hello

so let me begin this lecture by summarizing what we did last time and

so the first thing that we talked about is how does a source of emf uh works how does a common battery work the we said that the job of an emf is to supply energy to the rest of the circuit ah one thing i repeatedly want to point out electromotive force or emf is not a force what it does is to raise the energy of the positive charge carriers by taking them from a lower potential to a higher potential and the amount of work that the emf does is the emf multiplied by the current that it provides the emf is multiplied measured in volts and i is of course the numpy amperes then we gave you a method of calculating potential difference as you go along a circuit

so potential drop as you go along a circuit

so what we said is if you move in the direction of current flow there is a drop in potential as you cross a register for example if this is the situation this is the positive end and this is the negative end

so what will happen is this the current is flowing like this then let us call this a let us call this b then what we said is the potential at the point a is more than the potential at the point b by an amount i times r that is if you are going along the direction of current then the potential drops as you go along and of course the reverse is true if you move in the direction in which the electrons actually move which is opposite to the direction of current the potential is of course rise as you cross a potential resistance the amount of energy that a resistor absorbs from the source of m f is given by i square r and that is equal to v square over r

so this you have to be careful this v is the potential drop or potential difference between the ends of the resistor not the emf the potential supplied by the source of emf but this is the potential difference across the end ends of the register and this is of course valid for ohmic resistances and this is what we are going to be talking about most of it the towards the end of the last lecture we pointed out that resistances are major cause of power loss as you move along it transmission line see what actually happens is usually the generating stations are far away from the consuming stations and typically the towns cities and villages they would be consuming electricity and the power would be of course generated elsewhere now suppose p is the power to be delivered from a generating station to a receiving station and let us suppose there are cables which have resistance are on the way

so resistances of cables which carry the such currents then the power dissipated which let us call it power dissipated in cable is given by i square rc and since i is p by v

so it is p square by v square into rc and that's because power is nothing but current times the voltage in which it is applied

so what you need to do if you want to reduce your power loss is to supply the power at a fairly high voltage now but that causes a serious security concern because it can damage or be a source of hazard now incidentally though we are talking about the direct current transmission this is also true of alternating current transmission or ac transmission about which we might be talking about at a later stage but one of the advantages of ac transmission is you can build transformers which either step up or step down

so you could supply at high voltage and at the receiver's end reduce it there now of course this facility is not available for dc transmission

so you have to build you know send it on lower voltage but build booster stations on the way ah however the ac transmission suffers from serious disadvantages and will be talking about them later and particularly long distance transmissions always takes place by dc over thousands of kilometers and

usually they are by undersea cables
so anyway uh the this is one of the points that we should uh remember about it
so we discussed the source of the the fact that the resistances absorb power from the source of supply
so let us look at an example
so consider for example a circuit in which i have a current which is given to be 1.
6 ampere going in this direction and there is a resistance of 20 ohms on the way
so let me let me call this and a this and b and in this section of the circuit there is a source of emf but i am putting a question mark there because
so let me write it it's an emf source with no internal resistance
so the idea is this that what is given is when 1.
6 amperes of current passes in this direction this section of the circuit ac the section ac absorbs 64 watts of power that's the data which is given my job is to find out this how much of power is absorbed by this one not only that what is the polarity of the source of pmf supposing it is a battery which side is the positive terminal and which side is the negative terminal now vac is power which is 64 watts divided by the current which has been given to be 1.
6 amperes
so 64 divided by 1.
6 which is equal to 40 volts and likewise v a b now since this is just a resistance which is equal to i times r and i is 1.
6 r is 20 ohms
so that's equal to 32 volts now this immediately tells me that the since the potential difference between the point a and c is 40 volts and that between a and b is 32 volts the direction of the current has been shown
so that the point where it is entering in is at a higher potential
so therefore the voltage provided by the battery is 8 volts now notice that the section a b that is the resistance absorbs i square r amount of power which is 1.
6 square into 20 which is equal to 16 square is 2.
56 multiplied by 20 that's equal to 51.
2 watts but the total amount of power that the section a b has absorbed is 64.

so the power absorbed by the battery is 64 minus 51.
2 equal to 12.
8 watts now notice one thing this is the amount of power flowing into the battery now which is consistent with the fact that i had obtained that the battery is supplying an 8 volt and the current i is 1.
6 amperes
so therefore one point six into eight is twelve point eight as it ought to be more importantly since the battery is absorbing power that is power is flowing into it the side of the battery which is towards the point a should be positive it's that terminal should be positive
so that in effect what is happening is the battery is getting charged since we have been talking about power let us just do a small calculation that suppose just to give you an idea of how much is this power you know we frequently at home and particularly in offices we are very negligent in switching of power when we don't need it but let us look at some idea about how much power we might be wasting if we are careless now suppose i have a 100 watt bulb and let's suppose you are going on a vacation and by a mistake you forgot to switch it off for a period of one month
so this was kept switched on for one month let's say 30 days now let's look at how much money you would be actually wasting if you do that let me take a very

conservative price i will assume that each household unit of electricity costs 3 rupees what it means is it costs you 3 rupees per kilowatt hour this implies that if you put on a 1000 watt bulb for one hour you would be wasting essentially three rupees but let's let's see one of the things that we know is this that in india the household power supply takes place between 220 to 240 volts let me take 240 for convenience

so what we are given is v square over r where r is the resistance of the bulb is given to be hundred v square is two let me take v to be equal to two forty

so that is five seven six zero zero divided by r or divided by 100 is equal to r

so which means r is equal to 576 ohms

so what is also given is i times v is hundred

so the current that we are talking about is 100 divided by v

so it is 100 divided by 240

so let's keep it at 5 by 12 ampere

so what we have said is this that i have kept 100 watts per 10 hours

so what it means is per day which is 24 hours i am consuming 2.

4 units of electricity which works out to 30 days 72 units per month units meaning kilowatt hour at a conservative estimate of 3 rupees it is rupees 260 per month you'll be wasting of course nowadays incandescent bulb of the type that i discussed are going out of fashion giving way to new bulbs low wattage bulbs which are either lcd or led bulbs which consume much less power but have better luminescence but the purpose was not

so much to point out the amount of money that you lose but to tell you that given power and the voltage how to calculate data like the resistance of a bulb the current that is flowing through it etc continuing with our idea of bulb let me give another example suppose we are given two valves

so two bulbs one of power 60 watt and the another of power 90 words and they are to be put in 240 mains now there are two ways in which i can put it one of them is called series combination where you put the two resistance as end to end

so this is series combination about which will be talking about in this lecture in detail

so it is this that's r1 and this is r2 and this is the potential difference across them is 240 and we have said already what is the power rating of the bulb now when we say power rating of the bulb is 60 watts what it means is if you put connected across the line supply which i have taken to be 240 volts that's the amount of power it will consume in other words for the first bulb p1 i have v square over r1

so this means 60 is equal to 240 square divided by r

so solve for r 1 it is 5 7 6 0 0 divided by 60

so which is equal to 9 6 0 likewise the second bulb which is v square over r 2 equal to 90 that will lead to a similar calculation r2 equal to 640 ohms

so what we have said is this that which combination this is the series combination which combination will dissipate more power basically a series combination means that the same current is flowing through both there in a section of a circuit in which the same current is flowing

so therefore according to what we have learnt we have said when they are in series combination they drop across r one

so total drop v is equal to supposing current is i which is the same throughout

so that will be equal to i r one across the first register plus another term i r2 across the second register which will lead to the current being given by v divided by r 1 plus r add them up

so it is 240 if you add it up into 1600

so that is equal to 3 by 20 amperes

so that is one of the combinations and let us also calculate how much is my v1 and how much is my v2

so my v1 is 3 by 20 which is the current times r1

so 3 by 20 multiplied by 960

so that's equal to 144 volts and v2 will have a much lower one the same 3 by 20 into r2 and r2 are smaller and this turns out to be 96 volt if you add up these two you will of course get 240 as is expected

so what we are having is this that the power dissipated by the first bulb is equal to i square o times r1

so i was 3 by 20

so it is 9 by 400 multiplied by 960 that was the resistance

so if you do this calculation it works out to 21.

6 watts and a similar calculation p2 will give you 14.

4 watts

so total power dissipated will be 21.

6 plus 14.

4 equal to 36 watts

so this is what happens in a series combination when you put the 1 to n there is another type of combination possible and that is known as a parallel combination i will be dealing with both of them in detail in this lecture

so basically the definition of parallel combination it is very important that you understand what is parallel combination because very frequently one believes that because the circuit looks parallel it's a parallel combination that's not really true we will give you examples of circuit which looks parallel but is not really a parallel combination but

so what is the definition of a parallel conversation two resistances are supposed to be in parallel combination if the potential difference across both the resistors happens to be the same

so potential difference or voltage across the resistance are the same remember in series combination what we have said is the current that is flowing through both the resistances are the same

so that is the actual difference between a series combination and a parallel combination okay

so let us look at what type of combination we are talking about

so the combination is like this supposing this is my supply 240 volts as we said now what we do is to connect it like this

so this is r one and this

so notice that the potential difference between this pair of points is the same as the potential difference between this pair of point because the this or this is connected to this side of the battery this or this is connected to that side of the bed

so this is what actually happens

so therefore my voltage is the same therefore my current will be different because the resistances are different

so let us look at how much is the current i1

so current i1 then is since the potential difference is 240

so this divided by my r1 was calculated to be 960

so this is 960 that's equal to 1 by 4 ampere and i2 is 240 divided by r2 which was shown to be 640

so that's equal to 3 by 8 ampere now let us look at how much power is consumed in h

so this one clearly consumes i1 square r1

so power 1 is i1 square r1 and that's equal to 1 over 16 1 4 square times 960 and that's equal to 60 watts and p2 as you might expect i2 square r2 well i1 is

same as i2 is 3 by 8

so it is 9 by 60 64 multiplied by 640 that's equal to 90 but you remember that our power ratings were supposed to be 60 watts and 90 watts which means if you connected them across a 240 volt terminal then this is what would be the power

so this sort of works out

so therefore the total power consumed in this combination is essentially obtained by adding up the rated power

so total power consumed is 150 volts recall that in the series combination the amount of power that is consumed was only 36 watts

so it turns out that the parallel combination supposing these were bulbs and particularly these are very important when you use them in decorative lighting like christmas lighting or diwali lighting we use several strands of the wires which are in parallel combination and within each strand the bulbs are placed in a series combination as we have pointed out that within a strand bulbs being in series combination of course reduces effective brightness that a bulb could develop develop they deliver but the power expense becomes much less

so having discussed the series and the parallel combinations let us spend a little more time in trying to understand resistances in series and parallel

so we will be discussing resistances in series and parallel but let me start with the little more complicated one

so resistance is in parallel

so as i said that we define a parallel combination by this relationship that the potential drop across them okay is the same now what is the effect of that let me draw a picture

so this is a point a this is one of the resistances this is another resistance

so this is r1 this is r2 and this end is b

so what happens is this that supposing you want to go from the point a to the point b this is the point where the potential drop maybe it's connected to a battery source

so it's known now then you can take one of the many possible paths in this particular example you could go like this have the drop of potential across that come back and come back here alternatively you can take this path also in this case there are two parts but in principle there could be similar arrangement they look parallel but that's not the full story

so when i apply a potential difference across a b the same potential difference appears across all the resistors which are in parallel combination

so let us write down when a potential difference is applied across the combination that is from a to b the same potential difference appears across each branch

so i ask a question what is the effective resistance or equivalent resistance what is meant by equivalent resistance the equivalent resistances supposing this entire circuit that i have here this combination i am to replace by a single resistance then the current that is leaving a or entering b remains the same now remember when i had the branches there is a current coming in but then the current divides into two and in fact in this simple case you can realize because current is nothing but rate of change of charge

so whatever charge is coming in it is being divided into two paths

so therefore if the current on this is i 1 the current on this is i 2 then of course i expect i to be this is i to be equal to i 1 plus i 2 this is just a continuity of current

so by equivalent resistance i mean what should be the resistance with which i should replace the end this circuit such that the value of i remains the same

so effective resistance or equivalent resistance means

so a single resistance which can replace the combination such that i remains

the same now let us look at this in a little more detail notice one thing supposing delta v is the potential drop across any of these resistances because i have said if they are in parallel

 so let me emphasize here i am looking at parallel combination in this section if they are in parallel then delta v remains the same whether i am on this branch or on this branch since delta v is the same my current i1 is clearly delta v by r1 and current i 2 is delta v by r

 so therefore my current i equal to i1 plus i2 that is delta v by r1 plus delta v by r2

 so if i take delta v common it is 1 over r1 plus 1 over r2 supposing my equivalent resistance was our eq then i should have been because i said i remains the same

 so it should be delta v divided by r equivalent

 so if you compare this expression with that expression you get 1 over r equivalent is equal to 1 over r 1 plus 1 over r that is the standard formula for the parallel combination now i can easily extend the same thing to multiple resistances more than two because the principle is the same that potential drop across each resistance remains the same

 so all that will happen is supposing i have got r 1 r 2 r 3 etc the current in each branch will be given by delta v by i 1 delta v by r 1 delta v by r 2 etcetera and as a result my equivalent resistance for more than 2 situation would be 1 over r equivalent is 1 over r1 plus 1 over r2 plus 1 over r3 etcetera or which means a series 1 over m 1 over r i leave it to you to show that the value of req is smaller than the smallest resistance in the circuit

 so req is smaller than the smallest resistance in the circuit

 so let us look at now series combination recall i told you a while back that series combination simply means that the same current flows through each component circuit look at a situation like this that of course the simplest is i have point a connected to a resistance r one point another resistance r2 like this i can have any number of them this is b as long as the same current is flowing through this as we go through various resistances it is a series combination as a result the potential drop across a b

 so if let us call this delta v this is sum of potential drop across this one this is delta v 1 and potential drop across this delta v 2 and likewise this will be true for any number of

 so my delta v is delta v1 plus delta v2 which is equal to i r 1 plus i r 2 because same current passes through all of them

 so it is i times r 1 plus r 2 but if you have to replace this combination by a single register then the corresponding equivalent resistance would be simply this much

 so req in this case is r 1 plus r 2 and if i have n number of them then i have sum over i r i i equal to 1 but before i quit this discussion let me point out something supposing i give you a situation like this now if you look at this diagram it seems like parallel there are parallel lines connected but you look at it that if there is a current flowing through them it will be the same current which is flowing through

 so this is actually an example of a series resistance not parallel now since i have already obtained the relationship for the series and the parallel combination let me try to expand my scope a little bit and try to see how do they behave if i have combined situation its not very difficult let me take a very simple circuit suppose this is a point a this is a point b and this is a point c now look at this circle this is a combination of a parallel and a series combination

 so let me call this an example

so suppose a current i leaves the point a now of course since it is just passing through a resistance here

so current i would flow through this resistance which is let us call it r1

so the potential difference vab is given by the potential drop in this case is i times r1 now once it comes here meets the parallel combination then of course the current gets divided but the potential drop between these two points remains the same

so therefore vbc is equal to now you see this is i 1 this is i 2 because i know that the currents are different let's suppose this is r 2 this is r 3 but i have already told you that if the current in this section is i and this is true of this section also then this entire section you can replace by an equivalent resistance which is given by 1 over req equal to 1 over r2 plus 1 over r3

so this is the potential drop across v c is i times the r equivalent of this setting but r equivalent of this section is r 2 r 3 by r 2 plus r that is because 1 over r eq is 1 over r 2 plus 1 over r 3

so therefore req is there now

so what happens to v a c

so v a c is obviously v a b plus v b c potential drop across this plus the potential drop because that

so if i add it up this is i times r 1 which was already there plus i times r 2 r 3 by r 2 plus r

so the current can be obtained immediately if v ac is known to us supposing it is equal to v

so let us keep it as vac divided by r1 plus r2 r3 by r2 plus r3 you can simplify that and that will give you v ac times r2 plus r3 divided by r1 r2 plus r 2 r 3 plus r 3 r what i will do now is for the rest of this lecture i will give some illustrative examples of the way one calculates the problems connected with series and parallel combinations

so let us proceed with some typical simple ones and then we will gradually come to more complicated

so let me start with a problem of this type example

so suppose i have a circuit like this there is a battery here which is 8 volts let us take

so less r one let it let it be two ohms this is r two which is also equal to 2 ohms r 3 equal to 3 ohms

so let us number let us call this a this point b this point c this point d how does one solve such a problem now the first thing to know is in many of these circuits you will find it easy to first observe what type of combination do i have and to try to reduce this circuit gradually into simpler and simpler circuits of course this is not a complicated circuit anyway but nevertheless try to understand this

so one of the things that you realize is this that see when i have plane wires without any resistance there is no potential the reason is the connecting wires are always assumed to be resistanceless no resistance if there is no resistance there is no potential drop

so which means that this point and that point will be at the same potential likewise this point and that point would be at the same potential now remember that a and b will not be at the same potential because in going from a to b you will have to cross a resistance but since the potential drop across r2 is the same as the potential drop across cd potential that is potential drop across r3 by our definition of a parallel potential parallel combination r 2 and r 3 are parallel now if r 2 and r 3 is parallel

so let me write it r 2 is parallel to r3 not because in this diagram they are looking parallel but because the potential drop across their ends happens to be

the same this is important to realize the definition of a parallel combination is that different components of parallel combination have the same potential drop across each component and this is what i observe first now once i know that it's a parallel combination i can replace that parallel combination by an equivalent resistance
 so what is that equivalent resistance equivalent resistance of r2 with rna that is req is equal to r 2 r 3 divided by r 2 plus r 3 and in this particular example r 2 is 2 this is 3
 so 2 into 3 divided by 2 plus 3
 so that's equal to 6 by 5 ohms
 so this circuit is the same as this circuit this is r 1 which is equal to 2 ohms and i replace r 2 and r 3 by a single resistance of this type let us call this req and that is equal to six by five ohms and this was eight volts now notice this circuit has become very simple because r1 and req they are in series because the same current is flowing through them
 so therefore r1 in series with req
 so the effective or the new equivalent resistances is simply 2 plus 6 by 5 which is 16 by 5.

 so what it means is this circuit is finally replaced by a circuit which is has only a battery and a resistor
 so i have an 8 volt battery and a resistance which i have calculated just now to be 16 by 5 ohms
 so the current is immediately calculated that is the current supplied by the battery is immediately calculated which is equal to 8 divided by 16 by 5 which is simply equal to 2.
5 amperes
 so i have already found out that the current that is being supplied by the battery is 2.
5 ohms let us return back to our original picture now if this battery is supplying a current of 2.
5 ampere my question then is how much is the potential difference across a b and what is one thing the point a is at a lower potential than the positive end of the battery that is because the current is going like this and we are dropping the potential by i times r1 and how much is i times r1 the i times i is 2.
5 into 2
 so therefore what we find is that there is a voltage drop of 5 volt as you go from here to there which means this point a if i take this point to be at 8 volts plus 8 this point then is at 8 minus 5 that's equal to 3 volts now the point b is connected to this since this is my reference potential with respect to which i have taken the plus to be equal to h
 so this is also at the same zero potential
 so therefore v a b v a b which is same as v c d
 so let us write it down v a b is equal to 8 minus 5 which is equal to 3 volts which is also equal to v c d in my picture
 so let us return back to the figure again
 so this is three volt difference this is also a three volt difference
 so my current in this section of the circuit is 3 volts divided by 3 which is equal to 1 ampere the current in this section of the circuit because the potential drop is between these two points is 3 volts
 so 3 divided by 2 that's equal to 1.
5 amperes now notice this that my current i was 2.
5 amperes
 so therefore 2.

5 ampere gets split into 1.
5 year ampere and on it we will later on generalize this idea to situations where the there are more than two branches and see that we have certain laws which are in place let me give you a little more difficult example
 so let me look at this circuit
 so let us call this r1 let us call this r2 i take this battery to 21 volts this has 4 ohms this is 8 ohms in parallel with it well looking parallel at least i have r3 which is taken to be 12 ohms and r4 which is taken to be 8 ohms again and i connect them but my circuit has little more complication there is a switch here
 so supposing my switch is open as is being shown here now this problem is very similar to the problem which we just now did
 so what i have is that before the switch is closed
 so this part of the circuit is the material
 so i have r3 and r4 in series and r1 and r2 in series
 so r3 and r4 in series gives me 12 plus 8 equal to 20.

 so this will be equivalent to the following circuit
 so let me write down here before switch is closed r1 and r2 they give me an equivalent resistance of 12 ohms because 4 plus 8 and r3 and r4 gives me 20 ohms that is 8 plus 12.
 but then 12 ohms and 20 ohms are in parallel
 so the equivalent resistance req is 20 into 12 divided by 20 plus 12 that's equal to 7.
5 ohms this is 21 and you can calculate the current which is 21 volts divided by 7.
5 which is equal to 2.
8 amperes point is this is what happens when the switch is open now we would like to know what happens when this switch is closed the entire nature of that circuit changes i do not have time to do it in this lecture but in the next lecture i will take up the same problem and try to see what happens when the switch is closed
 so in this lecture what we have done is to basically point out two major types of connection that you have in electric circuits namely series combination and parallel combination what we pointed out is that combination of resistances in series is defined by the fact that as you go through various components which are in series the current flowing through each one of them will be identical parallel combination on the other hand has many branches and the current in each branch is different but what remains the same is potential drop across each of the members of the combination remains the same and this is the way and not by the visual picture of a parallel that you define what is a parallel combination we will continue and explore more about series and parallel combination in the next lecture you