

very good morning to all of you

so we

continue with our lectures on electrostatics till now i have introduced the concept of charge

the properties of charges then we discussed the coulomb's law which describes the force between

two charges two point charges and then we also discussed about principle of superposition where

if you have a charge if you have a couple of charges for example if you have one charge  $q_1$  one

another charge  $q_2$  another third charge  $q_3$  the force between charge  $q_1$  and  $q_2$  is

independent of the presence of the charge  $q_3$

so  $q_2$  the effect the charge  $q_1$  ah the

force on the charge  $q_1$  because of  $q_2$  is the same as given by coulomb's law in the

absence of  $q_3$  similarly the charge  $q_3$  has a force on  $q_1$  irrespective of the presence

of  $q_2$

so we can actually write the total force on  $q_1$  the charge  $q_1$  as the sum of the forces

due to  $q_2$  and the force due to  $q_3$  and remember force is a vector

so if for example

if this was a positive and this is positive and this is negative then this force will be in this

direction this force will be in this direction

so i have to add vectorially the forces between ah

$q_2$  and  $q_1$  and  $q_3$  and  $q_1$  and to get the total force on  $q_1$

so we have introduced

all this today i am going to introduce a very important concept in electrostatics

that is the concept of electric field now we saw in the experiments

that the two straws which were rubbed had charges

so they if i bring one charge

one straw close to the restaurant it repels the straw i also showed that if you have a straw

which is charged and if you have a glass rod which was charged if you bring the glass rod near

it attracts the straw and they stick to each other

so the question is how does this force get

transmitted how is this charge able to attract or repel another charge

although there is no direct

link between them there is no string connecting them there is no object connecting these two

so one way to visualize this is to assume that there is action at a distance that means i

can assume that this charge can act on this charge although there is no apparent connection

between these two similarly this charge can affect this charge either attract or repel

it there is another very nice way of describing this effect and that is through the

concept of electric field electric field

so what we say is that if you have a charge

say plus  $q$  charge here then this charge sets up in the surrounding space a field called the electric field and if you put another charge here which is say minus  $q'$  then this charge minus  $q'$  senses this electric field and gets attracted to this charge cube plus  $q$

so plus  $q$  charge sets up an electric field in the space surrounding the charge which then affects the charge minus  $q'$  by either attracting or repelling it similarly the charge minus  $q'$  sets up its electric field which then affects the plus  $q$  charge by attracting or repelling it depending on the size of the charges

so what we say is that every charge creates in its surrounding an electric field and it is that electric field which then affects other charges present in the system

so electric field is an intermediary between an effect forces between two charges please remember that the charge plus  $q$  sets up its electric field but that electric field cannot have any force on the charge itself

so the electric field produced by plus  $q$  charge affects all other charges in the vicinity similarly the electric field produced by minus  $q'$  affects all other charges present in the vicinity but not the charge itself

so this you must remember so we will define we will say that a charge if you have a charge plus  $q$  here then the electric field set up by this charge is given by  $\frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$  where  $r$  is the distance this one and this is  $\frac{1}{4\pi\epsilon_0}$  so actually this is valid for all charges

so let me not just plus  $q$  it is some charge  $q$  could be positive or negative so we say that any charge  $q$  sets up an electric field in its surrounding and the electric field at any point here at the point  $p$  which is at a distance small  $r$  from this charge capital  $q$  is given by  $\frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$  where  $\frac{1}{4\pi\epsilon_0}$  is the unit vector joining this charge  $q$  to the point  $p$

so if this electric field is set up we then say that if you put a charge small  $q$  here the force acting on the charge is  $q$  times electric field which is equal to  $\frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \times q$  which is nothing but coulomb's law

so what we say is every charge sets up an electric field and that electric field then exerts a force on any other charge present in this in the space and the force is given by the product of the charge and the electric field

so this electric field is produced by these charges and it is the electric field which is the intermediary which is responsible for attraction and repulsion of these charges from this discussion it also follows that i can define the electric field as force divided by charge or force exerted per unit charge

so if you have a charge capital  $q$  here i can put a unit charge at this point and see the force that is felt by this charge and that force will be called the electric field now i must be little careful in this definition because there may be a number of charges in in a in a region suppose i have a number of charges say  $q_1, q_2$  etcetera  $q_n$  and  $n$  charges

so i want to find the electric field here at this point so if i put a small charge here i can find out the force on this on this charge  $q$  and divide that force by this small charge  $q$  to get the electric field at that point now i must make sure in this definition that this charge  $q$  when you bring it here and put it here does not affect the position of all the remaining charges so these charges should not get displaced or moved because of the presence of this charge so they have to be held at the same place

so that what i measure here the force is exactly because of the electric field at that point because of all these charges so in this definition i can also define the electric field at this point is the force  $F$  felt by a charge in the limit of the charge going to zero

so this definition i must be ah i can use it so i can actually if you have for example if you have a positive charge if you have a positive charge here then ah the electric field at this point as as you can see the electric field we have defined as  $E = \frac{q}{4\pi\epsilon_0 r^2}$  into  $\hat{r}$  so if capital  $q$  is positive then the electric field is in the same direction as  $\hat{r}$  so positive charge will produce an electric field in this direction here in this point it will produce an electric field along this direction at this point it will produce an electric field along this direction at this point it will produce an electric field along this direction similarly if you have a negative charge then the electric field direction because capital  $q$  is negative the electric field direction will be along minus  $\hat{r}$  so the electric field at this point will be along this direction electric

field at this point will be along this direction electric electric field at  
 this point will  
 be along this direction similarly along at this point will be along this  
 direction so  
 electric field these electric fields are directed towards positive charges and  
 sorry away  
 from positive charges and towards negative charges now i can this is the  
 electric field for one point  
 similarly i can write the total electric field in the presence of a number of  
 charges as  $\sigma_i$   
 is equal to one to n one by four pi epsilon zero  $q_i$  by  $r_{pi}$  square into  $r_{pi}$   
 i so  
 i have a number of charges  $q_1$   $q_2$   $q_3$  and  
 so on and  $q_n$   
 so i am trying to find  
 out the electric field at this point point p  
 so i i have this vector these lines here joining  
 these these are lines here  
 so this is  $r_1$  p r sorry  $r_1$  this is  $r_2$  etcetera and similarly finally  
 this one  
 is  $r_n$  vector these are all vectors here  
 so the total electric field at this point is the  
 sum of the electric field produced by discharge discharge discharge and  
 so on and this is  
 nothing but the principle of superposition for electric fields that means the  
 total electric field at any point is the sum of the electric field produced by  
 each  
 and every charge in the system now this summation includes all charges present  
 in the system  
 and gives me the total electric field that is present at this point remember  
 that if you  
 were to calculate the force on this charge i must calculate the electric field  
 at this point  
 and in that electric field calculation i must not include this charge  
 so the electric field  
 here at this point will be the electric field produced by all other charges  
 and if i put  
 a charge  $q_1$  here that  $q_1$  charge will will have a force on it and that  
 force will be  
 determined by the electric field produced by all other charges inside the  
 system  
 so this  
 concept of electric field is extremely important and as i mentioned that  
 although in electrostatics  
 i may not really need this but in later advanced subjects in electromagnetics  
 this electric field  
 and magnetic fields form very basic foundations of electromagnetism itself  
 so every charge produces  
 in the surrounding an electric field and that electric field is felt by any  
 other charge  
 that comes in in that in the region of space  
 so whenever you have a space containing electric  
 field if you put a charge there there will be force on that charge  
 so if the electric field

depending on the direction of electric field the charge will try to be forced  
 in that to move  
 in the direction and the direction of the force will be the same at the  
 direction  
 of electric field at that point now i can use this to understand  
 what happens inside a conductor as i mentioned in the first lecture  
 conductors  
 are materials in which there are free electrons the outermost electrons of the  
 atom are free  
 to move in the entire body of the material and  
 so the electrons can react to any electric  
 field present inside the medium  
 so if you take a conductor if you take a certain conductor  
 of a certain size say for example copper then  
 so there are free electrons inside electrons  
 which are able to move inside the material if you have an electron here then  
 if there is  
 an electric field at this point in suppose the electric field is in this  
 direction the electron  
 will move try to move in this direction because it will be attracted  
 so please remember that  
 because there are free charges present inside the conductor they will react to  
 any electric field  
 present inside the conductor and move and because currently we are discussing  
 electrostatics that  
 means a situation when the condition is static there is no movement of charges  
 finally  
 when you reach an equilibrium position there cannot be any electric field  
 inside the  
 conductor because if there is an electric field inside the conductor that  
 electric field will  
 push the electron in an appropriate direction and until the electron comes to  
 a position  
 where it cannot move any further  
 so inside the conductor in a static situation  
 there cannot be any electric field at all now let me for example calculate  
 suppose i  
 have a a charge here say plus five nano coulomb and i want to calculate the  
 electric field at a distance of say one meter from here what is  
 electric field i want to calculate  
 so i can use this formula  $E$  is equal to one by  
 $4\pi\epsilon_0 q$  by  $r^2$  into  $r$  cap  
 so if i define  $r$  cap as this direction  
 then this is  $9 \times 10^9$  into  $5 \times 10^{-9}$  by  $1$  meter  
 square into  $r$  cap  
 so this is equal to 45 now the unit of this as you can see is force per  
 charge unit charge  
 so you can newton's coulomb later on we will introduce another unit for  
 electric field  
 so this is 45 newtons per coulomb and in the direction is  $r$  cap  
 so in this one meter  
 distance there is an electric field of this much  
 so if you happen to put a charge  
 say minus 5 nano coulombs here the force on that will be minus 45 into

5 into  $10^{-9}$  which is equal to  $10^9$  newtons and as you can see

it is minus  $r$  cap direction

so there will be force of attraction here towards the this first charge

so given a charge  $q$  i can immediately calculate the electric field and once i know the electric

field at this point i can use this the equation for force which is charge times the electric

field to calculate the total force on the charge

so for example you can also calculate

i will leave it to you to calculate what is the electric field produced

by minus five nano coulombs here and calculate the force of on the charge plus five

nano coulombs here and show that newton's third is valid

so i leave it as a problem to

calculate the electric field produced by minus five nano coulombs inside space what is

the electric field at this point and calculate the force on the plus five nano coulomb and

check whether newton's third law is valid now as i was mentioning the concept of concept of electric field ah is a very important concept that you

will be using later on ah

so for example let me ask the following question suppose i had

two charges fixed charges

so each charge is uh having some kind of a force on it this

charge has a force on this charge this force this charge has a force on this charge

now suppose i move the charge to the right now obviously the electric field of this charge

at this point has increased because the distance has decreased

so if i had one meter and i

begin to 50 centimeters the electric field here is increased by factor four because i

have reduced the distance by a factor of two the electric field must have increased by a factor of four now the question is when does this charge

feel that this charge has moved its position now at this moment i we cannot explain this

this number here but we will see later on that this charge will see the effect of this charge

after a certain interval of time and that interval is actually an interval which is this distance

divided by the speed of light in free space

so when i move this charge here this chart

will have will feel an effect of this charge after a time interval which is this distance

divided by the speed of light in free space so it is not an instantaneous action and this

action is actually

so this charge movement creates a disturbance in the electric field which propagates towards this charge and then as it arrives on the charge this

charge has its effect

on on this charge and this is the electromagnetic field which you which you will discuss later on

and

so electric and magnetic fields have their own real existence they are they are destroyed by dynamical equations and these equations you will maybe come across little later in your career when you study more details of electromagnetism itself so these electromagnetic fields can transport energy momentum and so on and so forth now electric field is a form of a field called vector field now what is the field field is any physical quantity which takes different values at different points so i can for example describe a field called temperature field so the temperature as a function of position temperature in my in the room as a function of position  $x y z$  that is called a temperature field and temperature being a scalar quantity is an example of a field called scalar field similarly i can describe pressure as a function of position this is called the pressure field it is again a scalar field i can describe suppose for example i take water flowing in a river i can describe a loss velocity field which is an example of a vector field so these are quantities which is described how a quantity like temperature or pressure or velocity depend on position in fact they can also depend on time and in a similar context we have the concept of electric field so electric field is also a vector field electric field is also a vector field it can depend on position right now we are doing static situation so there is no time dependence so this is a vector field also called as electric field so later on you will see similarly i will be able to describe a magnetic field as a function of position thats another vector field now it so happens later on you will see that electric and magnetic fields at any point depend on electric and magnetic fields in the nearby points and you can form differential equations which describe these electromagnetic fields and this is a very elegant representation of electromagnetism itself now this is fine as electric fields and magnetic fields it was michael faraday who introduced a very interesting concept for visualizing this michael faraday was a british scientist he invented ah what are called as lines of force this is not currently used we call them as field lines so electric field lines magnetic field lines etcetera so these are actually trying to visualize represent the fields in space so let me take for example a positive charge so what i do is the following i have the

expression

so suppose this charge has its magnitude  $q$

so i have an expression for

electric field one by four pi epsilon zero  $q$  by  $r^2$

so what i do is i calculate for example i

take this point i calculate the electric field at this point i know its magnitude from this

equation here i know this distance i know the value of the charge i know one by four epsilon

zero

so i can calculate this quantity and then i also know the direction at the direction

connecting these two

so i draw a vector here this vector has a length equal to the

magnitude of this electric field at this point and the direction is the direction

of the electric field at that point now you see here in this equation the electric

field remains the same if  $r$  remains the same the magnitude of electric field is independent

is the same for all points having the same  $r$  and all points having the same  $r$  will lie on a

circle around this point actually a sphere around this point charge

so all this point on the circle

will have the same magnitude of electric field but the direction will be different because at

this point the electric field will have this direction at this point the electric field will

have this direction at this point the electric field will have this direction they will all

have the same magnitude but different directions ok then i go to a further point

so at this point i know that this distance is larger

so electric

will be smaller and but the directional electric field will be in this direction

so this will be

large

so let me draw a bigger line here these are large electric fields this is slightly smaller

electrical similarly at this distance from here the electric will be here this point electric

field will be here this point the electric field will be here and then if i go further away

here the electric will be even smaller and the direction will be along the direction

joining that point to the charge

so please remember these are these are

the electric fields at these points these lines represent the the magnitude of the electric field the length of the line represents

the magnitude of the electric field this tips here these end points here are the

positions where i am drawing the electric field

so this is one representation of electric

fields but there is a problem in this that it it there is a better visual representation of this which faraday found out which one it discovered or made and

that is as follows

so what we do is the following we draw what we call as electric field lines which are such that the tangent through that line gives me the direction of the electric field and we forget about the magnitude of the electric field because here what

i am trying to do is to draw vectors of length equal to the magnitude of the electric field but

let me try to draw another figure and then i will interpret this

so i would draw for a positive

charge i draw electric field like this lines i draw continuous lines now when i draw continuous lines i have left over

the magnitude of the electric field because here in this figure the magnitude magnitudes

were contained in the length of these vectors here i have actually joined all the points and i

have lost track of that but i have another point and that is the closer the lines are the stronger

the electric field is

so i represent the electric field as something like number of lines crossing per unit area perpendicular to the direction so here for example if you i have drawn certain

number of lines here as you go further from the charge the lines separate out more and more

which means the electric field is decreasing as i move away from the charges as i come closer to the

charge the field lines are getting closer together and that means the electric field

is getting stronger and stronger now this is a two dimensional representation to get the complete three dimensional picture i must rotate this figure and get a complete

three dimensional representation that means i will have a sphere with ah pins coming out

in all from all directions of the sphere now how many lines do i draw

i can draw any number of lines if you have very thin pencil you

can draw a large number of lines and depending on the energy you have but one must make

sure that there is consistency

so if i draw 20 lines for a charge of 1 nano coulomb i must draw

40 lines for a charge of 2 nano coulomb i must draw 60 lines for a charge of 3 nano coulomb so

i must make sure that the number of lines i draw is consistent with the charge

so larger charges

will have larger number of lines starting

so what i have done now is i

have replaced individual vectors by lines these lines

represent electric field lines please remember these are not any line existing in

space these are representations they are not there is no line in space these are representations

all it implies is that if i look at this point this point has an electric field like this this

point there is an electric field like this and the number of lines which are lying here around this point gives me approximately the strength of the electric field similarly here the electric field is like this

so these lines represent electric field lines and this is the representation the closer the lines are the stronger the electric field the further the lines are the weaker the electric field now because of the positive charge points the lines are facing away from the charge

if i take a negative charge what will happen if i take a negative charge all the field lines will be pointing towards because you know that electric field is equal to one by four pi epsilon zero q by r square into r cap

so if q is negative then the electric field will be in the minus r cap direction

so for negative charges i will draw like this they will all be coming towards for positive charge the field lines were facing away from the positive charge for negative charge the field lines are all towards the charge

so what it implies is if you put a positive charge here it will be attracted in this direction if you put a positive charge here it will be attracted in this direction

so these are all electric field lines and these represent this this is a representation which michael faraday introduced ah for a visual representation and they can be used to picturize the electric fields in different situations now this i have drawn two point charges

now let me see what happens because my my problem is not just single point charges i will have many charges in the system

so what will the electric field lines look like if i have many charges in my system

so let me take an example of two charges one positive and one negative let me assume they have the same charge q and q

so now i want to draw electric field lines

so let me take a point ah this

so let me draw a line here which is the mid the mid midway line

so i take a point here at this point i know that this positive charge creates an electric field like this and the negative charge creates an electric field like this this is on the equatorial line

so this distance is equal to this distance

so the magnitude of this electric field and the magnitude of this electric field are equal that because this is positive the electric field is like this because this is negative electric field is like this the total

electric field here is the sum of these two and you can say that this will be like this it is actually the parallelogram of forces and the net electric field will be like this so this is the net electric field what about this point so this point you will have one electric field like this and another electric field like this please remember this point is farther away from this charge than this charge so this charge will have a stronger electric field here compared to this charge and so if you add parallelogram law of forces it will come like this similarly here you will have this one producing a charge force like this this one producing a large force like this and then net force will be like this so what you can see that every point the magnitude of the force the magnitude of the electric field changes and also its direction in a point charge this did not happen in a point charge if i move along this line the electric field is always pointing away from here wherever i am here the situation is different if i move from this point to this point the electric field line goes from this point this way to this way and to finally this way so now what i do is i draw a curve i draw a curve such that this vector is tangent to this curve at this point i draw a curve here such that this vector the total electric field is a tangent to this point i draw a line curve here so that this net electric field is tangent to this line so what i do is i draw a continuous line such that the electric field suppose i draw a line like this what it implies is electric field at this point is in the direction electric field in this point is in this direction electric field here is like this so i will have another line here for example this electric field is like this this is like this this is like this so these field lines are such that the tangent to the curve at any point represents the direction of the electric field at that point and as before the density of these lines how many lines are whether the lines are close together or far away from each other represents the strength of the electric field so similarly if i take instead of positive and negative if i take a positive charge and another positive charge you can see that at this point the midway line for example again like before this field is here like this this field is like this here the distance this distance is equal to this distance

so the magnitude of electric field because of this charge at this point is equal to magnitude of electric field at this point because of this charge both are the same charges and the directions are like this and so the net will be in this direction similarly here if you calculate this would be like this and this will be like this and the net will be in this direction so this way you can form again set of curves showing the electric field lines so you can ah if you calculate for example here this will be like this and this this will be like this so the net will be somewhere here like this so you expect lines to curve around these charges and so again just like before you i will show you a figure actual plot the curves go like this so this this curves are all electric fields are pointing like this so again like before at this point the electric field is like this at this point the electric field is in this direction at this point the electric field is in this direction so at any point i draw a tangent to the curve at that point and that tangent gives me the directional electric field as we move away from here the number of lines is decreasing per unit area that means they are getting further and further apart so electric field seems to be decreasing as i move away and if i get closer to the charges the electric fields increase so i have actually got some plots of this actual calculation of electric fields of point charges and i show you some slides so let me show you some slides representing uh electrical lines for a positive negative charge negative positive positive combinations so here is the field uh which here is the actual plot calculated plot of electric field lines between a positive and a negative charge ah it is similar to what i try to draw trying to represent so what it implies is that at this point the electric field is tangent to this point of the curve which is like this here from somewhere here the electric field will be like this at this point on this line the electric field like this actually they should be arrows on these curves these arrows are all going from positive to negative charges and as you can see here i have taken the same number of lines starting from a positive charge and they are all ending on negative charge so as i discussed earlier electric field lines start from a positive

charge and either end on a negative charge are  $\infty$  to infinity go to infinity similarly  
all charge all electric field lines will come and converge to a negative charge either from another  
positive charge or from infinity  
so that's a pair of positive and negative charges this is of equal magnitude this is called an electric dipole we will calculate actual electric fields of these  
dipoles a little later  
so as you can see here these represent electric field lines and this is what Faraday at that time had tried to introduce and now these are very nice representations of  
electric fields and as you can see here the two field lines the two charges seem to be attracting  
as you can see here they are trying to be pulling each other if you look at two positive charges  
the electric field lines are very different from this pair of positive and negative charges  
as you can see here they look like attaching each other these look like repelling each other  
so the electric field lines are different here here the electric field lines start from both  
the positive charges and go towards infinity there is no convergence actually they finally  
go up to infinity and stop there let me show you another figure three positive charges  
so what we  
do is we calculate electric field at every point draw curves such that at any point the direction  
of electric field is tangent to that point to that curve  
so here for example the electric field  
will be tangent to this curve here at this point the electric will be tangent to the curve at  
this point somewhere here the electric will be tangent to this curve at that point and  
so on so  
i can draw field lines like this for combination like this or two positive and one negative charge  
and  
so on and  
so forth  
so this is an interesting way to visualize electric fields between charges and this is one representation which can be very useful now i must mention  
i must  
caution against you are assuming that these electric field lines are not lines of constant electric field they do not represent lines of constant electric field as you move along the line the electric field changes as you move along  
any of these lines the electric field itself is changing as approximate position  
so the electric  
field strength is represented by the spacing between these how many lines are there close  
by here the electric field strength is larger because there are lines are

closer here here  
the electric field strength is smaller because the lines are further away and  
so on  
so these  
lines do not represent lines of constant electric field that's one point that  
you must remember  
the second point is if i put a charge here do not make a mistake that the charge  
will  
go along the curve if i put a charge here a positive charge the charge will be  
acted upon by  
an electric field in this direction tangent to the curve and then that  
particular force will  
accelerate or decelerate or whatever it is to the charge there will be force  
on the charge so  
this if you put a charge on on at this point it is not it is not necess it's  
not that the charge  
moves along this line doesn't move along that line except of course in this in  
the case of a  
single charge if you take a single positive charge to take a single positive  
charge and put an put  
a charge on one of the lines here if i were to charge here if it is a positive  
charge it will  
move along this line if you put a negative charge it will move along this line  
towards this but not  
in general not in general situations these lines do not represent curves where  
the charges will  
move  
so for a given electric field distribution at any point i know the total  
electric field  
that total electric field will give me a force on any charge and that force i  
use in newton's  
laws to describe the motion of that particle ok now this particular  
so again let me recall again electric  
field line starts from positive charges electric field lines end on negative  
charges  
so the charges starting from positive either go towards a negative charge or  
go towards infinity  
similarly charges negative charges the electric field lines converge to that  
negative charge  
either from a positive charge or from infinity second thing i must also again  
remember that  
electric field lines never cross each other because if an electric field line  
crosses suppose  
i have one electric field like this another one like this what is the  
directional electric field  
here is it tangent to this curve or is it tangent to this curve obviously  
electric field cannot  
have two different orientations at one point  
so electric field lines never cross each other as  
you have seen in the figures the electric field lines do not cross and because  
electric  
field at any point is a unique direction ok  
so lets start calculating for example let us  
take an electric what is called as energy dipole an electric dipole is a pair of

charges which had rule earlier a positive and negative charge ah let me draw this let me draw the other way around  
 so this is negative this is positive okay  
 so ah same same charges  
 $q$  and  $q$   
 so minus  $q$  and plus  $q$   
 so let me draw the  $x$  axis here ah and let me try to calculate what is the electric field because of this pair of charges  
 so i can actually calculate electric field at any point but for simplicity let me start with calculating electric field at some point  $p$  here and let me assume the distance of this point so this is origin let me assume this distance is  $x$  ok and let me assume that this separation is  $2a$   
 so 2 charges plus 2 and minus  $q$  kept at a separation of two  $a$  and i am trying to calculate the electric field along the line joining the two charges  
 so i take a point  $p$  which is at a distance  $x$  from the center of these two charges  
 so this is my  $x$  axis and this is my  $y$  axis here ok  
 so the electric field at this point the total electric field is the electric field because of plus  $q$  plus electric field equal to minus  $q$  please remember super position principle electric field at this point total electric field at this point is electric field at this point because of plus charge plus electric field at this point because of minus charge the presence of plus charge does not affect the electric field created by the negative charge here similarly the presence of negative charge does not affect the electric field created by the positive charge at this point  
 so what are the electric fields  
 so  $e$  plus  $q$  is equal to one by four pi epsilon zero  $q$  by this distance square this distance square  
 so that is  $x$  minus  $a$  whole square and this is the direction  $i$  cap ok i must clarify something here in an earlier lecture i had used  $x$  cap this is the same as  $i$  cap  $y$  cap is the same as  $j$  cap and  $z$  cap is the same as  $k$  cap unit vectors unit vector along the  $x$  direction is  $i$  cap or  $x$  cap unit vector on the  $y$  direction is  $j$  cap or  $y$  cap unit vector on the  $z$  direction is  $k$  cap or  $z$  cap  
 so you will should get used to the notations sometimes people use  $i$  cap  $j$  cap  $z$  cap sometimes we will use this  $x$  cap  $y$  cap  $z$  cap  
 so they represent unit vectors along the  $x$   $y$  and  $z$  directions  
 so  $e$  plus  $q$  is given by this and whatever  $e$  minus  $q$  one by four pi epsilon zero  $q$  by this distance square

and that distance is  $x + a$  and  
 so this electric field plus  $q$  is this direction and minus  $q$  is  
 in this direction  
 so minus  $i \cap$   
 so the plus charge creates an electric field  
 towards the plus  $x$  axis here the minus charge creates an electric field in  
 this direction  
 so the total electric field let us calculate  $E$  is equal to  $E$  plus  $q$  plus  $E$  minus  
 $q$  which is  
 equal to  $\frac{1}{4\pi\epsilon_0} \frac{q}{(x-a)^2} \hat{i} - \frac{1}{4\pi\epsilon_0} \frac{q}{(x+a)^2} \hat{i}$   
 sine of  $\theta$   $q$  by  $x$  plus  
 $a$  whole square  $i \cap$  which is  $\frac{1}{4\pi\epsilon_0} \frac{q}{(x-a)^2} - \frac{1}{4\pi\epsilon_0} \frac{q}{(x+a)^2}$   
 minus  $1$  by  $x$  plus  
 $a$  whole square  $i \cap$  which is equal to  $q$  by  $4\pi\epsilon_0$   
 so this is nothing but  $x$  plus  
 $a$  whole square minus  $x$  minus  $a$  whole square divided by  $x$  plus  $a$  whole square  
 into  $x$  minus  $a$  whole square  $i \cap$  which is actually  $q$  by  $4\pi\epsilon_0$  zero  
 $a$  plus  $b$  square minus  $a$  minus  $b$  square is  $4xa$  divided by this is  $x$   
 square minus  $a$  square whole square  
 so that's the electric field at that point with  
 coordinate with the distance  $x$  from the uh from the center and as you can see  
 here for charge for  
 points here the net electric field is given by this and the directional  
 electric factor is along  
 the  $x$  axis as expected because the two electric fields both because of  
 positive negative charges  
 are along the  $x$  axis either plus  $x$  axis or minus  $x$  axis and the sum of these  
 two vectors is also  
 along the  $x$  axis  
 so as  $x$  increases the strength of the electric field keeps on decreasing if  $i$   
 take  
 a distance  $x$  which is much much greater than  $a$  if  $i$  take a distance  $x$  much much  
 greater  
 than  $a$  then  $E$  will be approximately  $q$  by  $4\pi\epsilon_0$  zero  $4xa$   $i$   
 can neglect  $a$  in comparison to  $x$   $i$  will get  $x$  four into  $i \cap$  which  
 is actually  $q$  by  $4\pi\epsilon_0$  zero ok  $4xa$   $i$  by  $x^3$   
 so let me write this like  
 this  
 so this is  $q$  times  $2a$  by  $2\pi\epsilon_0$   $i \cap$   $i$  purposely written like this  
 $q$  is the charge plus  $q$  and minus  $q$  and two is the separation between  
 the two charges as you can see here this is my geometry here the charges are  
 plus two  
 and minus  $q$  two is the separation between the two charges this particular  
 quantity  $q$  times two  $a$  is  
 called is given a name it's called dipole moment and this dipole moment is a  
 vector it is written  
 as a vector from the minus sign minus charge to the plus charge  
 so it is given a small sign  
 here  $p$   $p$  vector  
 so  $i$  define the dipole moment it is a vector dipole moment is a vector which  
 has a magnitude of charge  
 times the separation between them and the direction of the dipole moment is  
 from the negative charge with positive charge now a little later  $i$  will tell  
 you

the importance of these dipoles but what we have seen is here that the electric field of the dipole keeps on decreasing as you move away from the dipole and it decreases in the following fashion

so i can write this as  $p$  is the type of moment this quantity  $q$  times two  $a$  times  $\epsilon_0$  is  $v$  vector and by  $2\pi \epsilon_0 x^3$

so one thing to note here is that for a point charge the electric field decreased as one by distance square what is  $x$  is the distance

of this point from the center of the dipole because along the  $x$  axis i am calculating  $x$  here

so for the dipole the electric field decreases as  $1/x^3$  if i had a positive charge only along the  $x$  direction suppose i take a positive charge and look at the electric field along the  $x$  direction

how will it decrease

so if i had a positive charge if i had only a positive charge here and this is  $x$  axis

so from the if this distance is  $x$  the electric field will decrease as  $q$  by  $4\pi \epsilon_0 x^2$  into  $\epsilon_0$

so electric field will decrease as  $1/x^2$  for a point charge it decreases with  $1/x^2$  for a dipole

so the decrease in char the electric field is much faster in fact if your separation between the two charges keeps on decreasing

the dipole moment keeps on decreasing and

so what is actually happening is if you are very far from the dipole the electric fields of the positive and negative charges become almost equal and they are in opposite directions

so they try to cancel off

so the electric field decreases much faster

so we will end the class here what i will do in the next class is to calculate the electric field on this equatorial plane i

would like to calculate what is the electric field here because of plus  $q$  sorry minus  $q$  and plus  $q$

separated by distance  $2a$  and this is the  $y$  axis this is  $x$  axis

so i want to calculate at a point  $p$

ah the total electric field and again we will see that the electric field will decrease as

the cube of the distance of this char of this point from the dipole yeah at the end i

want to leave a problem for you to think about a simple problem

so write an expression for the electric field produced by a point charge placed at a point with coordinates  $x, y, z$

so here is my plane here is my

so this

is my point charge here ah plus  $q$  for example the coordinate is  $x, y, z$  so

write the electric field as a function of  $x, y, z$  thank you