hello welcome all of you to this course of lecture what i will be doing in the current and the next few lectures is to discuss about current electricity let me first point out that

so far you have discussed charges at rest and what we are going to do in this chapter is to look at charges which are in motion and that is what we call as current now before i go to physics of currents let me also tell you that current occurs in nature as well the most common one being lightning which occurs due to electric discharge during an electric electrical storm see what happens is this that when drops of water go and reach the cloud at fairly high height they essentially become like ice clouds and when different parts of these clouds they uh collide with each other they usually lead to generation of electric current and such discharge which you call as lightning could occur between electrically charged regions of a cloud or between two clouds or between a cloud and the ground now of course you all know that the power of a lightning could be quite significant because an average bolt of lightning transfers about 15 coulomb of electric charge now i wish to tell you that a coulomb a single coulomb is a fairly large amount of electric charge because you might recall that the charge of an electron is 1.
6 into 10 to the power minus 19 coulombs

so therefore when i talk about one coulomb it means 10 to the power 19 times the charge in an electron and if you are talking about a very large lightning then the amount of charge that is transferred could be as high as uh something like 300 to 400 uh coulombs and a typical potential difference in an lightning could be as high as 200 000 to 500 000 volts and that can can go even up to as high as 30 million volts in addition to this another thing that occurs in nature and with a really beautiful consequences is that sun emits gases and particles which move towards the space at a fairly high speed and part of which also reaches the earth and some of these which reach the atmosphere particularly at the higher atmosphere they i happen to ionize things and they sort of work in or circulate in the region of atmosphere known as the ionosphere and and this current they create some beautiful sights known in the northern hemisphere as aurora borealis are also called the northern lights and very similar things also happen in the southern hemisphere which we call as the southern light or also known as aurora australis and in fact i have shown you a image of the aurora borealis in the northern hemisphere from nasa public website and but they occur in different types of colors now in addition in nature there are certain fish actually six categories of fish prominent among them being eels and catfish which also emit electric charges now remember that our muscle cells have electric potentials and but in some phase they sort of evolve into cells which are called electrolyte cells and which can generate potential differences of the order 800 to 1000 volts or

so and much smaller scale even within a human body we know that many of our body functions for example the pumping of blood into our hearts they take place by signals which arrive there from the brains and these signals are also electrical in nature and of course they are much smaller will be talking about their magnitude there but but basically these examples that i gave you they are examples of situations where the current is not steady

so what we are interested are in situations where the current remains steady and this lecture and the subsequent ones we would be primarily interested in talking about currents which are steady and later on we'll see that steady currents also become sources of magnetic field very loosely speaking electric current is nothing but flow of charges this is the formal definition and let us try to make this a little clearer now let me say that i have an arbitrary surface some area doesn't matter and suppose i have charges let's say positive

charges which i will call q plus and negative charges group their q minus and they are passing through this surface now

so whatever enters into that surface comes out

so therefore

so this is the charge in and they are coming out on the other side of that surface

so this is my charged out obviously that is also equal to q plus and this is the q minus now

so the net amount of charge q which is flowing in is q plus minus q minus now supposing these charges were steadily flowing through that surface then the amount of charge that is going through that surface would be proportional to the time t

so this is proportional to time t during which we make our observation

so in other words the rate at which the charge flows that i will call as the or define formally as my current this is equal to q divided by t now this of course assumes that my flow is steady but supposing it is not now then i would take the formal definition in a slightly different way and i will say that take a small time interval delta t now during which the amount of charge that is flows through that surface that i talked about is delta q then my current i at that instant around which i have taken that delta t can be defined as limit of delta t going to 0 i take as small as time interval as possible delta q divided by delta t you recall from your calculus that this is nothing but my definition of dq by dt

so this is my formal definition of current let's look at what are the units of current

so note that current is defined as charge divided by time

so therefore obviously the unit that i expect is coulomb per second actually

so this is given a name ampere actually in s i units the ampere is defined not as coulomb per second because coulomb is not a fundamental unit ampere is it is defined in terms of its magnetic effects but that will be we'll be talking about in later parts

so ampere is a fundamental unit in

so let us go back to the cases that we talked about for example typical household appliances in india you know that indian electricity supply is in the range of 222 to 40 volts and typical current values for household appliances is of the order of a few amperes

so let's say of the order of 5 amperes or

so if you want to compare this with for instance the strength of the current that takes place in a lightning this could be typically several thousand amperes aurora borealis that we talked about could also go to millions of amperes now on the other side i talked about certain fish like catfish and eel which give out electric currents there again the natural things they are typically about an ampere on the lower end the human nervous system gives a micro amperes

so now that we have talked about the definition of electric current let me now try to tell you how exactly we look at the flow of currents though it is not a an exact similarity but there is a lot of similarity with water flow flow of water for instance through a pipe now remember that for example at your homes you have a water faucet and typically there is a pipe which is going through and supposing at this end there is a water faucet and i know that if you open the tap the water immediately starts coming out now what happens is this we have also observed that there is no time difference between almost no time difference between the time you open the tap and the water comes out now actually what is happening is this that water is being pushed from one end but because there is a closed faucet at the other end it is not able to go and it's stopped and and

so there is no movement of water physically from here to there because the pipe is already full of water now when you open the faucet then basically all that happens is the water gets pushed but almost as soon as you open it because there is already water at this end the water starts flowing in there

so the incoming water is pushing the water which is there in this and of course then the water comes out now almost very similar thing happens in electricity for example at your home now you switch on for example a light and you will find that there is no perceptible time difference between the time you switch on the light and the light coming up and the main reason is again the same thing the in the wire which is there there are electric charges already there

so what you did when you pushed the switch is to essentially push provide that push like what i showed here

so therefore the what we need to do because the electrons are already there as a part of the matter and what we need to do is to essentially push it

so what we will be talking about is how this mechanism of pushing the electrons is arrived at and you know how does charges actually flow

so let us look at how is current created

so first thing that you have to recognize is that the ability of a material to conduct electricity depends on the property of the material we know that there are two types of charges there are positive charges and negative charges now what we require is a separation of charges in order to ensure there is a flow of charge now for instance we could create a static charge by rubbing together two materials this you have learned in your first lecture on electricity where we talked about static electricity for instance if you rub a piece of amber with animal fur then of course i generate static electricity and then if we touch amber to the ground the current immediately passes through and the static electricity is lost of course this current that we talked about doesn't last for very long and like the other cases that i mentioned these are also not currents which can be utilized in a any useful way

so so this is the way one talks about generating electric current

so let us now come to what type of material are suitable for generating electric current

so first thing that we know is all material consists of atoms and molecules and

so behavior of a material electrical property or any other property for that matter depends upon the atoms and molecules which constitute a matter and their interaction ability to conduct also depends upon physical condition of the material for example pressure temperature etcetera we will be talking about one or two of these things later but but this is this is roughly what happens but for the purpose of electric current the class of materials that we are interested in are known as conductors these are typically substances such as silver copper aluminum etcetera mostly in solid state but of course you also have mercury which at normal temperature is a liquid and is an exception

so these are materials which readily conduct electricity now that of course happens if these things are brought into a closed circuit and an electric field is applied

so the reason it happens is that the atoms in a conductor they have the ability to very easily give up when i say very easily it means with very little cost little cost of energy uh give up one or more valence electrons and and then this valence electrons which are contributed by the atoms which comprise that solid that they all belong to the material as a whole and not to that particular atom or atoms to which it belonged and very frequently we use the word electron gas

so these are also called free electron gas they are free in the sense that they are not tightly bound to an atom but they belong to the solid as a whole

so belong to solid as a whole now this electron gas that we have talked about

when you apply an external electric field they are free to move because as we know charges accelerate in an electric field now in our lectures on electrostatics we have learned that inside conductors i cannot have an electric field

so electrostatics e inside is zero what we will see now is that under dynamic condition this statement will not remain valid

so let me i will come back to it again but will say not true under dynamic condition now we have been just talking about ah current in mostly solids and in this case since that is the most common form of electrical conduction we have been talking about motion of electrons but let me tell you that conduction or transport of charges do not necessarily happen only with electrons it can happen even with positive charges and the typical example is what is known as an electrolyte you might recall your elementary chemistry a little bit for example if i have an electrolytic solution let us just take a simple situation like a common salt solution now i know that these are typical common salt these are what are known as ionic compounds the way it happened is this that these sodium atoms and chlorine atoms have this property that the outside valence electron in sodium atom for example was extremely loose in the sense that it was very weakly bound to sodium atom and as a result sodium could may easily lose that and when sodium lost an electron this is one example which you might have seen there

so basically what happens is that if it actually loses an electron and thereby becoming a sodium plus

so i should probably write it as this minus electron

so sodium plus plus an electron now this electron that is there is easily attracted by chlorine

so chlorine very readily agrees to accept this electron in its valence cell and

so the chlorine accepts the electron and becomes a negatively charged chlorine ion

so therefore what happens in a sodium chloride solution is that we have instead of sodium chloride together as atoms we have n a plus c l minus now

so suppose i had a situation like this this is a electrolytic solution

so for my typical example i am talking about sodium chloride

so let us look at that now i insert two electrodes and i will see that i will need to sort of connect them with a battery the the positive end connected to one of the electrodes the negative end is connected to the other electrode

so this in our usual language this is a positive electrode also called an anode this is a negative electrode called a cathode now look at this since the cathode is negative the electrode is negative it has the ability of attracting the sodium plus ions

so the sodium plus ions will start moving in this direction now likewise the chlorine ions would move in the reverse direction and of course if there is a current this would if there is a closed circuit this would give rise to a current but basically the reason i talked to you was that though generally we talk about electrons being the agent of conducting electricity we also have the sodium and the chlorine ion for example the positive ions can also conduct electricity and in fact we will see later on in our lectures on semiconductors that even the absence of electrons does the vacancies which behave like positive charges they contribute to the electrical current

so now what what is the situation in an insulator in an insulator unlike the case of a conductor or the case of an electrolyte for instance the electrons are tightly bound and and as a result they are not free to move

so tightly bound electrons unlike in the case of a conductor where we have said that there cannot be under static condition electric field inside a conductor in case of insulators different distribution of charges occur and the inside the

electric field need not be zero at this moment i postponed my definition or the properties of what are called semiconductors because that requires a detailed discussion by itself but we will come back occasionally to this
 so let us look at first the metals or the conductors metals are of course conductors and let us look at what happened in electrostatics now suppose i had a piece of metal and i let's suppose that this is a sample and these are my two ends and let us suppose artificially i provided a positive charge plate here and a negative charges here now look at what actually happens the free electrons which are here they would start moving towards the plate with the positive charge and and you see initially before this happens because one end had a positively charged plate the other end has a negatively charged plate i had essentially created an electric field but if this is a good conductor as soon as this happens this will attract the the positive plate will attract the electrons and of course the as a result the negatively charged nature of the other plate will disappear and the motion of the electrons inside would sin stop soon stop
 so this is what would happen in static condition but let us look at it slightly differently suppose i had a situation like this but i did not have a static condition because i had applied an external electric field
 so let us let us draw the external electric field and see what happens
 so i have the same situation there and let's suppose i have an external electric field in which this has been placed now you realize immediately electrons would start moving opposite to the direction of the electric field
 so that will charge up this side and
 so that would make that side positive the result of this is to create an effective field inside the material
 so let us call it e in and this will go on till the field inside which was e external to begin with that has been exactly cancelled and there is no longer any field around there now this is this is precisely what happens and and as a result the picture that emerges out of this is like this a conductor in a an external electric field the field lines are like this no field inside
 so i have negative charges here the positive charge is there this is my e external
 so basically what is happening is this that it is the electrons which are moving from the right to the left creating an effective electric field and that exactly cancels the external field that we had put the material in and the net field inside in a static condition is equal to zero now suppose i do something more what i do is i have a method of removing these electrons which come here fast enough
 so basically what i am creating is a pump
 so let me go back to the same picture again but create dynamic condition
 so the same picture i had an electric field and we had seen that this electric field had made this side negative this side positive and what i do is this i have a mechanism we'll discuss more about what mechanism it is later but supposing there is a method of taking out this electrons and feeding it back there
 so creating something like a charge pump if you like how we do it i am not given in this picture but you might have realized that what we do is to join it by a battery and things like that but but this charge pump removes the electrons almost as soon as they arrive here and then feeds it there
 so this has the effect that no electric field internal electric field will be created a internal equal to 0 for conduct which would mean that current would flow regularly and this is the way charges would flow
 so this is the way the current appears
 so hence charges will flow

so now that we have talked about that current is basically a flow of charge and we have seen that though there are situations where both positive and negative charges could flow uh most of the time we are restricted to talking about electrons

so let me talk about what about the direction because we all know that for example when i gave the example of water flowing we also know that it has a direction because it depends upon the way they are being pushed

so direction of current now conventionally in spite of the fact that the electrons contribute from the bulk for the bulk of the currents in situations that we are interested in but it has always been defined as the direction of flow of positive charge

so the picture that i gave you a little while back

so i had this situation

so we said that there are these electrons which are moving to this plate

so let me still show that electrons moving in they are being removed continuously

so the electron is moving in this direction

so according to this definition that i gave you this is a situation where the direction of current is the reverse direction

so let me say that that is the direction in which the current is flowing

so in other words the direction of current is defined according to a convention as the direction opposite to the direction in which the negative charges flow that is the direction in which the positive charges flow now notice one thing that you would immediately notice that we have said current has a direction however current though it has a direction is not a vector this is something which needs a little little bit of thinking to appreciate

so current i has a direction but is a scalar it's not a vector and this is primarily because it doesn't satisfy the algebraic law of addition of vectors we'll see how currents are added up and in fact we'll be discussing it at a later stage

so let us look at or go back to our original definition we said dq by dt is my current

so if i take any arbitrary surface

so the amount of charge that is flowing through any arbitrary surface is related to current by this relationship integral idt

so we have made a statement that current is not a vector and we have talked about its unit

so we define a quantity which is related to current but turns out to be a vector

so the current density j is a vector though current is not a vector

so let me explain how it works uh let us suppose i am talking about a current which is passing through an arbitrary surface let me show you your surface here let's suppose is the end of a wire cross section of a wire and the current is entering like this and is leaving from the surface like any other definition of density i define the magnitude of the current density as the amount of current passing through a unit area

so let us first talk about the magnitude and then i will come to what is its direction

so magnitude of j is i divided by area

so this is of course a scalar because current is a scalar area as we understand is a scalar since j is a vector we need to define its direction now you are all aware that if you take an infinite small surface area that area can be made as flat as you want by making the surface area smaller and smaller and

so that i can associate a direction with it this you have learnt even in your

mechanics course for instance

so what we are now saying is this that we define d s the direction of the area element as a direction which is perpendicular to the cross section obviously this definition makes sense only if the area is infinitesimally small now uh

so the this direction now you realize that every surface has two directions one in which the current is coming in and the other side of the surface is the direction from where the coming current is coming out now we take the direction of ds as that surface the direction of that surface from which the current is coming out

so and we define j to be in the direction of current flow

so what does it mean supposing i have a wire with this cross section and i have current entering like this

so the positive charges are flowing in this direction

so that is my direction of j and when the current comes out it is this surface from where they come out and

so therefore it is outward normal to this surface

so this is your direction of ds this implies that j dot ds is positive for positive current

so current is not a vector but current density which is a point definition by point definition i mean that i take a small enough area i can make that area as small as i like

so that density is defined as a point function

so at every point in the material i define the density

so we have seen that under electrostatic condition there is no field inside a conductor now what happens uh in such a situation see the electrons are still free and

so let's write it down static condition

so no field inside the material

so what happens is this that in such a situation the free electrons themselves have what are known as thermal velocities now typical thermal velocity of electrons in a metal is of the order of 10 to the power 6 meter per second fairly large velocity now what happens inside the metal is this that these electrons move inside the metal in a random fashion and let me explain to you what actually happens

so in a metal there are these ions or atoms which are located there is a periodicity type of thing but let us not worry about that i am drawing essentially a pattern here

so what happens is this if you take a particular electron this electron is continuously colliding with atoms or ions and then bouncing back back from the atom and then collides with another one

so typically a situation could be like this if this is an electron it could go here then here then here

so all sorts of things can happen there is no particular pattern and let me explain why this collision is essentially elastic in nature

so these are elastic collision

so we are talking about in the absence of any field inside

so let me say e inside is zero

so elastic collisions take place now this is something which is very similar to when for instance a very light particle collides against a heavier one

so for instance a tennis ball bouncing against a wall or a stone bouncing against a truck

so we know that a light particle colliding against a heavier mass bounces back almost with an unchanged speed now and only that the direction in which emerge will sort of depend upon what is the direction in which the collision colliding

particle approached the ion and then of course it comes out and the result of collision and recollision is such that the electron moves around in all directions now if you look at a collection of electrons the because of this random nature the velocities of the electrons different electrons are uncorrelated now

 so let me write it down the velocities of different electrons are uncorrelated now as a result supposing i say that v i let me put an average sign here represents the velocity of the ith electron the average velocity of the highest electron if i sum it over i equal to let us say 1 to let us say n number of particles are there

 so 1 over n this is equal to 0 this is equal to 0 because the directions of the velocities are totally uncorrelated

 so average velocity of the collection of electrons is zero

 so let us return to dynamic condition now we have seen that under dynamic condition the electric field inside need not be zero

 so let us say e inside is not equal to now in such a situation the electrons which we said move with a thermal velocity because of the presence of the electric field inside are also accelerated

 so let's say the electrons are accelerated the the velocity or speed with which they move in is still the thermal velocity but they are accelerated what is the result the result is that the picture that i gave you for the static condition roughly holds but because of the presence of the electric field on an average the collection of electrons would move or drift in a direction opposite to that of the electric field

 so the collection of electrons would move in a direction opposite to that of the electric field a simple analogy might help understand the situation supposing you are in a room and there are chairs it's a classroom and a few of you you your eyes are tied and you decide to move around in the room now since you cannot see you are likely to bump against the chairs you are also of course likely to bump against yourselves but i assume that for reasons that i will explain i i will assume that you don't collide with each other but collide with the static chairs now once you have collided with chair you obviously change your direction and start moving in another direction and again collide with another chair now if this situation where the what happened in case of static condition then after some time if you look at the positions of all the players in the room they would be essentially random which corresponds to the situation the average velocity is equal to zero now let me now assume that there is a door to that room where there is a sound signal that is coming up maybe somebody a friend of yours is playing flute there now then since you still cannot see you will be colliding but when after collision you want to change the direction of your motion you are more likely to move towards the direction from where the music is coming

 so what happens in such a situation after some time that the distribution is still roughly random but on an average the group of students who are there in that room they would drift towards the door and this is essentially the concept of drift velocity now when i told you that let us assume that you don't collide with each other the analogy is because of this in this case my colliding particles are electrons and the electrons as we know can be regarded as point particles when i compare their dimensions with data ions now since the electrons have negligible volume

 so the probability that they collide against each other is almost non-existent and because of that we assume that the electron interaction is neglected now
 so what happens to the expression for drift velocity in our situation
 so let us return back to this picture and i assume that i am considering a

parallel pipe with a cross-sectional area a and length l now what we are saying is this all the electrons which are within a volume a times l

so all electrons within a volume a times a will pass through the right this phase now in this picture this is the direction of the electric field which is also the direction of the current density and the electrons are on an average moving towards this right and that is the direction of the drift velocity which we represent by v d suppose n is my electron density then the number of electrons which are in that volume is obviously n into l into a

so this area is a and the charge that is contained is e times n into l into a well this being electronic charge the charge would be negative but in this case i am talking about the magnitude of the charge

so in this case my e is the magnitude of electronic charge which is of course equal to 1.

6 into 10 to minus minus 19 coulomb

so therefore the current density is given by q divided by a times t this is the amount that has passed through this surface in time t

so therefore this is given by e times n a has cancelled out i am left with l divided by t

so that is my e times n times the magnitude of v d now since the direction is opposite to that of the current density i write my current density j as equal to minus e times n times vd the direction of the current density is opposite to the direction in which the electrons are moving

so what i have basically done today is to define what is electric current realize that electric current is simply an alternative name for electric charges which are moving flowing we have pointed out that it is not a vector we defined a related quantity called current density and we realized that current density because it is a point function can be regarded as a vector and we started talking about the concept of a drift velocity which we will elaborate in more detail next time

you