

a very good morning to all of you till now we have been discussing electrostatics and magnetostatics and then we discussed laws of dynamics electrodynamics and then finally we introduced the concept of maxwell's equations and electromagnetic waves

so in all these lectures we have tried to understand the basic concepts through the various laws gauss's law ampere's law faraday's laws of induction and

so on and try to understand how charges and electric currents behave what are the forces acting on them and some applications we have discussed a lot of concepts now what i want to do is i would like to discuss some problems in the area of electrostatics and magnetostatics and also the waves

so that we understand better how to utilize some of the concepts that we have developed in the course during the course of lectures we have also discussed some problems but today i would like to discuss some additional problems which will help you to understand some of the concepts that we have developed problem solving is a very important aspect of physics and the more problems you solve using various concepts that has been developed in your career the more you will understand the the concepts themselves and their applications

so i have picked up some problems in the field of electrostatics today which i would like to discuss and

so let's start with the first problem

so the first thing that we have seen that electrostatic fields are fields produced by charges in rest and those fields satisfy certain kinds of equations we have seen coulomb's law we have seen gauss's law and

so on now the first question which i want to look at is is it possible to have an electrostatic field of the form $\mathbf{E} = E_0 \hat{j}$

so that is a vector field with magnitude E_0 and it depends on position x and it is directed along the y axis \hat{j}

so the question is can this be a vector field and can this vector field represent an electrostatic field now we have discussed electrostatics in great depth

so what we know is all electrostatic fields satisfy the following equation $\oint \mathbf{E} \cdot d\mathbf{l} = 0$ if you take the electrostatic field and do a line integral over a closed path then you will find it to be zero because these are conservative fields and electrostatic fields satisfy this equation

so if this field is to represent an electrostatic field it must satisfy this equation that means if i take any closed path $\oint \mathbf{E} \cdot d\mathbf{l}$ must be equal to zero

so i am at liberty to choose any particular closed path

so i would like to choose a closed path for which this integral can be analytically solved if i take a very complex path i may have difficulty in solving the equation integral but i would like to take a simplified path

so the path which i would like to take is the following

so let me draw the x and y axis here this is x axis this is y axis

so i take a path like this i take a path in this form

so i go from here i start from the origin and complete once one complete rectangular square path here

so let me assume that this is a rectangular path here is a this is b

so let me call this a b c and d

so electrostatic fields must satisfy this equation $\oint \mathbf{E} \cdot d\mathbf{l} = 0$

so what i would like to do is to use this electric field electrostatic this field this vector field in this equation and find out whether this particular field integral $\oint \mathbf{E} \cdot d\mathbf{l}$ over this path $a \rightarrow b \rightarrow c \rightarrow d \rightarrow a$ is zero

so $\int_a^b \mathbf{E} \cdot d\mathbf{l} + \int_b^c \mathbf{E} \cdot d\mathbf{l} + \int_c^d \mathbf{E} \cdot d\mathbf{l} + \int_d^a \mathbf{E} \cdot d\mathbf{l}$

$\int_a^b \mathbf{e} \cdot d\mathbf{l}$ plus $\int_c^d \mathbf{e} \cdot d\mathbf{l}$ plus $\int_d^a \mathbf{e} \cdot d\mathbf{l}$ this complete closed path integration now what is $\int_a^b \mathbf{e} \cdot d\mathbf{l}$ is equal to $\int_a^b e_x dx$ now e_x is nothing but $e \sin \theta$ now $d\mathbf{l}$ is $dx \hat{i}$ I am integrating from a to b that means $d\mathbf{l}$ must be along the x axis

so $d\mathbf{l}$ is nothing but $dx \hat{i}$ and because $\mathbf{e} \cdot \hat{i} = e \cos \theta$ this is equal to zero $\int_a^b \mathbf{e} \cdot d\mathbf{l} = \int_a^b e \cos \theta dx = 0$

so similarly you can show that $\int_c^d \mathbf{e} \cdot d\mathbf{l}$ is also zero because the electric field is pointing along the y axis and the integration is along the x axis along the x direction

so these integrals are zero now what about the remaining two $\int_b^c \mathbf{e} \cdot d\mathbf{l}$ is equal to now b and c are on the same value of x and electric field depends only on x and the value of x at this in this line is x is equal to a

so this is equal to $\int_b^c e_x dx$

so b is x is equal to zero and c is x is equal to b $e \sin \theta$ now the value of x here is a because electric field as you can see here is $e \sin \theta$ on this line x is equal to a

so $e \sin \theta = e \cos \theta$ $\int_b^c \mathbf{e} \cdot d\mathbf{l} = \int_b^c e \cos \theta dx = e \cos \theta (c - b)$

so this is nothing but $a \sin \theta = e \cos \theta$ times a now what about the final integral one which is $\int_d^a \mathbf{e} \cdot d\mathbf{l}$ is equal to now this is the line which is on the x is equal to zero line here and at x is equal to zero as you can see the electric field itself is zero

so this integral is also equal to zero

so what I have been able to show is $\int \mathbf{e} \cdot d\mathbf{l}$ for this field vector field is nothing but $e \sin \theta$ and this is not equal to zero

so e is equal to $e \sin \theta$ \hat{j} cannot represent an electrostatic field

so please remember it has not all vector fields will represent can represent electrostatic fields only those vector fields for which $\int \mathbf{e} \cdot d\mathbf{l}$ over the closed path is equal to zero you will represent electrostatic fields

so the way to check is given in vector field like this I take a suitable path of integration and if I find this integral to be non zero that means this vector field cannot represent an electrostatic field now I will here like a leave a question to you how about a vector field how about the following field \mathbf{e} is equal to $e \sin \theta \hat{i}$ can this represent an electrostatic field

so please work out in a similar fashion like we have done and find out whether this particular field can represent an electrostatic field follow the same procedure as we have done and you will be able to find out whether this can represent an electrostatic field now let me look at a second question now remember electric fields and potentials are related to each other

so I given the following electrostatic potential calculate the corresponding electric field

so potential is V is equal to V_0 for r is equal to square root of $x^2 + y^2 + z^2$ less than a is equal to V_0 by square root of $x^2 + y^2 + z^2$ for r is equal to square root of $x^2 + y^2 + z^2$ greater than a

so what is given is that it is a this vertical spherical distribution the potential is V_0 within this sphere of radius a and outside the potential decreases as $1/r$ as you move away from the center the question is what is the corresponding electric field distribution now to solve this problem we have during the course of lectures we have derived the following equation the x component of electric field is related to potential to this equation the y component is $-\frac{\partial V}{\partial y}$ and the z component is $-\frac{\partial V}{\partial z}$ remember I am using partial derivatives because potential V is a function of x , y and z all three coordinates and this is a differential with respect to x keeping

y and z constant differential with respect to y keeping x and z constant
differential with respect to z keeping x and y constant

so first for r less than a for r less than a the potential is constant

so we will have e_x is equal to $-\frac{dv}{dx}$ minus $\frac{db}{dx}$ is equal to zero similarly e_y is equal to minus $\frac{db}{dy}$ is equal to zero and e_z is equal to minus $\frac{dv}{dz}$ is equal to zero

so within this sphere of radius a because the potential is constant there is no electric field within the sphere of radius a now what about for r greater than a outside the sphere lets calculate the three components

so e_x is equal to minus $\frac{db}{dx}$ which is equal to minus $\frac{dv}{dx}$ of a look at the potential here

so $b = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$ by square root of $x^2 + y^2 + z^2$ which is equal to minus $\frac{dv}{dx}$ of $\frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$ by square root of $x^2 + y^2 + z^2$ this is a simple differential

so minus $\frac{dv}{dx}$ of $\frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$ into minus half one by $x^2 + y^2 + z^2$ raise to the power three by two into two x differentiating this with respect to x gives me minus half divided by $x^2 + y^2 + z^2$ square three by two into two x and this is nothing but $\frac{1}{4\pi\epsilon_0} \frac{q}{r^3}$ x by r^3 cube r^2 square root of $x^2 + y^2 + z^2$

so this is nothing but $\frac{1}{4\pi\epsilon_0} \frac{q}{r^3}$

so e_x happens to be $\frac{1}{4\pi\epsilon_0} \frac{q}{r^3}$ x by r^3 now if you look at this equation here the potential is symmetric with respect to x , y and z

so just by symmetry i can immediately write down the values of e_y and e_z

so e_y will be equal to minus $\frac{db}{dy}$ which is equal to $\frac{1}{4\pi\epsilon_0} \frac{q}{r^3}$ y by r^3 and e_z will be equal to minus $\frac{db}{dz}$ which is equal to $\frac{1}{4\pi\epsilon_0} \frac{q}{r^3}$ z by r^3

so we have e_x , e_y and e_z is this e_y is this and e_z is this

so i can write the total electric field e is equal to $e_x \hat{i} + e_y \hat{j} + e_z \hat{k}$ which is equal to $\frac{1}{4\pi\epsilon_0} \frac{q}{r^3}$ into $x \hat{i} + y \hat{j} + z \hat{k}$ which is nothing but $\frac{1}{4\pi\epsilon_0} \frac{q}{r^3}$ \vec{r} and here \vec{r} vector is nothing but $x \hat{i} + y \hat{j} + z \hat{k}$

so the electric field this potential distribution which i have written here this potential distribution corresponds to an electric field given by e is equal to 0 within the

so $e = 0$ within the sphere and outside the sphere the electric field goes as $\frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$ \vec{r} now please note one interesting aspect here that the electric field was zero inside the sphere and is non zero outside the sphere and it is discontinuous

so at $r = a$ if you come from within the sphere the electric field is zero if you come from outside the sphere the electric field has a finite value

so the electric field here at this interface is not continuous the potential distribution is continuous but electric field distribution is not continuous

so it is possible in situations that the electric field may not be continuous and in an advanced course you will understand this better because it

so happens that the normal component of electric field may will not be continuous across interface like this

so that is the second problem we have discussed now i want to look at another problem which is suppose i have a pair of charges a pair of charges plus two q and minus two q are placed at a separation d as shown the point p is midway between the two charges what will be value of integral p to q $e \cdot dl$ along a semi circular path of radius $d/2$

so we are given two charges this is a minus two q here and a plus two q here there is a point p midway here and there is a path which i choose is this one

this is q and this radius is d by two and this distance is d

so the question is what is the integral $\int \mathbf{E} \cdot d\mathbf{l}$ from p to q along this semicircular path now please remember that we have seen that potential we can define a potential for electrostatic field and potential gives nothing but the work done in moving a charge from one point another point that is the potential difference

so i can use this concept to immediately calculate the the value of integral $\int \mathbf{E} \cdot d\mathbf{l}$ from p to q irrespective of the path taken actually

so we have essentially integral $\int_p^q \mathbf{E} \cdot d\mathbf{l}$ is equal to potential at p minus potential at q integral $\int \mathbf{E} \cdot d\mathbf{l}$ from p to q is simply the difference in potential between p and q irrespective of the path taken

so whether i take a semicircular path here or another path here as long as my starting point is p and ending point is q the value of integral $\int \mathbf{E} \cdot d\mathbf{l}$ is nothing but $V_p - V_q$ now what is V_p the potential at p now this point p is midway between these two charges

so potential you know is charge which is $2q$ divided by $4\pi\epsilon_0$ into distance of the point p from the charge plus $2q$ which is nothing but $2q/d$ by two and then you also have a potential here because of the second charge which is minus $2q$ by $4\pi\epsilon_0$ into again d by two distance from here to here is d by two distance from here to d by two and

so that is zero

so the potential at this point is zero its equidistant from two charges equal charges plus q and minus $2q$ what about the potential at q

so q is at a distance d by two from plus $2q$ and $3d$ by two from charge minus $2q$

so the potential is $2q$ by $4\pi\epsilon_0$ into d by two minus $2q$ by $4\pi\epsilon_0$ into $3d$ by two which you can simplify and show this is $2q$ by $3\pi\epsilon_0$

so integral $\int_p^q \mathbf{E} \cdot d\mathbf{l}$ is equal to $V_p - V_q$ which is equal to minus $2q$ by $3\pi\epsilon_0$

so please remember i could have made the problem more complicated by calculating the electric field as a function of position and actually substituting the electric field inside and integrating that would have made my life very difficult but because integral $\int \mathbf{E} \cdot d\mathbf{l}$ is nothing but the potential difference between the points p and q i can very quickly solve this problem and get the value of integral $\int \mathbf{E} \cdot d\mathbf{l}$ from p to q as this now now i leave it as an exercise to you to please think what is the significance of this minus sign here integral $\int_p^q \mathbf{E} \cdot d\mathbf{l}$ is minus $2q$ by $3\pi\epsilon_0$

so please give a thought as to what is the significance of the minus sign in this equation and try to analyze why there is a minus sign ok now let me look at another problem consider an electrostatic field given by $\mathbf{E} = 20\mathbf{i} + 30\mathbf{j}$ cap poles per meter calculate the potential difference between the origin and a point p with coordinates x is equal to two meters y is equal to two meters z is equal to two meter

so that is the constant electric field as you can see $20\mathbf{i} + 30\mathbf{j}$ cap and i want to find out the potential difference between two points one is origin and another is a point x is equal to two meters y equal to meters z equal to meters let me draw the figure here

so x by z

so this is i mean two meters here then two meters here and two meters here

so this is the point

so i have to do i have to calculate the done a potential difference between this point and this point and the potential is actually nothing but minus integral suppose i call this a b c and d a to a to d along the path along this

path shown $\int_C \mathbf{E} \cdot d\mathbf{l}$ I can just choose any path but I would like to choose this path for simplicity

so this actually consists of three parts minus a to b $\int_C \mathbf{E} \cdot d\mathbf{l}$ now if I go from a to b what is $\int_C \mathbf{E} \cdot d\mathbf{l}$ $\int_a^b dx$ minus $\int_b^c \mathbf{E} \cdot d\mathbf{l}$ plus $\int_c^d \mathbf{E} \cdot d\mathbf{l}$ this is $\int_C \mathbf{E} \cdot d\mathbf{l}$ for path a b this is $\int_C \mathbf{E} \cdot d\mathbf{l}$ for path b c and that is $\int_C \mathbf{E} \cdot d\mathbf{l}$ for path c d

so this is equal to minus integral now a to b is zero x goes from zero to two because this has coordinates two meters two meters two meters and E is given by $20x + 30y$

so this is nothing but $20x$ minus b to c value of b at y at b is zero and c is two meters and $\int_C \mathbf{E} \cdot d\mathbf{l}$ is $30y$ by minus now electric field has no component along k cap

so $\int_C \mathbf{E} \cdot d\mathbf{l}$ is zero that's zero and this is nothing but minus forty minus 60 which is equal to minus 100 volts

so that's the potential difference between a and d that between the origin and this point d which is minus 100 volts

so what I have essentially done is an integration $\int_C \mathbf{E} \cdot d\mathbf{l}$ by taking an appropriate path you can take any path from a to d and you can do the integration and in principle it is good to choose a path for which the integral can be analytically evaluated easily now let me look at another problem in which there are forces

so two point charges of equal mass m and carrying equal charges q are suspended from a common point by two strings having negligible mass and of length l obtain an expression relating q and θ at equilibrium now let me show θ here

so this is this one charge which is here

so this is q this is q and this is θ

so because of repulsion electrostatic repulsion the two charges move away and they are connected to a string

so they are in equilibrium position like this now the question is what is the relationship between q and θ

so to solve this I must write down the force balance equations

so let me draw the figure again here

so you have one charge here another charge here that is the normal this is θ

so there is a force mg acting here there is an electrostatic repulsive force acting here and there is a tension on the string and if I draw a perpendicular here this is also θ

so I can immediately write at equilibrium that all the forces must balance each other

so if I look at the vertical component I have $T \cos \theta$ is equal to mg $T \cos \theta$ is the component of the tension in this direction

so that must balance mg and the component along the horizontal direction must balance the electrostatic repulsion

so $T \sin \theta$ is equal to F_e which is equal to $\frac{q^2}{4\pi\epsilon_0 r^2}$ and what is this distance this is this length is l

so this is $l \sin \theta$

so the total distance is $2l \sin \theta$

so $(2l \sin \theta)^2$ which is equal to $\frac{q^2}{16\pi\epsilon_0 l^2 \sin^2 \theta}$

so two equations I can eliminate the tension T from these two equations by dividing the second equation by the first equation and I get $\tan \theta$ is equal to

so I have

so if i divide $t \sin \theta$ by $t \cos \theta$ on the reference side i get $\tan \theta$ on the right hand side i will get the following equation q^2 by $16 \pi \epsilon_0 l^2 \sin^2 \theta$ into 1 by $m g$

so q^2 is equal to $16 \pi \epsilon_0 l^2 m g \sin^2 \theta$ and

so if you know the charge that is put on this on this particles of mass m you can actually relate find out the angle θ at which the equilibrium position will be obtained

so what is essentially happening is the i have to write the force balance equation there are there is a mass which weight which is acting downwards there is an electrostatic repulsion acting sideways here and there is a tension in the string

so i can actually write down the force equations and eliminate the tension and get a solution connecting the charges and the angles now we had done this discussed about electric fields in matter

so in that connection let me take a problem

so free charge is embedded in a linear dielectric sphere of dielectric constant k_1 and radius r the free charge density ρ_f is equal to αr where α is a constant and r is the distance from the center this sphere is surrounded by another spherical shell of radii r and $2r$ and of dielectric constant k_2 calculate the electric field and the displacement vector \mathbf{D} everywhere

so the problem is essentially the following

so i have a sphere of radius r dielectric constant k_1 surrounded by another sphere a spherical shell between r and $2r$ this is dielectric constant k_2 here there is a free charge density equal αr in this

so the problem is to calculate the electric field and the displacement vector now remember in when we discuss gauss's law in dielectrics we obtained a form of very important form of gauss's law which is $\oint \mathbf{D} \cdot d\mathbf{a} = q_{\text{enclosed}}$ that is $\oint \mathbf{D} \cdot d\mathbf{a} = \int \rho_f d\tau$ the displacement vector \mathbf{D} was defined as $\mathbf{D} = \epsilon_0 \mathbf{E} + \mathbf{P}$ \mathbf{P} was the polarization vector and $\oint \mathbf{D} \cdot d\mathbf{a}$ is equal to free charge enclosed by that surface now the advantage of this formulation as we saw at that time is i do not need to know the presence or absence of the bound charges anywhere it is only the free charges which i need to know which will decide my displacement vector \mathbf{D} now because of the symmetry of this problem again \mathbf{D} vector \mathbf{E} vector and \mathbf{P} vector will be along radial direction everywhere and will only depend on r where small r is the distance of a point from the origin because of spherical symmetry \mathbf{D} , \mathbf{E} and \mathbf{P} will all be radial in the radially oriented direction and will only depend on small r

so i can use this immediately to solve the problem

so for example for $0 < r < R$ that is within the inner sphere of radius R

so i have this is my sphere of radius r

so i take a sphere of radius small r

so and i integrate over this

so $\oint \mathbf{D} \cdot d\mathbf{a}$ is equal to $q_{\text{free enclosed}}$ now because displacement vector is radial and does not depend on the position on the sphere

so in the left hand side will be simply D into $4 \pi r^2$ and the free charge enclosed i have to calculate because the free charge density is not constant

so this will be $\int_0^r \alpha r' \cdot 4 \pi r'^2 dr'$

so $4 \pi r^2 D$ is elemental area elemental volume lying between a radius small r and radius small $r + dr$

so that spherical shell will contain $h r$

so much that is the volume multiplied by the charge density and if i integrate this i will get all the charge line between zero and r

so this is nothing but four pi alpha integral r cube d r zero to r which is equal to pi alpha r is power four

so d vector d is equal to alpha by four r square r cap this is for zero less than r less than r and i know the relationship between d and e vector

so e vector is equal to d vector by epsilon zero time dielectric constant

so this is nothing but alpha r square by four epsilon zero k one into r cap

so thats the electric field and in fact you can calculate the polarization also p is equal to v minus epsilon zero e which is equal to epsilon 0 into k 1 minus 1 into e which is equal to k 1 minus 1 divided by 4 k 1 alpha r square that's a polarization vector

so what i have done is i use gauss's law and i have symmetry arguments to find out the displacement vector within the sphere and also from there the electric field vector and the polarization now i can similarly do for the space between the two dielectrics that means in this spherical shell between smaller this capital r and capital two r again

so for for r greater than r but less than two r again i will use this formula d dot d a is equal to q f enclosed

so i get four pi r square into d is equal to now please remember the free charge is enclosed only within this inner sphere

so i will get integral zero to capital r only alpha r four pi r square d r which is nothing but pi alpha r four

so i can write an expression immediately d vector is equal to alpha by four r four by r square r cap and e vector is equal to d vector by epsilon zero now k two the directory constant

so this is alpha r four by four epsilon zero k two r square r k that is electric field and you can write down expression for immediate depolarization which is d minus epsilon zero e

so what i have done essentially is for this problem there are dielectrics and i have been able to solve the calc the i have been able to obtain the electric field and displacement vector now for r greater than two r again i will apply the same formula d dot d a is equal to q f enclosed and i will get two pi r square sorry four pi r square d is equal to now the free charge enclosed is still pi alpha r s power four

so d vector comes out to be equal to alpha by four r four by r square into r cap at the d vector and e vector because it is free space d vector by epsilon zero which is equal to alpha by four epsilon zero r four by r square rk that is electric field and p will be equal to d minus epsilon zero e please find out what is the value of polarization outside in the region beyond small r is equal is greater than two r ok

so find out the polarization that region and check for yourself and try to conceptually understand why you get a certain value of polarization ok now i want to look at another problem which is the following a point charge q is placed at a distance a by two above the center of a horizontal square surface of edge a the electrostatic flux through the square surface will be now let me give you four choices q by epsilon zero q by four epsilon zero q by six epsilon zero and zero

so the problem is essentially i have a a flat square surface of side a and i have kept a charge q at a distance a by two from the surface along the central line the question is what is the flux passing through this surface because of this point charge now obviously you can do an integration e dot d a to calculate the flux but thats much more complicated i can very quickly solve the problem by understanding that because i have this surface here let me construct the

complete cube around this and the charge is at the center of this cube because this is side a this is side a and this is side a and this height is a by two so the charge is placed at the center of a cube of side a and because it's a point charge the electric flux is uniform it does not depend on the angle it depends only on the position

so and these six surface there are six surfaces now of the cube which are surrounding this and they are equidistant from the point source

so the total flux can be emitted by the total flux coming out of the charge q is q by ϵ_0 the total flux and out of this one sixth must be passing through this surface one sixth each must be passing through each of these surfaces because they are all equidistant from the point charge

so the correct answer to this problem is the answer c here which is q by six ϵ_0

so in many of these problems as you can see here I should be able to use symmetry arguments to solve the problem very quickly because that can help me to resolve the problems very very easily now let me give you another problem here consider a set of two point charges q_1 and q_2 and a uniformly charged sphere of radius r with uniform volume charge density ρ obtain the values of $\oint_C \mathbf{E} \cdot d\mathbf{l}$ over curve C for what value of ρ will $\oint_S \mathbf{E} \cdot d\mathbf{A}$ over the closed surface S will vanish and draw a closed surface through which $\oint_S \mathbf{E} \cdot d\mathbf{A}$ will be independent of ρ

so the figure is as follows

so you have a spherical charge distribution of radius r and you have another point charge here q_2 and the points are q_1

so that is my surface this is the closer surface S and that is my contour C

so the first thing is what is the value of $\oint_S \mathbf{E} \cdot d\mathbf{A}$ over the closed surface S

so we know from Gauss's law $\oint_S \mathbf{E} \cdot d\mathbf{A}$ is equal to charge enclosed by ϵ_0

so $\oint_S \mathbf{E} \cdot d\mathbf{A}$ over the surface S is the charge enclosed by the surface S divided by ϵ_0 the charge enclosed by the surface S has now these are two charges the charge q_2 is enclosed by surface S and the entire charge contained in a sphere is also enclosed by surface S

so this is nothing but one by ϵ_0 times q_2 plus the total charge of the sphere because the sphere is uniformly charged $\frac{4}{3}\pi r^3 \rho$ that must be the value of the electric flux electrogenic flux crossing the surface S now what about $\oint_C \mathbf{E} \cdot d\mathbf{l}$ over curve C please remember no matter what path you take for an electrostatic field $\oint_C \mathbf{E} \cdot d\mathbf{l}$ over a closed path is always zero

so same thing will happen for the curve C the contour C $\oint_C \mathbf{E} \cdot d\mathbf{l}$ will be simply zero now the next question is for what value of ρ will $\oint_S \mathbf{E} \cdot d\mathbf{A}$ vanish

so I must put this equal to zero and I can get the charge density required to make out that the total flux crossing the surface S becomes zero all that you need is that the charge contained in the sphere must be equal and opposite to the charge q_2 .

so if q_2 is positive I need to have negative charges in the sphere if q_2 is negative I need to have positive charges in the sphere

so the total charge enclosed by the surface S divided by ϵ_0 is the flux and if the total charge is zero the net flux becomes zero and then you draw a closed surface to which $\oint_S \mathbf{E} \cdot d\mathbf{A}$ will be independent of ρ

so I leave this problem to you please think of a surface in this in this figure where you can draw such that $\oint_S \mathbf{E} \cdot d\mathbf{A}$ will become independent of the

charge density on the sphere another interesting question that we must understand is let me look at the following the relation $\epsilon = \epsilon_0 + \frac{P}{E}$ holds good only in free space or only inside a dielectric or only outside a dielectric and $D = \epsilon_0 E + P$ everywhere in space

so we had introduced this equation relating electric field and polarization to displacement vector D vector and the question is whether this equation is valid everywhere or only in certain regions

so please think about this and right one just try to analyze this problem and try to understand where this particular relationship will be valid now i want to look at the final problem here

so two non conducting spheres solid spheres of radii r_1 and r_2 are having uniform volume charge densities ρ_1 and ρ_2 respectively touch each other the net electric field at a distance r_1 from the center of the smaller sphere along the line joining the centers is zero obtain ρ_1 by ρ_2 ok

so let me draw the figure

so you have a bigger sphere and a smaller sphere this is radius $2r_1$ this radius r_1

so it is given

so ρ_1 is the charge ρ_1 is a charge density here ρ_2 charge density here

so it is given that at a distance $2r_1$ from the center of the smaller sphere the electric field happens to be zero

so there are and on the line joining the two centers

so let me draw the line joining the centers

so there is one point which is a distance $2r_1$ from here

so so this is this distance is $2r_1$ and there is another point here which is also a distance $2r_2$ from here

so you need to calculate the total electric field at this point because of ρ_1 and ρ_2 and you need to calculate the electric field here because of ρ_1 and ρ_2

so find out the ratio of ρ_1 to ρ_2 for making this electric field zero and the ratio of ρ_1 to ρ_2 to make this electric field zero

so i give you the two solutions here you can show that you can have ρ_1 by ρ_2 is equal to minus thirty two by twenty five to make the electric field zero here and to make the electric field zero at this point $2r_1$ by ρ_2 is equal to minus four please be careful in calculating the electric field here although the entire sphere is charged to calculate the electric field here you must be careful in calculating that field inside a uniform charge density distribution and use that electric field to calculate and show that there are two solutions of problem the electric field will be zero here provided this ratio is minus thirty two by twenty five and the electric field here is zero provided r_1 by ρ_2 is minus four

so today i have discussed certain problems in electrostatics i picked up some problems which contained calculation of electric fields calculation of displacement vector calculation of forces and

so on and trying to calculate the flux the potential difference etcetera to make you understand a little better i would urge you to solve more and more problems based on the concepts developed understand the concepts very well and use those concepts concepts to solve problems and that will help you to further understand the concepts and help you to solve problems

so we will now stop here in the next lecture i will discuss problems containing magnetostatics and electromagnetic induction and

so on thank you very much you