Conceptual physics practice page chapter 4 answers

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1.1 Definition- Charge is that property that is associated with the matter due to which it produces and experiences electrical and magnetic effects.1.2 TypeThere exist two types of charges in nature. They are:i. Positive chargeii. Negative chargeCharges with the same electrical sign repel each other while charges with opposite electrical signs attract each other.1.3 Unit and Dimensional FormulaS.I. unit of charge is coulomb (C), [illegible]

$W_{\text{coulamb force}}$ If charges are assembled from infinity: $\Delta U = U(r) - U(\infty) = U(r)$ [$U(\infty) = 0$] We know, $\Delta U = W_{ext}$ [when $\Delta K.E. = 0$] If $U(\infty) = 0 \Rightarrow U(r) = W_{ext}$ If $W_{ext} = 0 \quad \Delta KE + \Delta U = 0$ or $K.E_{i} + U_{i} = K.E_{f} + U_{f}$ 10.2 Zero Potential due to a System of Two Point ChargeI. For internal point : Q_1 and Q_2 (opposite signs)(Image will be uploaded soon) $\dfrac{Q_1}{x_1} = \dfrac{Q_2}{(x - x_1)} \Rightarrow x_1 = \dfrac{x}{\left(\left| Q_2 \right|/\left| Q_1 \right| + 1 \right)}$ II. For External point : (Image will be uploaded soon) Q_1 and Q_2 (opposite signs) $\left. \left| Q_1 \right| < \mid Q_2 \right)$ $\dfrac{\left| Q_1 \right|}{x_2} = \dfrac{\left| Q_2 \right|}{(x + x_2)} \Rightarrow x_2 = \dfrac{x}{\left(\left| Q_2 \right|/\left| Q_1 \right| - 1 \right)}$ 11. Electric Dipole11.1 Electric Field Due to a Dipole(Image will be uploaded soon)Using the concept that if we know potential electric field can be calculated we have already calculated $V_p = \dfrac{kp\cos\theta}{r^2}$ To Calculate net electric field at P we need E_r (Radial Component) & E_1 (tangential component) of electric field at P. $E_r = \dfrac{-dV}{dr}$. (When we travel in the radial direction). $E_t = -\dfrac{dV}{rd\theta}$ (When we travel in the tangential direction). $V_p = \dfrac{kP\cos\theta}{r^2}$ $E_r = \dfrac{-d}{dr}\left(\dfrac{kP\cos\theta}{r^2} \right) = \dfrac{2kP\cos\theta}{r^3}$ $E_t = \dfrac{-d}{rd\theta}\left(\dfrac{kP\cos\theta}{r^2} \right) = \dfrac{-kP}{r^3}\dfrac{d}{d\theta}\cos\theta = \dfrac{kP\sin\theta}{r^3}$ $E_{net} = \sqrt{E_r^2 + E_t^2} = \sqrt{\left(\dfrac{kP}{r^3} \right)^2\left[4\cos^2\theta + \sin^2\theta \right]}$ $E_{net} = \sqrt{\left(\dfrac{kP}{r^3} \right)^2\left[1 + 3\cos^2\theta \right]}$ $E_{net} = \dfrac{kP}{r^3}\sqrt{1 + 3\cos^2\theta}$ (Image will be uploaded soon) $\tan\alpha = \dfrac{E_t}{E_r} = \dfrac{\dfrac{kP}{r^3}\sin\theta}{2\dfrac{kP\cos\theta}{r^3}} = \dfrac{\tan\theta}{2} \quad \alpha = \tan^{-1}\left[\dfrac{\tan\theta}{2} \right]$ (Note: α is the angle with the radial direction)11.2 Equilibrium of DipoleWe know that, for any equilibrium net torque and net force on a particle (or system) should be zero.We already discussed when a dipole is placed in an uniform electric field net force on dipole is always zero. But net torque will be zero only when $\theta = 0^o$ or 180^0. When $\theta = 0^o$ i.e., dipole is placed along the electric field it is said to be in stable equilibrium, because after turning it through a small angle, dipole tries to align itself again in the direction of electric field.(Image will be uploaded soon)When $\theta = 180^o$ i.e., dipole is placed opposite to electric field, it is said to be in unstable equilibrium.Stable equilibrium Unstable equilibrium $\tau = 0$ $\tau_{\max} = pE$ $\tau = 0$ $W = 0$ $W = pE$ $W_{\max} = 2pE$ $U_{\min} = -pE$ $U = 0$ $U_{\max} = pE$ 11.3 Angular SHMIn a uniform electric field (intensity E) if a dipole (electric) is slightly displaced from it's stable equilibrium position it executes angular SHM having period of oscillation. If $I =$ moment of inertia of dipole about the axis passing through it's centre and perpendicular to it's length.For electric dipole : $T = 2\pi\sqrt{I/pE}$ 11.4 Dipole-Point Charge InteractionIf a point charge is placed in dipole field at a distance r. from the mid point of dipole then force experienced by point charge varies according to the relation $F \propto \dfrac{1}{r^3}$ 11.5 Electric Dipole in Non-Uniform Electric FieldWhen an electric dipole is placed in a non-uniform field, the two charges of dipole experiences unequal forces, therefore the net force on the dipole is not equal to zero.Due to two unequal forces, a torque is produced which rotate the dipole so as to align it in the direction of field.(Image will be uploaded soon)So in non-uniform electric field.(i) Motion of the dipole is translatory and rotatory(ii) Torque on it may be zero.Gauss's Law1. Electric Flux1.1 DefinitionElectric flux is defined as proportional to number of field lines crossing or cutting any area of cross section in space.'The number of field lines passing through perpendicular unit area will be prop ortional to the magnitude of Electric Field there" (Theory of Field Lines) $\dfrac{N}{A_\bot} \propto E \Rightarrow N \propto E_\bot$ (Image will be uploaded soon) $\therefore \quad$ Electric Flux, $\Phi_{A_\bot} = EA_\bot$ As θ increases, flux through area A decreases. If we draw a vector of magnitude A along the positive normal, it is called the area vector, $\vec A$ corresponding to the area A.(Image will be uploaded soon) $\therefore \quad$ Electric Flux, $\Phi_A = EA\cos\theta = \overrightarrow{E} \cdot \overrightarrow{A}$ (Assuming Electric Field is uniform over whole area)Note:If Electric field is not constant over the area of cross section, then $\Phi = \int_A \overrightarrow{E} \cdot d\overrightarrow{A}$ 1.2 Unit and DimensionFlux is a scalar quantity.S.I. unit : (volt $\times$ m) or $\dfrac{N \cdot m^2}{C}$ It 's Dimensional formula: $\left(M L^3 T^{-3} A^{-1} \right)$ 1.3 Types of FluxFor a closed body outward flux is taken to be positive, while inward flux is taken to be negative.(Image will be uploaded soon)2. Gauss's Law2.1 DefinitionAccording to Gauss's law, total electric flux through a closed surface enclosing a charge is $\dfrac{1}{\varepsilon_0}$ times the magnitude of the charge enclosed.i.e., $\phi_{not} = \dfrac{1}{\varepsilon_0}\left(Q_{cc} \right)$ i.e., $\oint \vec E \cdot d\vec A = \dfrac{Q_{en}}{E_0}$. Note:Gauss's law is only applicable for a closed surface.2.2 Gaussian SurfaceThe closed surface on which Gauss law is applicable is defined as a Gaussian surface.Note:Gaussian surface can be of any shape & size, only condition is that it should be closed.Gaussian surface is hypothetical in nature. It does not have a physical existence.2.3 Deriving Gauss's Law from Coulomb's LawLet's take a spherical gaussian surface with charge '$+ Q$' kept at the centre.(Image will be uploaded soon)We know field lines for a +ve charge are always radially outward.Angle between $d\vec A$ and $\vec E$ is zero. $E = \dfrac{kQ}{r^2} = \dfrac{Q}{4\pi \in_0 r^2}$ (Image will be uploaded soon)Hence Net flux $= Q/\varepsilon_0$. Although we derived gauss law for a spherical surface it is valid for any shape of gaussian surface and for any charge kept anywhere inside the surface.2.4 Coulomb's Law from Gauss's LawWe choose an imaginary sphere (Gaussian surface) of radius r centred on the charge $+ q$. Due to symmetry, E must have the same magnitude at any point on the surface, and $\vec E$ points radially outward, parallel to $\overrightarrow{dA}$. Hence we write the integral in Gauss's law as:(Image will be uploaded soon) $\phi_{net} = \oint \vec E \cdot \overrightarrow{dA} = \oint E\, dA = E\oint dA = E\left(4\pi r^2 \right)$ $Q_{enclosed} = q$ Thus, $E\left(4\pi r^2 \right) = \dfrac{q}{\varepsilon_0}$ or $E = \dfrac{q}{4\pi\varepsilon_0 r^2}$ From the definition of the electric field, the force on a point charge q_0 located at a distance r from the charge q is $F = q_0 E$. Therefore, $F = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q q_0}{r^2}$ which is Coulomb's law.3. Applications of Gauss's LawUsing Gauss's law to derive 'E' due to various charge distributions.3.1 Electric Field Due to a Line ChargeConsider an infinite line which has a linear charge density λ. Using Gauss's law, let us find the electric field at a distance 'r' from the line charge.The cylindrical symmetry tells us that the field strength will be the same at all points at a fixed distance r from the line. Thus, if the charges are positive. The field lines are directed radially outwards, perpendicular to the line charge.The appropriate choice of Gaussian surface is a cylinder of radius r and length L. On the flat end faces, S_2 and S_3, $\overrightarrow{E}$ is perpendicular $d\overline{S}$, which means flux is zero on them. On the curved surface S_1, $\vec E$ is parallel to $d\bar S$, so that $\overrightarrow{E} \cdot \overrightarrow{dS} = EdS$. The charge enclosed by the cylinder is $Q = \lambda L$. Applying Gauss's law to the curved surface, we have $E\oint dS = E(2\pi rL) = \dfrac{\lambda L}{\varepsilon_0}$ or $E = \dfrac{\lambda}{2\pi\varepsilon_0 r} = \dfrac{2k\lambda}{r}$ Note:This is the field at a distance r from the line. It is directed away from the line if the charge is positive and towards the line if the charge is negative.3.2 Electric Field Due to a Plane Sheet of ChargeConsider a large plane sheet of charge with surface charge density (charge per unit area) σ. We have to find the electric field E at a point P in front of the sheet.(Image will be uploaded soon)Note:If the charge is positive, the field is away from the plane.To calculate the field E at P. Choose a cylinder of area of cross-section A through the point P as the Gaussian surface. The flux due to the electric field of the plane sheet of charge passes only through the two circular caps of the cylinder.According to Gauss law $\oint \vec E \cdot d\bar S = q_{in}/\varepsilon_0$ $\int_{\text{I circular surface}} \overrightarrow{E} \cdot \overline{dS} + \int_{\text{II circular surface}} \overrightarrow{E} \cdot \overline{dS} + \int_{\text{cylindricalr surface}} \overrightarrow{E} \cdot \overline{dS} = \dfrac{\sigma A}{\varepsilon_0}$ or $EA + EA + 0 = \dfrac{\sigma A}{\varepsilon_0}$ or $E = \dfrac{\sigma}{2\varepsilon_0}$ Note:We see that the field is uniform and does not depend on the distance from the charge sheet. This is true as long as the sheet is large as compared to its distance from P. 3.3 Uniform Spherical Charge Distribution3.3.1 Outside the SphereP is a point outside the sphere at a distance r from the centre.(Image will be uploaded soon)According to Gauss law, $\oint \overrightarrow{E} \cdot d\overrightarrow{s} = \dfrac{Q}{\varepsilon_D}$ or $E\left(4\pi r^2 \right) = \dfrac{Q}{\varepsilon_D}$ Electric field at P (Outside sphere) $E_{out} = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{r^2} = \dfrac{\sigma R^2}{\varepsilon_0 r^2}$ and $V_{out} = -\int_\infty^r \overrightarrow{E} \cdot d\overrightarrow{r} = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{r} = \dfrac{\sigma R^2}{\varepsilon_0 r}$ Note: $Q = 0 \times A$ $= \sigma \times 4\pi R^2$ 3.3.2 At the surface of sphereAt surface $r = R$ So, $E_e = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{R^2} = \dfrac{\sigma}{\varepsilon_0}$ and $V_\varepsilon = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{R} = \dfrac{\sigma R}{\varepsilon_0}$ 3.3.3 Inside the SphereInside the conducting charged sphere electric field is zero and potential remains constant everywhere and equals to the potential at the surface.Graphical Variation of Electric Field and Potential With Distance(Image will be uploaded soon)3.4 Uniform Spherical Volume Charge DistributionWe consider a spherical uniformly charge distribution of radius R in which total charge Q is uniformly distributed throughout the volume.The charge density $\rho = \dfrac{\text{total ch arge}}{\text{total volume}} = \dfrac{Q}{\dfrac{4}{3}\pi R^3} = \dfrac{3Q}{4\pi R^3}$ 3.4.1 Outside the Sphere at $P(r \geqslant R)$ According to Gauss law $\oint \overrightarrow{E} \cdot \overrightarrow{ds} = \dfrac{Q}{\varepsilon_0}$ or $E\left(4\pi r^2 \right) = \dfrac{Q}{\varepsilon_O}$ $E_{out} = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{r^2}$ and $V_{out} = -\int_\infty^{l} \overrightarrow{E} \cdot d\overrightarrow{\mathbf{r}} = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{r}$ using $\rho = \dfrac{Q}{\dfrac{4}{3}\pi R^3}$ $E_{out} = \dfrac{\rho R^3}{3\varepsilon_0 r^2}$ and $V_{0ut} = \dfrac{\rho R^3}{3\varepsilon_J \mathbf{r}}$ $(V(\infty) = 0)$ 3.4.2 At the Surface of SphereAt surface $r = R$ $E_e = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{R^2} = \dfrac{\rho R}{3\varepsilon_0}$ and $V_s = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{R} = \dfrac{\rho R^2}{3\varepsilon_0}$ 3.4.3 Inside the SphereAt a distance r from the centre. $(r \leqslant R)$ $\oint \vec E_{in} \cdot \overrightarrow{ds} = \dfrac{q_{in}}{\varepsilon_0} = \dfrac{Qr^3}{\varepsilon_0 R^3}$ or $E_{jn}\left(4\pi r^2 \right) = \dfrac{Qr^3}{G_0 R^3}$ $E_{in} = \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Qr}{R^3} = \dfrac{\rho r}{3\varepsilon_0}$ $\left\{ E_{in} \propto r \right\}$ and $V_{in} = -\int_k^r \vec E \cdot d\vec r = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q\left[3R^2 - r^2 \right]}{2R^3} = \dfrac{\rho\left(3R^2 - r^2 \right)}{6\varepsilon_a}$ Note:At centre $(r = 0)$. $V_{centre} = \dfrac{3}{2} \times \dfrac{1}{4\pi\varepsilon_0} \cdot \dfrac{Q}{R} = \dfrac{3}{2}V_o$ i.e., $V_{centre} > V_{surface} > V_{out}$ Graphical Variation of Electric Field and Potential With Distance.(Image will be uploaded soon)4. Properties of Conductors1. Inside a Conductor, Electrostatic Field Is ZeroConsider a conductor, neutral or charged. There may also be an external electrostatic field. In the static situation the electric field is zero everywhere inside the conductor. As long as electric field is not zero, the free charge carriers would experience force and drift. In the static situation, the free charges have so distributed themselves that the electric field is zero everywhere inside. Electrostatic field is zero inside a conductor.2. At the Surface of a Charged Conductor, Electrostatic Field Must Be Normal to the Surface at Every Point.If E were not normal to the surface, it would have some nonzero component along the surface. Free charges on the surface of the conductor would then experience force and move. In the static situation, therefore, E should have no tangential component. Thus electrostatic field at the surface of a charged conductor must be normal to the surface at every point. (For a conductor without any surface charge density, field is zero even at the surface).3. The Charge Kept in the Material of a Conductor Will Come to Its Outermost Surface.We know electric field at all points inside the material of a conductor is zero. This means '$E^\prime$' is at all points on the Gaussian surface is zero. $\int \overrightarrow{E} \cdot \overrightarrow{dA} = \dfrac{Q_{e1}}{\varepsilon_0} \Rightarrow E = 0 \Rightarrow Q_{en} = 0$ Charge cannot remain inside so it comes outside dotted surface.4. Electrostatic Potential is Constant Throughout the Volume of the Conductor and Has the Same Value (As Inside) on Its Surface.This follows from results 1 and 2 above. Since $E = 0$ inside the conductor and has no tangential component on the surface, no work is done in moving a small test charge within the conductor and on its surface. That is, there is no potential difference between any two points inside or on the surface of the conductor Hence, the result. If the conductor is charged, electric field normal to the surface exists; this means potential will be different for the surface and a point just outside the surface.In a system of conductors of arbitrary size, shape and charge configuration, each conductor is characterised by a constant value of potential, but this constant may differ from one conductor to the other.5. Electric Field at the Surface of a Charged Conductor $E = \dfrac{\sigma}{\varepsilon_0}n$ where σ is the surface charge density and $\hat n$ is a unit vector normal to the surface in the outward direction.For $\sigma > 0$, electric field is normal to the surface outward; for $\sigma > 0$, electric field is normal to the surface inward.5. Gauss Law5.1 Some Important Points About Gauss Law1. In the above expression, charge enclosed is $\left(Q_1 \text{ and } Q_2 \right)$. Net flux will only depend on $Q_1 \text{ and } Q_2$. But 'E' in the Gauss Law will be due to all the charges Q_1, Q_2, $Q_3 \text{ and } Q_4$. Hence electric field calculated through Gauss law is not just due to enclosed charges but due to all the charges.2. If Q_{en} by a gaussian surface is given to be zero then it does not necessarily imply that $E = 0$. It may or may not be zero. For example: $Q_{en} = 0$ but electric field on the Gaussian surface is present.3. If E at all points on the gaussian surface is zero then it mean Q_{en} has to be zero.Because $\oint \overrightarrow{E} \cdot \overrightarrow{dA} = \dfrac{Q_{en}}{\varepsilon_D}$. 5.2 Zero Flux(i) Net charge equals to zeroIf a dipole is enclosed by a surface, $\phi = 0; Q_{enc} = 0$ If the magnitude of positive and negative charges are equal inside a closed surface.(ii) Charges are absentIf a closed body (not enclosing any charge) is placed in an electric field (either uniform or non-uniform) total flux linked with it will be zero.5.3 Observe Flux through Common Geometrical Figures5.3.1 Cube(i) Charge at the centre of cube.(Image will be uploaded soon)Note: $\phi_{total} = \dfrac{1}{\varepsilon_0} \cdot (Q)$ Flux through each face, $\phi_{face} = \dfrac{Q}{6\varepsilon_0}$ (ii) Charge situated at the corner of a cube.(Image will be uploaded soon)For the charge at the corner, we require eight cube to symmetrically enclose it in a Gaussian surface. The total flux $\phi_T = \dfrac{Q}{\varepsilon_0}$. Therefore the flux through one cube will be $\phi_{cube} = \dfrac{Q}{8\varepsilon_0}$. The cube has six faces and flux linked with three faces (through A) is zero $(ABCD, AHED, ABGH)$, so flux linked with remaining three faces will $\dfrac{Q}{8\varepsilon_0}$. Now as the remaining three are identical so flux linked with each of the three faces will be $= \dfrac{1}{3} \times \left[\dfrac{1}{8}\left(\dfrac{Q}{\varepsilon_0} \right) \right] = \dfrac{1}{24}\dfrac{Q}{\varepsilon_0}$. Charge Position ϕ_r Cube centre q/ε_0 Face centre $q/2\varepsilon_0$ At corner $q/8\varepsilon_0$ At centre of edge $q/4\varepsilon_0$ 5.3.2 Hemisphere $\phi_{out} = \phi_{in} = \pi R^2 E$ $\phi_T = 0$ $\phi_T = \dfrac{q}{\varepsilon_0}, \phi_{hemisphere} = \dfrac{q}{2\varepsilon_0}$ (dotted part shows imaginary part to enclose the charge completely)(Image will be uploaded soon)5.3.3 Cylinder $\phi_T = \dfrac{q}{\varepsilon_0}, \phi_{cy1} = \dfrac{q}{2\varepsilon_0}$ (Image will be uploaded soon)6. Cases of Concentric Shells $V_a = \dfrac{kQ_1}{r_1} + \dfrac{k\left(-Q_1 \right)}{r_2} + \dfrac{k\left(Q_1 + Q_2 \right)}{r_2}$ $V_b = \dfrac{kQ_1}{r_2} + \dfrac{k\left(-Q_1 \right)}{r_2} + \dfrac{k\left(Q_1 + Q_2 \right)}{r_2}$ 7. Cases of Earthing a Conductor1. Firstly do charge distribution before earthing.2. After charge distribution, assume some 'x' charge flown to ground (after earthing).3. Do re-distribution of charge.4. Take a point on the conductor (which is earthed) & do net potential of it equals 0. Calculate x. $V_P = 0 = \dfrac{kQ_1}{r_2} + \dfrac{k\left(-Q_1 \right)}{r_2} + \dfrac{k\left(Q_1 + Q_2 - x \right)}{r_2} \Rightarrow x = Q_1 + Q_2$ Charge is flown from outer surface because as long as Q_1 remains on inner shell, '$-Q_1$' will be induced on inner shell. $V_P = 0 = \dfrac{k\left(Q_1 - x \right)}{r_1} + \dfrac{k\left(-\left(Q_1 - x \right) \right)}{r_2} + \dfrac{k\left(Q_1 + Q_2 - x \right)}{r_2}$ $\dfrac{Q_1 - x}{r_1} - \dfrac{\left(Q_1 - x \right)}{r_2} + \dfrac{Q_1 + Q_2 - x}{r_2} = 0$ $\Rightarrow \quad \dfrac{Q_1}{r_1} + \dfrac{Q_2}{r_2} = \dfrac{x}{r_1} \Rightarrow x = Q_1 + \dfrac{Q_2 r_1}{r_2}$ Note:As it can be seen not all charge on the surface flows to ground. When the outermost conductor is earthed then the charge residing on the outermost surface of outer conductor will flow to ground.8. Connection of Charged ConductorsSteps1. Do charge distribution before connection.2. Assume 'x' charge flows from one conductor to another.3. Do redistribution of charges.4. Equate net potential of conductor (1) equal to net potential of conductor (2).Assumption: Distance between them is very large. $V_P = V_P$ $\Rightarrow \dfrac{k\left(Q_1 - x \right)}{r_1} = \dfrac{k\left(Q_2 + x \right)}{r_2} \Rightarrow x = \dfrac{Q_1 r_2 - Q_2 r_1}{r_1 + r_2}$ Final ChargesFinal common potential $k = \left(\dfrac{Q_1 + Q_2}{r_1 + r_2} \right)$ $V_P = V_R$ $V_P = \dfrac{k\left(Q_1 - x \right)}{r_1} + \dfrac{k - \left(Q_2 - x \right)}{r_2} + \dfrac{k\left(Q_1 + Q_2 \right)}{r_2}$ $\Rightarrow V_R = \dfrac{K\left(Q_1 - x \right)}{\mathbf{r}_2} + \dfrac{k - \left(Q_1 - x \right)}{\mathbf{r}_2} + \dfrac{k\left(Q_1 + Q_2 \right)}{\mathbf{r}_2}$; $V_P = V_R$ $\Rightarrow \dfrac{k\left(Q_1 - x \right)}{r_1} - \dfrac{k\left(Q_1 - x \right)}{r_2} \Rightarrow \left(Q_1 - x \right)\left[\dfrac{1}{r_1} - \dfrac{1}{r_2} \right] = 0$ $\Rightarrow \quad x = Q_1$ This indicates that all the charge on shell (1) will flow to shell(2).9. Self Energy of Charged SphereConsider a uniformly charged sphere of radius R having a total charge Q. The electric potential energy of this sphere is equal to the work done in bringing the charges from infinity to assemble the sphere.${\text{U}} = \dfrac{{3{Q^2}}}{{20\pi {\varepsilon _0}{\text{R}}}}\quad {\text{U}} = \dfrac{{{{\text{Q}}^2}}}{{8\pi {\varepsilon _0}{\text{R}}}}$10. Energy DensityThe energy stored per unit volume around a point in an electric field is given by ${u_{\text{e}}} = \dfrac{{\text{U}}}{{\text{ Volume }}} = \dfrac{1}{2}{\varepsilon _0}{{\text{E}}^2}.$ If in place of vacuum some medium of dielectric constant K is present then ${u_e} = \dfrac{1}{2}K{\varepsilon _0} {E^2}$11. Plate Theory11.1 Charged Conducting PateNet Flux $ = \dfrac{{Q_{en}}}{{\varepsilon _0}}} = \dfrac{{\sigma \pi {r^2}}}{{\varepsilon _0}}}$ (cylindrical Gaussian surface)${\text{E}}\pi {{\text{r}}^2} = \dfrac{{\sigma \pi {{\text{r}}^2}}}{{\varepsilon _{\text{o}}}}}$$E = \dfrac{\sigma }{{\varepsilon _0}}}$Net electric field at point P, near a conducting surface, ${\sigma ^\prime }$ is given by $\left[{\sigma /{\varepsilon _0}} \right]$(Image will be uploaded soon)11.2 Parallel Plate TheoryTo find charge distribution on each surface of plates.Two conducting plates having area 'A' (area is large as compared to distance, so that field is uniform) and the thickness of plates is small so that charge only appears on parallel faces.Since the field lines are parallel, the net flux through the gaussian surface will be zero, surface (1) and (2) be inside the material of the conductor.(Image will be uploaded soon)Hence it can be said that net charge enclosed will be zero which implies the charges appearing on the facing surfaces are equal & opposite to each other.Net electric field at any point 'P' or 'R' has to be zero.${\left({{E_{{\text{net }}}}} \right)_P} = 0$There are 4 distributions, the net field at ${\text{P}}$ should be zero.${({E_P})_1} = \dfrac{\sigma }{{2{\varepsilon _0}}}(\to) = \dfrac{{\left({{Q_1} - q} \right)}}{{2A{\varepsilon _0}}}(\to){\left({{E_P}} \right)_2} = \dfrac{q}{{2A{\varepsilon _0}}}(\leftarrow)$${\left({{E_P}} \right)_3} = \dfrac{q}{{2A{\varepsilon _0}}}(\to)\quad {\left({{E_P}} \right)_4} = \dfrac{{{Q_2} + q}}{{2A{\varepsilon _0}}}(\leftarrow)$$ \Rightarrow \left| {{{\left({{E_P}} \right)}_1}} \right| + \left| {{{\left({{E_P}} \right)}_3}} \right| = \left| {{{\left({{E_P}} \right)}_2}} \right| + \left| {{{\left({{E_P}} \right)}_4}} \right|$This shows $\dfrac{{{Q_1} - q}}{{2A{\varepsilon _0}}} + \dfrac{q}{{2A{\varepsilon _0}}} = \dfrac{q}{{2A{\varepsilon _0}}} + \dfrac{{{Q_2} + q}}{{2A{\varepsilon _0}}}$$q = \dfrac{{{Q_1} - {Q_2}}}{2}$ so final distributions would be,Note:When charged conducting plates are placed parallel to each other, the two outermost surfaces get equal charges and the facing surfaces get equal and opposite charges.11.3 Force on a Charged conductorTo find force on a charged conductor (due to repulsion of like charges) imagine a small part ${\text{XY}}$ to be cut and just separated from the rest of the conductor ${\text{MLN}}$. The field in the cavity due to the rest of the conductor is ${E_2}$, while field due to small part is E. Then(Image will be uploaded soon)Inside the conductor$\therefore {{\text{E}}_1} - {{\text{E}}_2} = 0{\text{ or }}{{\text{E}}_1} = {{\text{E}}_2}$Outside the conductor ${\text{E}} = {{\text{E}}_1} + {{\text{E}}_2} = \dfrac{\sigma } {{\varepsilon _0}}}$. Thus, ${E_1} = {E_2} = \dfrac{\sigma }{{2{\varepsilon _0}}}$To find force, imagine charged part ${\text{XY}}$ (having charge σdA placed in the cavity MN having field ${{\text{E}}_2}$). Thus force ${\text{dF}} = (\sigma {\text{dA}}){{\text{E}}_2}$ or ${\text{dF}} = \dfrac{{{\sigma ^2}}}{{2{\varepsilon _0}}}\;{\text{d}}\;{\text{A}}$. The force per unit area or electric pressure is ${\text{P}} = \dfrac{{{\text{dF}}}}{{{\text{dA}}}} = \dfrac{{{\sigma ^2}}}{{2{\varepsilon _0}}}$. (Electrostatic pressure) The force is always outwards as ${(\pm \sigma)^2}$ is positive i.e., whether charged positively or negatively, this force will try to expand the charged body.A soap bubble or rubber balloon expands on given charge to it (charge of any kind $ + $ or $ - $).capacitorsCapacitors1. Capacitance1.1 DefinitionWe know that charge given to a conductor increases it's potential i.e., ${\text{Q}} \propto {\text{V}} \Rightarrow {\text{Q}} = {\text{CV}}$Where C is a proportionality constant, called capacity or capacitance of conductor. Hence capacitance is the ability of conductor to hold the charge (and associated electrical energy).1.2 Unit and Dimensional FormulaS.I. unit is $\dfrac{{{\text{ Coulomb }}}}{{{\text{ Volt }}}} = $ Farad (F)Smaller S.I. units are ${\text{mF}},\mu {\text{F}},{\text{nF}}$ and ${\text{pF}}$$\left({1{\text{mF}} = {{10}^{ - 3}}\;{\text{F}},1\mu {\text{F}} = {{10}^{ - 6}}\;{\text{F}},1{\text{nF}} = {{10}^{ - 9}}\;{\text{F}},1{\text{pF}} = {{10}^{ - 12}}\;{\text{F}}} \right)$C.G.S. unit is Stat Farad. $1\;{\text{F}} = 9 \times {10^{11}}$ Stat Farad.Dimension: $[{\text{C}}] = \left[{{{\text{M}}^{ - 1}}\;{{\text{L}}^{ - 2}}\;{{\text{T}}^4}\;{{\text{A}}^2}} \right]$.2. Capacitor2.1 DefinitionA capacitor is a device that stores electric energy. It is also named condenser.or,A capacitor is a pair of two conductors of any shape, which are close to each other and have equal and opposite charge.2.2 SymbolThe symbol of capacitor are shown below:(Image will be uploaded soon)2.3 CapacitanceThe capacitance of a capacitor is defined as the magnitude of the charge Q on the positive plate divided by the magnitude of the potential difference V between the plates i.e., ${\text{C}} = {\text{Q}}/{\text{V}}$.Note:Capacitance of a capacitor is constant for the given dimensions & medium.2.4 Charge on CapacitorNet charge on a capacitor is always zero, but when we speak of the charge Q on a capacitor, we are referring to the magnitude of the charge on each plate.2.5 Energy StoredWhen a capacitor is charged by a voltage source (say battery) it stores the electric energy.Energy density $ = \dfrac{U}{{{\text{ vol }}}} = \dfrac{1}{2}{\varepsilon _0} {{\text{E}}^2}$If ${\text{C}} = $ Capacitance of capacitor; $Q = $ Charge on capacitor and $V = $ Potential difference across capacitor then energy stored in capacitor ${\text{U}} = \dfrac{1}{2}{\text{C}}{{\text{V}}^2} = \dfrac{1}{2}{\text{QV}} = \dfrac{{{{\text{Q}}^2}}}{{2{\text{C}}}}$.Note:In charging capacitor by battery half the energy supplied is stored in the capacitor and remaining half energy $(1/2QV)$ is lost in the form of heat.2.6 Types of CapacitorsCapacitors are of mainly three types as described in given table:Parallel Plate CapacitorSpherical CapacitorCylindrical CapacitorIt consists of two parallel metallic plates (may be circular, rectangular, square) separated by a small distance$A = $ area of plate$Q = $ Magnitude of charge(Image will be uploaded soon)Capacitance:$C = \dfrac{{{\varepsilon _0}A}}{d}$$\sigma = $ Surface charge density${\text{V}} = $ potential difference${\text{E}} = $ Electric field between the platesthe plates $\left({ = \sigma /{\varepsilon _0}} \right)$In the presence of dielectricbetween plates ${\text{C}} = \dfrac{{{\text{K}}{\varepsilon _{\text{O}}}{\text{A}}}}{{\text{d}}}$It consists of two concentric conducting spheres of radii a and $b(a < b)$. Inner sphere is given charge $ + Q$, while outer sphere is given charge $ - {\text{Q}}$ [by battery](Image will be uploaded soon)Capacitance: $C = 4\pi {\varepsilon _0}\dfrac{{ab}}{{b - a}}$in C.GS. ${\text{C}} = \dfrac{{{\text{ab}}}}{{{\text{b}} - {\text{a}}}}$.In the presence of dielectric medium (dielectric constant ${\text{K}})$ between the spheres${{\text{C}}^\prime } = 4\pi {\varepsilon _0}\;{\text{K}}\dfrac{{{\text{ab}}}}{{{\text{b}} - {\text{a}}}}$It consists of two concentric cylinders of radii a and $b(a < b)$, inner cylinder is given charge $ + Q$ while outer cylinder is given charge -Q. Common length of the cylinders is l then(Image will be uploaded soon)Capacitance:$C = \dfrac{{2\pi {\varepsilon _0}l}}{{\ln \left({\dfrac{b}{a}} \right)}}$In the presence of dielectric medium (dielectric constant K) capacitance increases by ${\text{K}}$ times and${C^{\prime \prime }} = \dfrac{{2\pi {\varepsilon _0}Kl}}{{\ln \left({\dfrac{b}{a}} \right)}}$2.7 Capacity of an Isolated Spherical ConductorWhen charge Q is given to a spherical conductor of radius R, then potential at the surface of sphere is,$V = \dfrac{1}{{4\pi {\varepsilon _0}}}.\dfrac{Q} {R}$Hence it's capacity ${\text{C}} = \dfrac{Q}{{\;{\text{V}}}} = 4\pi {\varepsilon _0}{\text{R}}$$\Rightarrow {\text{C}} = 4\pi {\varepsilon _0}{\text{R}} = \dfrac{1}{{9 \times {{10}^9}}} \cdot {\text{R}} $$\,\,\,\,\,{\text{ in C}}{\text{.G}}{\text{.S}}{\text{. C}} = {\text{R}}$2.8 Force Between the Plates of a Parallel Plate CapacitorField due to charge on one plate on the other is ${\text{E}} = \dfrac{\sigma }{{2{\varepsilon _0}}}$, hence the force $F = QE$3. Properties of an Ideal Battery(a) A battery has two terminals.(b) The potential difference V between the terminals is constant for a given battery. The terminal with higher potential is called the positive terminal and that with lower potential is called the negative terminal.(c) The value of this fixed potential difference is equal to the electromotive force or emf of the battery. If a conductor is connected to a terminal of a battery, the potential of the conductor becomes equal to the potential of the terminal. When the two plates of a capacitor are connected to the terminals of a battery, the potential difference between the plates of the capacitor becomes equal to the emf of the battery.(d) The total charge in a battery always remains zero. If its positive terminal supplies a charge Q, its negative terminal supplies an equal, negative charge $ - {\text{Q}}$.(e) When a charge Q passes through a battery of emf $\mathcal{E}$ from the negative terminal to the positive terminal, an amount QE of work is done by the battery.(Image will be uploaded soon)An ideal battery is represented by the symbol shown in figure. The potential difference between the facing parallel lines is equal to the emf $\mathcal{E}$ of the battery. The longer line is at the higher potential.4. Grouping of Capacitors4.1 Series grouping4.2 Parallel grouping(1) Charge on each capacitor remains same and equals to the main charge supplied by the battery.(2) Equivalent capacitance $\dfrac{1}{{{C_{{\text{eq }}}}}} = \dfrac{1}{{{C_1}}} + \dfrac{1}{{{C_2}}} + \dfrac{1}{{{C_3}}}$(3) If two capacitors having capacitances ${C_1}$ and ${C_2}$ are connected in series then${{\text{V}}_1} = \left({\dfrac{{{{\text{C}}_2}}}{{{{\text{C}}_1} + {{\text{C}}_2}}}} \right) \cdot {\text{V and }}{{\text{V}}_2} = \left({\dfrac{{{{\text{C}}_1}}}{{{{\text{C}}_1} + {{\text{C}}_2}}}} \right){\text{V}}$(4) If n identical capacitors each having capacitances C are connected in series with supply voltage V thenEquivalent capacitance ${{\text{C}}_{eq}} = \dfrac{{\text{C}}}{{\text{n}}}$ and Potential difference across each capacitor ${{\text{V}}^\prime } = \dfrac{{\text{V}}}{{\text{n}}}$.Note:Two capacitors are in series when charge leaving one capacitor directly enters into another capacitor, undivided and undisturbed.In series combination equivalent capacitance is always lesser than that of either of the individual capacitors.(1) Potential difference across each capacitor remains same and equal to the applied potential difference.(2) ${{\text{C}}_{ - {\text{eq}}}} = {{\text{C}}_1} + {{\text{C}}_2} + {{\text{C}}_3}$(3) If two capacitors having capacitance ${{\text{C}}_1}$ and ${{\text{C}}_2}$ respectively are connected in parallel then${{\text{Q}}_1} = \left({\dfrac{{{{\text{C}}_1}}}{{{{\text{C}}_1} + {{\text{C}}_2}}}} \right) \cdot {\text{Q and }}{{\text{Q}}_2} = \left({\dfrac{{{{\text{C}}_2}}}{{{{\text{C}}_1} + {{\text{C}}_2}}}} \right) \cdot {\text{Q}}$(4) If n identical capacitors are connected in parallel Equivalent capacitance ${{\text{C}}_{{\text{eq }}}} = n{\text{C}}$ and Charge on each capacitor ${Q^\prime } = \dfrac{Q}{n}$.Note:Two capacitors are in parallel when their positive plates are connected and negative plates are also connected with each other.In parallel combination, equivalent capacitance is always greater than the individual capacitance.5. Simple Circuits (series and parallel)Suppose equivalent capacitance is to be determined in the following networks between points A and B.6. DielectricDielectrics are insulating (non-conducting) materials which transmits electric effect without conducting. We know that in every atom, there is a positively charged nucleus and a negatively charged electron cloud surrounding it. The two oppositely charged regions have their own centres of charge. The centre of positive charge is the centre of mass of positively charged protons in the nucleus. The centre of negative charge is the centre of mass of negatively charged electrons in the atoms/molecules.6.1 Polarization of a Dielectric SlabIt is the process of inducing equal and opposite charges on the two faces of the dielectric on the application of electric field.Suppose a dielectric slab is inserted between the plates of a capacitor. As shown in the figure.(Image will be uploaded soon)Induced electric field inside the dielectric is ${{\text{E}}_{\text{i}}}$, hence this induced electric field decreases the main field ${\text{E}}$ to ${\text{E}} - {{\text{E}}_{\text{i}}}$ i.e., New electric field between the plates will be ${E_{{\text{net }}}} = E - {E_1}$.6.2 Dielectric ConstantAfter placing a dielectric slab in an electric field. The net field is decreased in that region hence,If ${\text{E}} = $ Original electric field and ${{\text{E}}_{{\text{net }}}} = $ Net electric field. Then $\dfrac{E}{{{E_{{\text{nut }}}}}} = K$ where K is called dielectric constant K is also known as relative permittivity $\left({{\varepsilon _r}} \right)$ of the material.The value of ${\text{K}}$ is always greater than one. For vacuum there is no polarization and hence $E = {E^\prime }$ and $K = 1$${{\text{E}}_{\text{i}}} = {\text{E}}\left[{1 - \dfrac{1}{{\text{k}}}} \right]{\sigma _{\text{i}}} = \sigma \left[{1 - \dfrac{1}{{\text{k}}}} \right]$6.3 Dielectric Breakdown and Dielectric StrengthIf a very high electric field is created in a dielectric, the outer electrons may get detached from their parent atoms. The dielectric then behaves like a conductor. This phenomenon is known as dielectric breakdown.The maximum value of electric field (or potential gradient) that a dielectric material can tolerate without it's electric breakdown is called it's dielectric strength.S.I. unit of dielectric strength of a material is${\text{V}}/{\text{m}}$ but practical unit is ${\text{kV/mm}}$.6.4 Variation of Different Variables (Q,C, V, E and U) of Parallel Plate CapacitorSuppose we have an air filled charged parallel plate capacitor having variables as follows:Charge: QSurface charge density: $\sigma = \dfrac{Q}{A}$,Capacitance: $C = \dfrac{{{\varepsilon _0}A}}{d}$Potential difference across the plates: ${\text{V}} = {\text{E}}.{\text{d}}$Electric field between the plates: $E = \dfrac{\sigma }{{{\varepsilon _0}}} = \dfrac{Q}{{A{z_0}}}$Energy stored: ${\text{L}} = \dfrac{1}{2}C\;{{\text{V}}^2} = \dfrac{{{{\text{Q}}^2}}}{{2C}} = \dfrac{1}{2} {\text{QV}}$QuantityBattery is removedBattery remains connectedCapacity charge potentialIntensity Energy\[{\text{C' = KC}} \]\[{\text{Q' = Q}}\,\,\,\,\left({{\text{Charge is conserved}}} \right) \]\[{\text{V' = V/K}} \]\[{\text{E' = E/K}} \] \[{\text{U' = U/K}} \]\[{\text{C' = KC}} \] \[{\text{Q' = KQ}} \]${\text{V' = V}}$ (since battery maintains the potential difference) \[{\text{E' = E}} \] \[{\text{U' = KU}} \]Note:If nothing is said it is to be assumed that the battery is disconnected.7. Van De Graff Electrostatic GeneratorA Van de graff generator is a device used for building up high potential differences of the order of a few million volts Such high potential differences are used to accelerate charged particles like electrons, protons, ions etc. needed for various experiments of Nuclear Physics.(Image will be uploaded soon)It was designed by Van de graff in the year 1931.Principle: This generator is based on(i) the action of sharp points, i.e., the phenomenon of corona discharge.(ii) the property that charge given to a hollow conductor is transferred to outer surface and is distributed uniformly over it.Construction: The essential parts of Vat de graff generator are shown in fig. S is large spherical conducting shell of radius equal to a few meters. This is supported by a conducting shell of radius equal to a few metres. This is supported at a suitable height (of several metres above the ground) over the insulating pillars ${p_1},{{\text{P}}_2}.$ A long narrow belt of insulating material like, silk, rubber or rayon is wrapped around two pulleys ${P_1}$ and ${P_2} \cdot {P_1}$ is at the ground level and ${{\text{P}}_2}$ is at the centre of ${\text{S}}$. The belt is kept moving continuously over the pulleys with the help of a motor (not shown). ${{\text{B}}_1}$ and ${{\text{B}}_2}$ are two sharply pointed metal combs fixed as shown. ${B_1}$ is called the spray comb and ${B_3}$ is called the collecting comb.The positive ions to be accelerated are produced in a discharge tube D. The ion source lies at the head of the tube inside the spherical shell. The other end of the tube carrying the target nucleus is earthed.The generator is enclosed in a steel chamber C filled with nitrogen or methane at high pressure in order to minimise leakage in a steel spherical conductor.Working: The spray comb is given a positive potential $\left({ \approx {{10}^4}} \right.$ volt) w.r.t. the earth by high tension source H.T. Due to discharging action of sharp points, a positively charged electric wind is set up, which sprays positive charge on the belt (corona discharge). As the belt moves, and reaches the comb., a negative charge is induced on the sharp ends of collecting comb ${{\text{B}}_2}$ and an equal positive charge is induced on the farther end of ${B_2}$. This positive charge shifts immediately to the outer surface of S. Due to discharging action of sharp points of ${B_2}$, a negatively charged electric wind is set up. This neutralises the positive charge on the belt. The uncharged belt returns down, collects the positive charge from ${{\text{B}}_1}$, which in turn is collected by ${{\text{B}}_2}$. This is repeated. Thus, the positive charge on S goes on accumulating.Now, the capacity of spherical shell $c = 4\pi {\varepsilon _0}R$, where R is radius of the shell.As $\quad V = \dfrac{Q}{C}\therefore V = \dfrac{Q}{{4\pi { \in _0}R}}$Hence the potential V of the spherical shell goes on increasing with increase in Q.The breakdown field of air is about $3 \times {10^6}\;{\text{V}}/{\text{m}}$. The moment the potential of spherical shell exceeds this value, air around S is ionised and leakage of charge starts. The leakage is minimised by housing the generator assembly inside a steel chamber filled with nitrogen or methane at high pressures.If ${\text{q}}$ is the charge on the ion to be accelerated and ${\text{V}}$ is the potential difference developed across the ends of the discharge tube, then energy acquired by the ions $ = {\text{qV}}$. The ions hit the target with this energy and carry out the artificial transmutation etc.8. Combination of DropsSuppose we have n identical drops each having - Radius $ - {\text{r}}$, Capacitance $ - {\text{c}}$, Charge $ - {\text{q}}$, Potential - ${\text{v}}$ and Energy $ - {\text{u}}$.If these drops are combined to form a big drop of Radius $ - {\text{R}}$, Capacitance $ - {\text{C}}$, Charge $ - {\text{Q}}$, Potential $ - {\text{V}}$ and Energy - U then -(i) Charge on big drop:$Q = nq$(ii) Radius of big drop:Volume of big drop$ = n \times $ volume of a single drop i.e.,$\dfrac{4}{3}\pi {{\text{R}}^3} = {\text{n}} \times \dfrac{4}{3}\pi {{\text{r}}^3},{\text{R}} = {{\text{n}}^{1/3}}{\text{r}}$(iii) Capacitance of big drop:${\text{C}} = {{\text{n}}^{1/3}}{\text{c}}$(iv) Potential of big drop:${\text{V}} = \dfrac{{\text{Q}}}{{\text{C}}} = \dfrac{{{\text{nq}}}}{{{{\text{n}}^{1/3}}{\text{c}}}}$${\text{V}} = {{\text{n}}^{2/3}}{\text{v}}$(v) Energy of big drop:${\text{U}} = \dfrac{1}{2}{\text{C}}{{\text{V}}^2} = \dfrac{1}{2}\left({{{\text{n}}^{1/3}}{\text{c}}} \right){\left({{{\text{n}}^{2/3}}{\text{v}}} \right)^2}$${\text{U}} = {{\text{n}}^{5/3}} {\text{u}}$Note:It is a very common misconception that a capacitor stores charge but actually a capacitor stores electric energy in the electrostatic field between the plates.Two plates of unequal area can also form a capacitor because effective overlapping area is considered.Capacitance of a parallel plate capacitor depends up on the effective overlapping area of plates $({\text{C}} \propto {\text{A}})$, separation between the plates $({\text{C}} \propto 1/{\text{d}})$ and dielectric medium filled between the plates. While it is independent of charge given, potential raised or nature of metals and thickness of plates.The distance between the plates is kept small to avoid fringing or edge effect (non-uniformity of the field) at the bounderies of the plates.Spherical conductor is equivalent to a spherical capacitor with it's outer sphere of infinite radius.A spherical capacitor behaves as a parallel plate capacitor if it's spherical surfaces have large radii and are close to each other.The intensity of electric field between the plates of a parallel plate capacitor $\left({{\text{E}} = \sigma /{\varepsilon _0}} \right)$ does not depends upon the distance between them.Radial and non-uniform electric field exists between the spherical surfaces of spherical capacitor.b(CircuitSolving method)Sometimes it may not be easy to find the equivalent capacitance of a combination using the equations for series-parallel combinations. We may then use the general method as follows:Step 1:Identify the two points between which the equivalent capacitance is to be calculated. Call any one of them as A and the other as ${\text{B}}$.Step 2:Connect (mentally) a battery between ${\text{A}}$ and ${\text{B}}$ with the positive terminal connected to ${\text{A}}$ and the negative terminal to ${\text{B}}$. Send a charge $ + {\text{Q}}$ from the positive terminal of the battery and $ - {\text{Q}}$ from the negative terminal of the battery.Step 3:Write the charges appearing on each of the plates of the capacitors. The charge conservation principle may be used. The facing surfaces of a capacitor will always have equal and opposite charges. Assume variables ${Q_1},{Q_2} \ldots .$ etc. for charges wherever needed. Mark the polarity across each circuit element correspond ing to higher (+) and lower (-) potential ends.Step 4:The algebraic sum of all the potential differences along a closed loop in a circuit is zero.While using this rule, one starts from a point on the loop and goes along the loop, either clockwise or anticlockwise, to reach the same point again. Any potential difference encountered (from -ve to +ve) is taken to be positive and any potential drop (from + ve to -ve) is taken to be negative. The net sum of all these potential differences should be zero.The loop law follows directly from the fact that electrostatic force is a conservative force and the work done by it in any closed path is zero.Step 5:Number of variables ${Q_1},{Q_2}$, etc. must be the same as the number of equations obtained (loop equation). The equivalent capacitance ${C_{ \oplus q}} = \dfrac{Q}{V}$, where V is the potential difference across the assumed battery terminals.10. Wheatstone Bridge Based CircuitIf in a network five capacitors are arranged as shown in following figure, the network is called wheatstone bridge type circuit. If it is balanced then(Image will be uploaded soon) $\dfrac{{{C_1}}}{{{C_2}}} = \dfrac{{{C_3}}}{{{C_4}}}$ hence ${C_5}$ is removed and equivalent capacitance between ${\text{A}}$ and ${\text{B}}$${C_{AB}} = \dfrac{{{C_1}{C_2}}}{{{C_1} + {C_2}}} + \dfrac{{{C_3}{C_4}}}{{{C_3} + {C_4}}}$11. Extended Wheatstone BridgeThe given figure consists of two wheatstone bridge connected together. One bridge is connected between points AEGHFA and the other is connected between points EGBHFE.(Image will be uploaded soon)This problem is known as extended wheatstone bridge problem, it has two branches ${\text{EF}}$ and ${\text{GH}}$ to the left and right of which symmetry in the ratio of capacities can be seen.It can be seen that ratio of capacitances in branches ${\text{AE}}$ and ${\text{EG}}$ is same as that between the capacitances of the branches ${\text{AF}}$ and ${\text{FH}}$. Thus, in the bridge AEGHFA; the branch EF can be removed. Similarly in the bridge EGBHFE branch ${\text{GH}}$ can be removed${C_{SE}} = \dfrac{{2C}}{3}$12. Infinite Network of Capacitors(i) Suppose the effective capacitance between A and B is ${C_{{\text{P: }}}}$ Since the network is infinite, even if we remove one pair of capacitors from the chain, remaining network would still have infinite pair of capacitors, i.e, effective capacitance between ${\text{X}}$ and I would also be ${{\text{C}}_{\text{R}}}$.Hence equivalent capacitance between A and $B$${{\text{C}}_{{\text{AB}}}} = \dfrac{{{{\text{C}}_1}\left({{{\text{C}}_2} + {C_{\text{f}}}} \right)}}{{{{\text{C}}_1} + {{\text{C}}_2} + {{\text{C}}_{\text{R}}}}} = {{\text{C}}_{\text{R}}}$$ \Rightarrow \quad {{\text{C}}_{{\text{AB}}}} = \dfrac{{{{\text{C}}_2}}}{2}\left[{\sqrt {\left({1 + 4\dfrac{{{{\text{C}}_1}}}{{{{\text{C}}_2}}}} \right)} - 1} \right]$(ii) For what value of${C_0}$ in the circuit shown below will the net effective capacitance between A and B be independent of the number of sections in the chain.(Image will be uploaded soon)Suppose there are n sections between A and B and the network is terminated by ${{\text{C}}_0}$ with equivalent capacitance ${{\text{C}}_{{{\text{R}}^\prime }}}$ Now if we add one more sections to the network between ${\text{D}}$ and ${\text{C}}$ (as shown in the following figure), the equivalent capacitance of the network ${C_R}$ will be independent of number of sections if the capacitance between D and C still remains ${C_0}$ i.e.,Hence ${{\text{C}}_0} = \dfrac{{{{\text{C}}_1} \times \left({{{\text{C}}_2} + {{\text{C}}_0}} \right)}}{{{{\text{C}}_1} + {{\text{C}}_2} + {{\text{C}}_0}}} \Rightarrow {\text{C}}_0^2 + {{\text{C}}_2}{{\text{C}}_0} - {{\text{C}}_1}{{\text{C}}_2} = 0$On simplification ${{\text{C}}_0} = \dfrac{{{{\text{C}}_2}}}{2}\left[{\sqrt {\left({1 + 4\dfrac{{{{\text{C}}_1}}}{{{{\text{C}}_2}}}} \right)} - 1} \right]$13. Circuits With Extra Wire (plate numbering method)If there is no capacitor in any branch of a network then every point of this branch will be at same potential. Suppose equivalent capacitance is to be determine in following cases.14. Using Symmetry Between Two Points1. Symmetry is always defined between 2 points.2 Equivalent (symmetric) paths have same number, value and order of circuit elements along it.3. When two or more paths in any network are equivalent, then charges flowing through those paths will be same. This technique makes the circuit easy to comprehend.15. Battery Superposition Method15. Battery Superposition MethodIn a circuit involving multiple batteries, the charge flowing will be the superposition effect of each battery.Effect of $10\;{\text{V}}$ batteryEffect of 5 V battery Combined effectNote:When more than 2 batteries are present, take the individual effect of the battery, assuming other batteries are absent. And then superimpose to get the total effect.16. Dielectric16.1 Series and Parallel (With Dielectrics)(a) When dielectric is partially filled between the platesIf a dielectric slab of thickness $t(t < d)$ is inserted between the plates as shown below, then ${\text{E}} = $ Main electric field between the plates, ${{\mathbf{E}}_3} = $ Induced electric field in dielectric. ${E^\prime } = \left({{\text{E}} - {{\text{E}}_1}} \right) = $ The reduced value of electric field in the dielectric. Potential difference between the two plates of capacitor is given by\[{V^\prime } = {\text{E}}({\text{d}} - {\text{t}}) + {{\text{E}}^\prime }{\text{t}} = {\text{E}}({\text{d}} - {\text{t}}) + \dfrac{{\text{E}}} {{\text{K}}} \cdot {\text{t}} \]\[\Rightarrow \quad {{\text{V}}^\prime } = {\text{E}}\left({{\text{d}} - {\text{t}} + \dfrac{{\text{t}}}{{\text{K}}}} \right) = \dfrac{\sigma }{{\varepsilon _0}}}\left({\;{\text{d}} - {\text{t}} + \dfrac{{\text{t}}}{{\text{K}}}} \right) = \dfrac{Q}{{\;{\text{A}}{{\bar \varepsilon }_0}}}\left({{\text{d}} - {\text{t}} + \dfrac{{\text{t}}}{{\text{K}}}} \right) \]Now capacitance of the capacitor:${C^\prime } = \dfrac{Q}{{{V^\prime }}} \Rightarrow {C^\prime } = \dfrac{{{\varepsilon _0}A}}{{d - t + \dfrac{t}{K}}}$${C^\prime } = \dfrac{{{\varepsilon _0}A}}{{d - \left({{t_1} + {t_2} + {t_3} + \ldots \ldots } \right) + \left({\dfrac{{{t_1}}} {{{K_1}}} + \dfrac{{{t_2}}}{{{K_2}}} + \dfrac{{{t_3}}}{{{K_3}}} + \ldots \ldots } \right)}}$(b) When a metallic slab is inserted between the plates${{\text{C}}^\prime } = \dfrac{{{\varepsilon _0}A}}{{(\;{\text{d}} - {\text{t}})}}$${C^\prime } = \infty $ (In this case capacitor is said to be short circuited)(c) Advance case of compound dielectricsIf several dielectric medium filled between the plates of a parallel plate capacitor in different ways as shown.(i) The system can be assumed to be made up of two capacitors ${C_1}$ and ${C_2}$ which may be said to connected in series.${C_1} = \dfrac{{{K_1}{\varepsilon _0}A}}{{\dfrac{d}{2}}},{C_2} = \dfrac{{{K_2}{\varepsilon _0}A}}{{\dfrac{d}{2}}}$ and $\dfrac{1}{{{C_{eq}}}} = \dfrac{1}{{{C_1}}} + \dfrac{1}{{{C_2}}}$$ \Rightarrow \quad {C_{eq}} = \left({\dfrac{{2{K_1}{K_2}}}{{{K_1} + {K_2}}}} \right) \cdot \dfrac{{{\varepsilon _0}A}}{d}$ Also ${K_{eq}} = \dfrac{{2{K_1}{K_2}}}{{{K_1} + {K_2}}}$(ii) In this case these two capacitors are in parallel and${{\text{C}}_1} = \dfrac{{{{\mathbf{K}}_1}{\varepsilon _0}\;{\text{A}}}}{{2\;{\text{d}}}},{{\text{C}}_2} = \dfrac{{{{\text{K}}_2}{\varepsilon _0}\;{\text{A}}}}{{2\;{\text{d}}}}$Hence, ${C_{eq}} = {C_1} + {C_2} \Rightarrow {C_{eq}} = \left({\dfrac{{{K_1} + {K_2}}}{2}} \right) \cdot \dfrac{{{\varepsilon _0}A}} {d}$Also ${{\mathbf{K}}_{{\text{eq }}}} = \dfrac{{{{\mathbf{K}}_1} + {{\mathbf{K}}_2}}}{2}$(iii) In this case ${{\text{C}}_1}$ and ${{\text{C}}_2}$ are in series while this combination is in parallel with ${C_3}$${C_1} = \dfrac{{{{\text{K}}_1}{\varepsilon _0}\dfrac{{\text{A}}}{2}}}{{\dfrac{{\text{d}}}{2}}} = \dfrac{{{{\text{K}}_1}{\varepsilon _0}\;{\text{A}}}}{{\;{\text{d}}}},{{\text{C}}_2} = \dfrac{{{{\text{K}}_1}{\varepsilon _0}\dfrac{{\text{A}}}{2}}}{{\dfrac{{\text{d}}}{2}}} = \dfrac{{{{\text{K}}_2}{\varepsilon _0}\;{\text{A}}}}{{\;{\text{d}}}}$and ${C_3} = \dfrac{{{K_3}{\varepsilon _0}\dfrac{A}{2}}}{d} = \dfrac{{{K_3} {\varepsilon _0}A}}{{2d}}$${\text{ Hence, }}{C_{eq}} = \dfrac{{{C_1}{C_2}}}{{{C_1} + {C_2}}} + {C_3} = \dfrac{{\dfrac{{{K_1}{\varepsilon _0}A}}{d} \times \dfrac{{{K_2}{\varepsilon _0}A}}{d}}}{{\dfrac{{{k_1}{\varepsilon _0}A}}{d} + \dfrac{{{k_2}{\varepsilon _0}A}}{d}}} + \dfrac{{{k_3}{\varepsilon _0}A}}{{2d}}$$ \Rightarrow \quad {C_{?q}} = \left({\dfrac{{{k_1}{k_2}}}{{{k_1} + {k_2}}} + \dfrac{{{k_3}}}{2}} \right) \cdot \dfrac{{{\varepsilon _0}A}}{d}$Also ${{\text{k}}_{eq}} = \left({\dfrac{{{{\text{k}}_3}}}{2} + \dfrac{{{{\text{k}}_{\text{e}}}{{\text{k}}_2}}}{{{{\text{k}}_{\text{t}}} + {{\text{k}}_2}}}} \right)$16.2 When Separation Between the Plates Is ChangingIf separation between the plates changes then it's capacitance also changes according to ${\text{C}} \propto \dfrac{1}{{\;{\text{d}}}}$. The effect on other variables depends on the fact that whether the charged capacitor is disconnected from the battery or battery is still connected.(i) Separation is increasingQuantityBattery is removedBattery remains connectedCapacityChargeBatteryPotential differenceElectric fieldEnergyDecreases because ${\text{C}} \propto \dfrac{1}{{\;{\text{d}}}}$ i.e., ${{\text{C}}^\prime } < {\text{C}}$Remains constant because a battery is not present i.e., ${Q^\prime } = Q$Increases because ${\text{v}} = \dfrac{{\text{Q}}}{{\text{C}}} \Rightarrow {\text{V}} \propto \dfrac{1}{{\text{C}}}$ i.e., ${{\text{V}}^\prime } > {\text{V}}$ difference)Remains constant because ${\text{E}} = \dfrac{\sigma }{{{\varepsilon _{\text{D}}}}} = \dfrac{{\text{Q}}}{{{\text{A}}{\varepsilon _{\text{D}}}}}$ i.e., ${{\text{E}}^\prime } = {\text{E}}$Increases because ${\text{U}} = \dfrac{{{{\text{Q}}^2}}}{{2{\text{C}}}} \Rightarrow {\text{U}} \propto \dfrac{1}{{\text{C}}}$ i.e., ${{\text{U}}^\prime } > {\text{U}}$Decreases i.e., $\quad {C^\prime } < {\text{C}}$Decreases because battery is present i.e., ${Q^\prime } < Q$ Remaining charge $\left({Q - {Q^\prime }} \right)$ goes back to the${V^\prime } = V$ (Since Battery maintains the potentialDecrease because ${\text{E}} = \dfrac{Q}{{\;{\text{A}}{\varepsilon _0}}} \Rightarrow {\text{E}} \propto {\text{Q}}$ i.e., ${E^{\prime}}< E$Decreases because ${\text{U}} = \dfrac{1}{2}{\text{C}}{{\text{V}}^2} \Rightarrow {\text{U}} \propto C$ i.e., ${U^\prime } < {\text{U}}$(ii) Separation is decreasingQuantityBattery is removedBattery remains connectedCapacityChargeBatteryPotential differenceElectric fieldEnergyIncreases because ${\text{C}} \propto \dfrac{1}{{\;{\text{d}}}}$ i.e., ${C^\prime } > {\text{C}}$Remains constant because battery is not present i.e., ${Q^\prime } = Q$Decreases because ${\text{V}} = \dfrac{{\text{Q}}}{{\text{C}}} \Rightarrow {\text{V}} \propto \dfrac{1}{{\text{C}}}$ i.e., ${\text{V}} < {\text{V}}$Remains constant because ${\text{E}} = \dfrac{\sigma }{{{\varepsilon _0}}} = \dfrac{{\text{Q}}}{{{\text{A}}{\varepsilon _0}}}$ i.e., ${{\text{E}}^\prime } = {\text{E}}$Decreases because ${\text{U}} = \dfrac{{{{\text{Q}}^2}}}{{2{\text{C}}}} \Rightarrow {\text{U}} \propto \dfrac{1}{{\text{C}}}$ i.e.,${\text{U}} < {\text{U}}$Increases i.e., ${C^\prime } > C$Increases because battery is present i.e., ${Q^\prime } > Q$ Remaining charge $\left({{Q^\prime } - Q} \right)$ supplied from the ${V^\prime } = V$ (Since Battery maintains the potential difference)Increases because $E = \dfrac{Q}{{A{\varepsilon _0}}} \Rightarrow E \propto Q$ i.e., ${E^\prime } > E$ Increases because ${\text{U}} = \dfrac{1}{2}{\text{C}}{{\text{V}}^2} \Rightarrow {\text{U}} \propto {\text{C}}$ i.e., ${{\text{U}}^\prime } > {\text{U}}$16.3 Force on DielectricWhen dielectric is placed near the charged capacitor (rectangular plates), it experiences force towards the capacitor, due to fringing field just outside the plates.(Image will be uploaded soon)(a) Battery connected (V remains same)$F = \dfrac{1}{2}\dfrac{{{\varepsilon _0}b{V^2}(K - 1)}}{d}$ (towards capacitor)(Image will be uploaded soon)Note:Force doesn't depend on the amount of dielectric inside the plates.Force becomes zero when Dielectric is in middle of plates.(b) Battery disconnected (Q remains same)(Image will be uploaded soon)\[F=\dfrac {{Q^2}d\left (k-1 \right)}{2\varepsilon _0}b\left (l+x\left (k-1 \right) \right)^{2}}\]Note:Force depends on ${\text{x}}$ (amount of dielectric inside the capacitor plates).17. Redistribution of Charge Between Two CapacitorsWhen a charged capacitor is connected across an uncharged capacitor, then redistribution of charge occur to equalize the potential difference across each capacitor. Some energy is also wasted in the form of heat.Suppose we have two charged capacitors ${{\text{C}}_1}$ and ${{\text{C}}_2}$ after disconnecting these two from their respective batteries. These two capacitors are connected to each other as shown below (positive plate of one capacitor is connected to positive plate of other while negative plate of one is connected to negative plate of other).Charge on capacitors redistributed and new charge on them will be $Q_i^\prime = Q\left({\dfrac{{{C_1}}}{{{C_1} + {C_2}}}} \right),Q_2^\prime = Q\left({\dfrac{{{C_2}}}{{{C_1} + {C_2}}}} \right)$ The common potential ${\text{V}} = \dfrac{{{{\text{Q}}_1} + {{\text{Q}}_2}}}{{{{\text{C}}_1} + {{\text{C}}_2}}} = \dfrac{{{{\text{C}}_1}\;{{\text{V}}_1} + {{\text{C}}_2}\;{{\text{V}}_2}}} {{{{\text{C}}_1} + {{\text{C}}_2}}}$ and loss of energy $\Delta U = \dfrac{{{C_1}{C_2}}}{{2\left({{C_l} + {C_2}} \right)}}{\left({{V_1} - {V_2}} \right)^2}$.Note:Two capacitors of capacitances ${{\text{C}}_1}$ and ${{\text{C}}_2}$ are charged to potential of ${{\text{V}}_{\text{L}}}$ and ${{\text{V}}_2}$ respectively. After disconnecting from batteries they are again connected to each other with reverse polarity i.e., positive plate of a capacitor connected to negative plate of other. So common potential ${\text{V}} = \dfrac{{{{\text{Q}}_1} - {{\text{Q}}_2}}}{{{{\text{C}}_1} + {{\text{C}}_2}}} = \dfrac{{{{\text{C}}_1}\;{{\text{V}}_1} - {{\text{C}}_2}\; {{\text{V}}_2}}}{{{{\text{C}}_1} + {{\text{C}}_2}}}$.Class 12 Physics Revision Notes for Chapter 1 - Electric Charges and FieldsTo assist you with that, Vedantu is here with Class 12 Physics Chapter 1 Notes. Class 12 Physics Notes prepared by our subject experts will help you understand the important topics and remember the key points from the exam point of view. Below we have provided the class 12 physics chapter 1 electric charges and field notes. Physics Class 12 Chapter 1 NotesAs per the latest information, Unit-1 has a weightage of 9 % in the NEET exam. In the JEE Main exam, 2 to 3 questions with 8-12 % weightage are likely to come. This topic carries a greater weightage in board exams and the competitive entrance exams.The , electric charges and fields class 12 notes PDF will help to learn this topic more effectively.So, Class 12 Physics Chapter 1 is divided into two parts, i.e., Electric Charges and Electric Fields.Electric Charges and Fields Class 12 NotesUnlike charges: These charges repel each other.Like charges: These charges attract each other.Quantization of ChargeQuantization of electric charge is an attribute in which all free charges are an integral multiple of a basic unit of charge represented by e. The charge (q) of a body is given by: q =± ne   Here, + e is for proton & - e is for electron.   Additivity of ChargesThe total charge in the system = The algebraic sum of all the individual charges present in the system.Conservation of ChargeThe total charge of an isolated system remains conserved.For example, on rubbing the rod with silk, silk gains the charge, while the rod loses it.Coulomb's LawCoulomb's law tells about the force of attraction or repulsion between any two point charges. This force is directly proportional to their product and inversely proportional to the square of the distance between them. This force acts along the line joining the center of these two charges. It is given by: F α \[\frac{|q_{1}q_{2}|}{r^{2}}\]   F = k \[\frac{|q_{1}q_{2}|}{r^{2}}\]k = electrostatic force constant, which is equal to\[\frac{1}{4 \pi \epsilon _{0}}\].F = \[\frac{1}{4 \pi \epsilon _{0}}\] \[\frac{|q_{1}q_{2}|}{r^{2}}\] Here, ε0 = Permittivity of free space, with a value of 8.85 x 10-12C2N-1m-2and dimension of [M-1L-3T4A2].Forces Between Multiple ChargesCoulomb's Law helps to find the electrostatic force between two point charges, but how to find the force between multiple charges?Experiments show that force on a charge due to other charges around it, taken one at a time, is the vector sum of all the forces exerted by all the charges on that charge. This is given by the superposition principle, stated below.Superposition PrincipleThe superposition principle states that the individual forces of two charges remain unaffected due to the presence of other charges.Let us consider a system of three charges q1, q2 and q3. The force on q1 due to q2 is denoted by F12 and due to q3 is F13. The force on a charge, say q1 due to two other charges q2 and q3 can be obtained by vector addition of the forces due to q2 on q1 and q3 on q1. So, F12 = 14πεq1 q2 r212 r12   Similarly, F13 = 14πεq1 q3 r213 r13   Thus, the total force F1 on q1 due to q2 and q3 is,F1 = F12 + F13F1 = 14πεq1 q2 r212 r12 + 14πεq1 q3 r213 r13Properties of Electric Field LinesElectric Field lines are endless curves, but they can't form closed loops.They Intersect each other at infinity.Electric field lines initiate from positive charges and terminate at negative charges.Electric Field Due to Dipole\[|\overrightarrow{E}|\] = \[\frac{\overrightarrow{p}}{4 \pi \epsilon _{0}}\] \[\frac{2r}{(r^{2}-a^{2})}\]If the dipole is short, and 2a < < r, then the formula becomes:\[|\overrightarrow{E}|\] = \[\frac{2|\overrightarrow{p}|}{4 \pi \epsilon _{0}r^{3}}\]Gauss LawGauss law states that the total electric flux out of the Gaussian surface equals the integration of net charge enclosed in this surface divided by the permittivity of free space. Its formula is:ΦE = ∮S \[|\overrightarrow{E}|\] . \[| \overrightarrow{ds} | \] \[\frac{Q}{ \epsilon _{0}}\](Image to be added soon)Solved Sample Numerical ProblemHow should we divide a charge 'Q' to get the maximum force of repulsion between them?Let q, Q - q be two point charges, then,   F =\[\frac{1}{4 \pi \epsilon _{0}r^{2}}\] \[\frac{ |q||Q-q|}{r^{2}}\]For F to be maximum, dF/dq should be = 0So,\[\frac{dF}{dq}\]=\[\frac{1}{4 \pi \epsilon _{0}r^{2}}\] \[\frac{d}{dq}\] (\[\frac{ |q||Q-q|}{r^{2}}\])= 0=> \[\frac{1} {4 \pi \epsilon _{0}r^{2}}\] \[\frac{ |Q-2q|}{r^{2}}\]= 0 q = Q/2Electric Charges and Fields Class 12 Notes PDFFor downloading the Class 12 Physics Chapter 1 notes, click on the link specified below:Advantages of Vedantu's Solved PYQPVedantu aces at providing accurate solutions to numerical on Electric Charges and Fields.At Vedantu, you will get the following things for free.Model papers at the end of each chapter to check your progress in every chapter.PYQP to get an idea of the type and weightage of questions being asked in the past year papers.Sample papers to help track your accuracy in the topics.Mock tests with a timer to help check your time management level.12th physics notes to revise during exam times.Providing all these things for free is the foremost aim of Vedantu. Notes of Physics Class 12 – Chapter 1 Electric Charges and FieldsElectric Charges and Fields is a fundamental concept of Physics. The chapter explains the basic concepts like Electric Charge, its properties and electric field. Electric Charge is the physical property of matter when it comes in the electromagnetic field due to which other matters experience a force. There are two types of Electric Charges:Positive Electric ChargeNegative Electric ChargeElectric Field: Electric field is a region around a matter due to which another matter experiences a force.The formula of Electric Field is: E= F/qwhere E- Electric Field, F- Force and q- ChargeBased on Electric Charge and Electric Field, there are various equations, and laws are explained in Class 12 Chapter 1 Physics.CBSE Class 12 Physics Notes Chapter 1 Electric Charges and Fields provide you with a base for practical application questions along with the proper explanation of these equations and laws.While reading the CBSE class 12 physics Chapter 1 notes, students will come across various fundamentals topics like Electric ChargeElectric potential energyThe relationship between the electric field and potentialElectric dipoleGauss's Law and its applicationProperties of a conductorPlate theoryProperties of Charge Electroscope Coulomb's LawElectric Potential EnergyWhile these notes are invaluable, only reading the notes won't help, you will need to practice for easy implementation of the theoretical principles. ConclusionClass 12 physics chapter 1 electric charges and fields notes have been written concisely, but the lucid explanation helps for clear interpretation. CBSE Class 12 Physics Revision Notes Chapter 1 can be downloaded and read offline as well. The PDF will help students cover their syllabus well in time. Students must make sure to start reading these notes 3-4 months before the exams. This will help students to stay calm during the exam.

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