12}}$.
13. Potential energy of a system of n charges: $U = \sum_{\substack{i\neq j\\ ij=ji}} \dfrac{q_i q_j}{4\pi\varepsilon_0 r_{ij}}$.

   This is sum of the potential energy of all two charge system formed within the system.
   Total number of pairs in the collection of n charges is ${}^{n}C_2$.

14. Total potential energy of a system of charges in an external electric field is $U = \sum q_i V_i + \sum_{i \neq j} \frac{q_i q_j}{4\pi\varepsilon_0 r_{ij}}$.

15. Potential at a point on the axis of a ring of charge with radius R and charge Q at a distance x from the centre: $V = \frac{KQ}{\sqrt{x^2 + R^2}}$.

16. Electric potential at a point on the axis of a circular disc having surface charge density σ and radius R, at a distance x from the centre: $E = \frac{\sigma}{2\varepsilon_0}\left[1 - \frac{x}{\sqrt{x^2 + R^2}}\right]$.

17. Potential at point distant r from the center of a spherical uniform surface charge distribution, having total charge Q and the radius R: For $r > R$: $V(r) = \frac{Q}{4\pi\varepsilon_0 r}$ For $r < R$: $V(r) = \frac{Q}{4\pi\varepsilon_0 R}$

18. Potential at point distant r from the center of a spherical uniform volume charge distribution, having total charge Q and the radius R: For $r > R$: $V(r) = \frac{Q}{4\pi\varepsilon_o r}$ For $r < R$: $V(r) = \frac{Q}{8\pi\varepsilon_o R}\left(3 - \frac{r^2}{R^2}\right)$

19. Potential difference between the two points distant r_1 and r_2 from the from an infinite line of charge:

$$V(r_2) - V(r_1) = \frac{\lambda}{2\pi\varepsilon_0}\left[\ln\frac{r_2}{r_1}\right]$$

20. **Self Potential Energy**:

(i) of a spherical surface charge distribution $U_{self} = \frac{Q^2}{8\pi\,\varepsilon_0 R} = \frac{1}{2}QV$.

(ii) of a spherical volume charge distribution $U_{self} = \frac{3Q^2}{20\pi\varepsilon_0 R} = \frac{3}{5}QV$.

Conductors & Dielectrics

21. Electric field inside a conductor is 0. Inside the cavity, if any, field is also zero, provided there is no charge inside the cavity. This called electrostatic shielding.

22. Electric potential of a conductor is same at every point of the conductor. Therefore the volume of the conductor is an equipotential volume and its surface is equipotential surface.

23. Field just outside the surface of a conductor is $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$, where $\hat{n}$ is the normal unit vector at the surface of the conductor.

24. Electrostatic pressure on a charges surface: $P = \frac{\sigma^2}{2\varepsilon_0}$.

25. Charge and charge density of interconnected spheres: $\frac{Q_1}{Q_2} = \frac{R_1}{R_2}$, $\frac{\sigma_1}{\sigma_2} = \frac{R_2}{R_1}$.

26. Induced surface charge density on the surface of a dielectric slab: $\sigma' = \vec{P} \cdot \hat{n}$

27. Relation between $\vec{P}$ and $\vec{E}$: $\vec{P} = \varepsilon_0 \chi \vec{E}$. χ is called electric susceptibility and the dielectric for which this relation is valid is called "linear dielectric".

28. Relation between electric susceptibility and dielectric constant: $\chi_e = k - 1$.

29. Relation between free charge density and induced charge density on the surface of a dielectric: $\sigma_{induced} = \sigma_{free}\left(1-\frac{1}{k}\right)$.
30. Electric displacement vector $\vec{D}$ is defined as $\vec{D} = \varepsilon_0\vec{E} + \vec{P}$. This is equal to free charge density in magnitude.
31. **Dielectric Strength**: The value of electric field for which the molecules of a dielectric get ionized and dielectric becomes conducting, is called dielectric strength for the dielectric. This is a constant for the given electric.

Capacitor:

32. Capacitor is a system of two conductors separated by an insulator. The two conductors carry equal and opposite charges and an electric field exists between the conductors in which energy is stored.
33. Capacitance $C = \frac{Q}{V}$.

    (i) Parallel plate capacitor: $C = \frac{\varepsilon_0 A}{d}$.

    (ii) Spherical Capacitor: $C = \frac{4\pi\varepsilon_0 ab}{(b-a)}$

    (iii) Cylindrical capacitor: $C = 2\pi\varepsilon_0 l / \ln\frac{b}{a}$

    (iv) Two Parallel wires: $\boxed{C = \pi\varepsilon_0 / \ln\frac{d}{r}}$

34. Capacitance of two parallel wires of radius *r* separated by *d* (per unit length): $\boxed{C = \pi\varepsilon_0 / \ln\frac{d}{r}}$
35. Capacitors in series grouping: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$
36. Capacitors in Parallel grouping: $C = C_1 + C_2 + C_3$
37. Capacitor with partially filled dielectric: $C_{eq} = \frac{k\varepsilon_0 A}{d\left(k - \frac{t(k-1)}{d}\right)}$, *t* is the thickness of the dielectric.
38. Energy stored in capacitor: $U = \frac{Q^2}{2C}$ or $U = \frac{1}{2}CV^2$ or $U = \frac{1}{2}QV$
39. Energy density of electric field: $u = \frac{1}{2}\varepsilon_0 E^2$.
40. Force of attraction between the plates of a capacitor: $F = -\frac{q^2}{2\varepsilon_0 A}$.
41. Loss of energy when charged capacitors are reconnected: $\Delta U = \frac{C_1C_2}{2(C_1+C_2)}(V_1 - V_2)^2$
42. Force on a dielectric slab exerted by electric field between the plates if capacitor is connected to a cell of emf *V*: $F = \frac{\varepsilon_0 b(k-1)V^2}{2d}$.