welcome back

so let me begin by giving a summary of what we did in the last lecture

so first thing is we talked about series and parallel combination of resistances

so one of the things that i wanted you to understand is that these nomenclatures have specific meaning in fact i gave you an example of a situation where a resistance combination looks arranged parallelly but they are actually a series combination

so the way the it works is this that we defined parallel combination as a collection of resistances in which the arrangement is such that the voltage across any member of the combination is the same

so the way it works is this supposing this is a point a

so i have one resistance here another resistance here i could have any number of them actually third resistance here

so let us just call them r1 r2 r3

so what we are saying is this that the drop in the potential if you go through the resistances whether you go through this this or that is the same delta v

so this would mean that since the values of resistances are different the current in the branches would be different

so we will say that voltage across each member is the same but current carried is different

so voltage across is delta v supposing here i have i1 this is i2 this is i3

so expressions for delta v are either i1 r1 or i2 r2 or i3 r3 they are the same

so when you look at a combination the way to recognize whether it is a parallel combination or not is to check whether the voltage drop across various members are the same

so that's one the we next defined what is called a series combination

so that's of course a much simpler one

so there what happens is this that there are various resistances in that combination let's again call them r 1 r 2 r 3 and this is the point a to b now this is defined as a combination in which the same current passes through same current passes as a result since i is the same and here ours are different again

so therefore this is ir1 this is ir2 this is ir3 this is the drop across them

so therefore they drop delta v 1 across this delta v 2 across this delta v 3 across this

so the net drop across a b

so let us call this v a b is i times r1 plus r2 plus r3

so let us return to the example that we had started working out towards the end of our last lecture but couldn't complete it

so supposing i have a combination of resistances like this let's this was a 21 volt battery and what i had there was a switch which was initially open

so let us number them let us call this point a this is b this is c d and e and f

so what we said is this that when this switch is open

so this section doesn't actually do anything to the circuit but look at this pair of points the voltage drop across ce because c is connected to this side is connected to this side of the battery is 21 volts voltage drop across df is also 21 volts we are given some numbers uh to represent the

so this was 4 ohms this was 12 ohms

so i call this r1 call this r2 and this is r3 and this is r4

so r4 was 8 ohms and r2 was also it was let us look at what happened there

so if you look at it the current comes out from this positive terminal and part of it goes here part of it goes there

so let us call this is getting cluttered up

so let me use a slightly different ink let us call this i1 and since this is passing through r3 let us call this i3

so look at this if a current i is coming through this then clearly your i gets divided into i1 and i3 and because current is nothing but flow of charge and there is no accumulation of charge anywhere

so rate of flow of charge here plus the rate of flow of charge there must be equal to the rate of flow of charge which came through the circuit

so since we have said that the drop across this is the same as 21 volts

so what we notice is the following that here since this part of the circuit doesn't matter

so r1 is in series with r2

so in branch c r1 is in series with r2

so therefore this circuit has a net resistance of 4 plus 8 equal to 12

so let's call this r 1 2 that's equal to 12 volts and likewise r3 is in series with r4

so let's call this r34 that's equal to 8 plus 12 which is equal to 20 ohms now having done that you notice that this circuit is now reduced to a circuit like this

so this is 21 volts this is 12 ohms and this is 20 ohms but this 20 and 12 are now parallel

so we call this r 1 2 and we call this r 3 4

so we say r 1 2 and r 3 4 are parallel remember the formula for the parallel combination that i gave equivalent resistance

so the equivalent resistance of this combination is given by 1 over req equal to 1 over r 1 two plus one over r three four and that's equal to one over twelve plus one over twenty and if you invert this req will turn out to be equal to 15 by 2 that is 7 by 7.

5 ohms

so what i now do is this i draw a further equivalent circuit which is at 21 volts here and a 7.

5 ohms there and now i can easily find out how much current i was there because that is what is coming out

so which tells me that the current i which the battery supplied to the whole combination is given by 21 divided by 15 by 2 which if you work out it will become 42 by 15 which is 2.

8 amperes

so therefore if you look at the original circuit now

so what we said is just go one step back now if you go one step back what you realize this that this i which came in which was 2.

8 amps amperes got divided into this part and got divided into that part

so therefore the current in this section the current in this section

so this was 21 volts and we showed that this is 2.

8 amperes this is 12 ohms this is 20 ohms we call it i1 we call this i3

so this point is c d e f this was the situation where the a b were not connected

so in this case the drop across c ce is the same as the drop across df is equal to 21 volts

so delta v ce is delta v df is equal to 21 volts

so therefore my current i1 is 21 divided by 12 as r1 plus r2

so that's equal to 1.

75 amperes i2 is equal to 21 by 20 that is equal to 1.

05 amperes which of course agrees with our ah original current which is 2.

8 amperes now you can use this to find out the potential drop between the points c and a remember that a was here this was the point a

so now you know i1 the r1 was 4 ohms
so i1 times r1 is the drop across c2a c was at 21 volts
so the point a will be 21 minus i 1 times 4 you can easily calculate and find out that this v a was equal to 21 minus i1 r1 that's equal to 21 minus 7 by 4 into 4 that's equal to 14 volts and vb equal to 21 minus i3 r3 that's equal to 21 minus 21 by 20 into 12.
that's equal to 8.
4 volts now let us close that switch now when you close that switch the entire character of that circuit changes
so let's look at what is happening when i close that switch
so let us redraw that picture again
so this was a 21 volts battery i had a 4 ohms here r1 just indicate without this is r2 which was 8 on this side there was a r3 which was 12 and an r4 which is 8 again and i had this switch connected
so this was cd this is a this is b this is e this is f now let us look at what type of a combination is this first thing you realize is this that this when you close the switch point a and point b because this is a short this is a short because there is no resistance across this
so therefore v a must be equal to v b likewise v c is equal to v d and v e is equal to vf since c and d have the same potential a and b have the same potential this tells me that this 4 and 12 are parallel if you recall i had said that the way to recognize whether some resistances are in parallel or not you have to find out whether the potential drop across them is the same we can redraw the circuit in the following way
so remember that i had the 21 volt drop here and the circuit is essentially equivalent to the following situation this is r1 and this is in parallel with r3 and here i have an r2 in parallel with r4 the points with reference to original labeling is this is a point c or d as the case may be this the point is a this point is b this is a prime this is b prime they are the same points really a or a prime
so let us say a equivalent to a prime b equivalent to b prime and the last point is e or f as you desire
so since r1 is parallel to r3 my resultant is r13 equal to r1 r3 divided by r1 plus r3 and that's equal to 48 divided by 16 that's equal to 3 ohms likewise r2 is parallel to r4 and that leads to r24 equal to r2 r4 divided by r2 plus r4 they were all the same resistance
so this is 8 into 8 by 8 plus 8 which is equal to 4 ohms
so at that stage my circuit is this i have a three ohms here which we called as r13 and i have four ohms there which he called as r24 and this was 21 volts since r13 and r24 are in series my net resistance here is 7 ohms
so therefore my current is 3 amps now notice this thing the this point this was my point c this is my common point a or a prime and this was my common point e or f
so since 3 ampere current is reaching c then my drop across ca is 3 into 3 that is 9 volts and drop across a e c a and this is a e is 3 into 4 equal to 12 volts now you return to the original circuit let me redraw the original circuit again
so my current in this section ca is not equal to the current in this section cv in fact if we remember we called this one i1 this one i3 and this was i
so my i1 plus i3 that must be equal to the current supplied which is 3 amperes and we have seen that the drop across ca is equal to 9 volts
so i can easily calculate how much is the current i1
so current i1 is obviously 9 divided by 4 this was 4 ohms which is equal to 2. 25 amperes is equal to 12 volts
so if we call this i2 now

so that would be equal to 12 divided by 8 ohms that was the resistance of this
so that's equal to 1.
5
so you notice that 2.
25 ampere is coming in at c but 1.
5 ampere is going out through this section
so therefore there must have been a current in this section
so i a b which is the difference between the two because there cannot be any accumulation of charges there
so therefore iab must be this minus this that's equal to 0.
75 amperes now what you can do is you can do a consistency check by repeating this calculation here
so this drop was 9 volts you can find out how much is the current here and then similarly you can find out how much is the current there okay and you will find that the result would be the same that this minus this would be the amount of current that is flowing into the section at a b
so this gives you an example of how to calculate things in which we have parallel and series circuits
so let me show you some little complicated problems suppose i have a situation like this now what i will do is that instead of drawing wiggly line lines for resistances let me for the moment just draw them like this but i will tell you where the resistances are
so this is a this is b and what i am saying is these are all resistances and the upper part each is one ohm and the lower part of each is two ohms the connecting wires are of course not are resistances
so let us look at what can i say about this circuit
so look at this situation
so notice that here i have these two because there is no connecting remember that the connection to the circuit which means connection to external um battery or whatever is the source of emf is between a and b
so therefore if i look at this section and this section this is in series because whatever current comes through this that must come back to this
so one and o 1 are in series similarly 2 and 2 are in series
so therefore this section that i have got here these are connected to the next one
so this is one this is one this is two this is two
so this is the same as a two one resistance being parallel to a 4 ohm resistance
so i can redraw this circuit like this and then of course each of these sections will be connected to the next section and four of them will be there
so this is two ohms and this is four rows since two ohms is in parallel with four ohms i get the equivalent resistance to be equal to 2 into 4 divided by 2 plus 4
so that is equal to 8 by 6
so which is equal to 4 by 3 ohms
so this is nothing but a single 4 by 3 ohm resistance and four of them are connected in series
so therefore net resistance of this combination is 4 into 4 by 3 which is equal to 16 by 3 ohms let me take another example i will consider an infinite resistance network
so the network is like this you have resistances all of them have the value r and they are connected also my resistances are what is the effective resistance of such a circuit now in order to do that you have to make an observation remember i've said it's an infinite sector

so supposing there were an end to it now what do you mean by end of an infinite register section imagine the number to be n which is very large
so look at the last section
so this is let us suppose the last section see if i were to cut this like that then whatever remains there has the same structure as the other one the longer one and since i have said it is infinite it won't make any difference at all
so therefore if my equivalent resistance for the whole network is req then after they cut it out what remains is also req you take out an identical section from the end of an infinite network you are still left with an infinite network
so therefore the req which is the equivalent resistance what i am looking for is equal to the equivalent resistance of the infinite section to the left of this red line
so this is equal to req plus this sector which i have marked with red now let us look at what this actually means now notice what has happened as a result is this this req section has become parallel with this r
so req is parallel to r
so therefore the effective resistance that is coming from this section and that section this r
so that is simply equal to let's call this req the effective resistance req into r divided by r eq plus r
so this amount
so i will draw this again
so we are saying now that i have a resistance here which is this quantity that is let's call this req prime and of course these two are but this circuit is a simple circuit which is r r and r eq prime are in series
so therefore this is equal to r eq prime plus 2r and req prime i have already obtained a relationship which is req r divided by req plus r plus 2 r now if you solve this this leads to a quadratic equation
so let me write down req prime req r divided by r e q plus r in the denominator i have to add this to 2 r and that's equal to r uk let's simplify them which is r eq r and 2 r equals
so it is 2 r square plus 3 r eq in the numerator and denominator i cross multiply
so i get req square plus r into req
so therefore r eq square minus 2 r req minus 2 r square is equal to 0
so the solution for req is 2r plus or minus square root of 2 r whole square that is 4 r square plus 4 into 2 8 r square divided by 2 and that's equal to 2r plus or minus take away f4
so i get 2 times square root of 3 times r divided by 2 which is equal to 1 plus or minus root 3 r obviously i pick up the positive sign
so equivalent resistance of this infinite network is 1 plus root 3 times r once you know the value of r you can calculate now this idea that series resistances and parallel resistances i can find effective formula can be used to solve problems which do not look like the standard resistance network problem
so let me give you another example let us look at a resistor which has this shape this is a conical shaped resistor this section has a radius a and this section has a radius b and let us suppose that the length here is l now how do i find out the red supposing the material has a resistivity row how do i find out what is the resistance of such a sample of course we assume that the same current is passing through this each section which is circular image
so let us look at this now i can first assume or looking at what is the radius of the circle at a distance x from one of the ends
so this is what i am looking for this distance is x now this is linear
so we write down the radius of that section at a distance x is given by a plus

b minus a over l multiplied by x
 so supposing at that distance i consider a small cylinder of width dx
 so my resistance of that section d r at x will be given by rho times the length which is of course dx divided by cross sectional area which is pi into this radius square which is a plus b minus a by l x h square
 so what i do is this to find out how much is r rho over pi is of course a constant number i integrate this quantity dx divided by a plus b minus a over l times x whole square and the x is from 0 to l this is a straightforward integration i don't go through every step of that integration and you can find out immediately that this quantity is given by rho by pi into b minus a over a b and that's equal to rho by pi l times or l over a l is the length you notice that supposing a were equal to b then i will get the resistance to be given by rho l by pi a square which is what i expected for a normal cylindrical conductor another example i will give you where again i use the same principle of adding up resistances but this time with a slightly different application suppose i have a stack of aluminum and graphite
 so let me draw that
 so this is a stack of aluminum followed by a stack of graphite having the same cross section
 so let us say this is the length of aluminum section this is the length of carbon or the graphite section and the data that is given to us are the following that the resistivity for aluminum at 0 degrees is 2.
75 into 10 to the power minus 8 ohmmeter and its alpha value alpha aluminum that is the temperature coefficient of resistivity is 0.
004 per degree centigrade the corresponding data for graphite is 5 into 10 to the power minus 5 ohmmeter and alpha for carbon is negative 0.
0005 per degree centigrade now see this is essentially a series circuit because any current flowing into lets say aluminum will also pass through the carbon if there is a complete circuit now what we are looking for is what should be the ratio of the lengths of aluminum section to the carbon section
 so that the temperature coefficient of the combination will be zero now what it means is this that supposing i am looking at the resistance of the aluminum section at a temperature t plus the resistance of the carbon section at a temperature t
 so i get resistance of aluminum at 0 degrees into 1 plus alpha a l into delta t plus resistance of carbon at 0 temperature 1 plus alpha carbon into delta t now what we are essentially looking for is this that what should be the length of the ratio of the length of l aluminum to l carbon such that the this quantity is independent of temperature what it means is i am looking for r a l plus r c that should be identical to r a l 0 plus r c 0 now this were
 so what i require is that the contribution from the temperature dependent part of these two should cancel
 so what it means is r aluminum 0 alpha aluminum times delta t is i should have written as delta capital t equal to minus r carbon alpha carbon into delta t now remember my resistance is proportional to the length and inversely proportional to the cross section but in this case my cross section is the same
 so what i require is that alpha aluminum times well i can put a row r aluminum 0 is raw aluminum 0 times length of aluminum delta t would be cancelling out from both sides equal to minus alpha c rho c 0 times lc the corresponding data are given that enables you to find out what is the ratio of l aluminum to l carbon and that works out to l aluminum divided by l carbon is approximately 227
 so these were examples where the series and parallel resistances were used let me give you a final example in series and parallel combinations let's look at a circuit like this okay there are too many of them well let me number them this

is r1 this is r2 this is r3 this is r4 this is r5 let's call this r6 r7 r8 r9 and r2 doesn't look like a series or parallel combination but let us try to look at this a little more carefully
 so all that i need to do is whether to observe whether the same current is passing through or is the same voltage between two ends if it is former it is a series resistance if it is later its a parallel resistance
 so let us look at whats happening now notice here this point and this point these two points are at the same potential okay and this is a common point
 so which tells me r4 and r5 are parallel combination
 so let us write down r4 parallel to r5
 so let us denote that equivalent resistance to be r45
 so i will remove this section and put a r45 there now the moment i have removed this section and put r45 there i notice r2 r3 and r45 are in series
 so r2 r3 and r45 are in series
 so this section now this this and r45 here
 so our equivalent will be r well this was already 4 5 and i add 2 3
 so let's call this i r 2 3 4 5
 so this r 2 3 4 5 is obviously parallel with ourselves
 so i write down that that this is parallel there now once we have done that let us call that since the numbers are going on increasing let us call that r 7 prime now there what i do is this that i replace this whole thing with the following circuit is becoming little clumsy
 so let me redraw the equivalent circuit at this stage this is v i had r1 there this we call it r10 this was a r8 and an r6
 so this is r10 r8 this is r6 and this we had called it as r7 prime and there was a r9 hanging in here
 so what do we have here clearly r8 and r6 are in series r6 and r8 in series let's call it a single resistance r68 not only that notice that r10 and r9 have common points
 so therefore r9 is parallel to r10 this will call it as r 9 prime
 so my circuit at this stage looks like this this was r 7 prime this was r 1 this is r9 prime and this is r68 now look at this circuit now
 so what we find is that r 9 prime and r 6 8 are in series and this combination whatever you want to call it let's call it r689 this is parallel to r seven prime
 so therefore i can replace this with this resistance an equivalent resistance whatever you want to call it
 so let's say it leads to sum r prime and then my r prime and r1 are in series
 so therefore you notice a very complicated looking circuit has been reduced to series and parallel combination it is not true that always we can reduce any circuit to series and parallel combination there are more complicated circuits for which we will find out the rules of how to do it in the next lecture but let us proceed with whatever we have been doing now
 so far i have talked about resistances in series and parallel the only other element of the combination of circuits that we have been using are batteries
 so batteries are cells as they're called
 so the question is this that can we think of putting more than one battery in a circle in other words are the combinations like cells in series and parallel possible i will of course give you more examples of this later but let me try to define what is meant by cells in series and parallel
 so first let's talk about cells in series now this has great practical applications if you look up for example a laptop now you will find that the laptop batteries are not single batteries in fact what you have in the laptop is a collection of cells some in series combination and some in parallel

combination in fact in many household applications you use more than for example a normal torch light cell you don't use one battery you put two or three cells end to end with the positive of one being connected to the negative of the next one

so that is an example of something being in series this is routinely done in all appliances at home in in your remote for example in your remote you will find there will be two aaa batteries which are put in parallel

so let me first talk about cells in series now the cells in series are like this supposing i have an enf e1 with an internal resistance r1

so this is your first battery i will give you the way the combinations are used normally that is positive end of 1 being attached to the negative end of the next one

so therefore this is the way we would have it

so let's call this one e2 and internal resistance

so let us find out in nomenclature

so this is a this point is b and this point is c now what i am actually going to do is this i am asking the question is it possible to replace this combination with a an equivalent cell in that is is it equivalent to between a and c having a equivalent combination like this this is ac and if you like i will call them as e equivalent and r equivalent if it is possible to replace them how do i do it now let us look at this let us let us look at here

so what is vc now if i assume that the current is flowing like this here and is coming in like this then i look at the way the potential develops as i go from c to a

so i start with v c since this is in the direction of current i have a drop of current i r2

so current is the same

so i r2 then i am crossing a battery from negative to positive

so my potential rises by an amount e2 i proceed further have a further drop of i r1

so minus i r1 and once again my potential is raised here in going from negative to positive to e1 until i have reached the point a

so this is equal to va

so what is my va minus vc

so va minus vc is e1 plus e2 minus i r1 plus r2

so look at what have i done if instead i had a single cell with an effective emf of e and the total internal resistance of the pair where r1 plus r2 then i would have the same potential drop across the points a and c

so therefore i can replace the system by an equivalent emf which is e1 plus e2 and effective internal resistance which is simply the two resistances added in series i will in the next lecture talk about how to use cells in parallel i told you that if you look up normal torch light you put cells in series but look up your remote at your home you will find that the two positive ends are going together on the same side and they are in parallel

so i will obtain an equivalent emf and resistances for the parallel combination next time and i will also answer the question which you must be already raising within your mind that why should i use cells in series for instance why not i originally take a battery of a higher emf and of course having a little more internal resistance and

so therefore what is the purpose of using more than one cells instead of using a single cell of a higher emf and different registers we will try to answer that question also as you go along next time
you