

let me begin today by summarizing what we did in the last lecture
so as you recall we have been discussing various properties of material the electrical properties of a material

so for instance one of the things that we did is to discuss what is drift velocity and we had defined drift velocity and obtained its relationship with the current density and showed that the current density j is related to the electron drift velocity by minus n_e times the drift velocity minus sign because we talk about the electrons velocity and not the velocity of the charged carriers which was taken to be positive while formally defining the direction of current and we had obtained a relationship between the drift velocity and the applied electric field and the relaxation time by a relationship like this $e e \tau$ over m

so last time we also defined a new quantity which is called the mobility and we said that mobility qualitatively tells us how easy it is for electrons to drift when an electric field is applied and one defines mobility as a positive quantity which is the ratio of the magnitude of the drift velocity to the applied electric field and in connection in terms of the relaxation time the drift velocity expression as you can see it because v_d is proportional to the electric field strength

so this is nothing but $e \tau$ over m where τ is the relation of time the mobility is rather a small quantity in case of metals because we have seen that the τ is of the order of 10 to the power minus 14 seconds or

so or minus 14 minus 15 seconds and the electron charge is 1.6×10^{-19}

so in spite of the fact that the mass of electron which is about 10 to the power minus 30 is in the denominator we still get a number which is of the order of a few you know tens of centimeter square per volt second we in fact calculated for copper it was found to be 40 to 45 centimeter square per volt second we said that this is low compared to the mobility of the charge carriers for instance in case of semiconductors and that is primarily because there being too many charge carriers in case of the metals the frequency of collision is lot more and as a result we find that the mobility is affected the drift velocity is small and

so this quantity in case of semiconductors is somewhat large in fact we made a statement that large mobility is required for semiconductor devices to function smoothly we also obtained a relationship between the conductivity and the mobility from our expression for the conductivity in terms of the relaxation time and density etcetera that was n_e square τ over m and that gave us that this is nothing but $n_e \mu$ now in case of semiconductors about which we will be discussing in detail in later sequence of lectures we have two types of charge carriers ah there are of course these electrons which are which contribute to the current but in addition there are vacancies of electrons and these vacancy sites they also move contributing to current and these vacancies behave like positive charges and they are called as holes and for semiconductors the conductivity expression is given by n_e times μ_n that is the electron density number density times the mobility of the electron plus the hole density which is usually denoted by p times μ_h and these numbers are substantially bigger than larger than the num corresponding numbers for the conductors for instance for silicon we had stated that the electron mobility is of the order of 1400 centimeter square per volt second and for the whole mobility is about 450 centimeter square per volt second now this is obviously much larger compared to what we said in case of the conductors the next thing that we discussed is about the linear relationship that exists between current and the applied voltage for a wide class of conductors and these are known as a ohmic conductor and the

corresponding law is called ohms law

so ohm's law is stated as the relationship between applied potential difference and the current which is linear and this is given by v equal to ir or stated in terms of the current density this is j equal to σe this ohmic relationship is going to be quite useful to us in our next few lectures because we assume that the resistances that are given to us particularly in labs etcetera are usually ohmic though we did discuss the departure from linearity that exists in several conductors another thing that we talked about is the fact that the resistance or resistivity of a material it depends upon the temperature in which the material is kept and we found that for many conductors there is a linear region that is the with increase in temperature the resistive resistance or resistivity rises and the primary reason is this that as temperatures increase the ions in the solid they start vibrating and they don't stay put in their mean position and of course there is an increase in the thermal velocities also but more importantly the ions which are fixed let us say at absolute zero they start vibrating as a result the frequency of collision increases and that's the reason why the relaxation time decreases and the corresponding label conductivity also decreases and the resistance increases and the relationship in the region where the resistance increased linearly with temperature is given by ρ_t equal to $\rho_{t_0} [1 + \alpha (t - t_0)]$ now this is in the linear region this is what we normally discuss we made a statement that in case the linearity is not valid to this term you may have to add the quadratic and the cubic terms as well

so now what is t_0 is unimportant because as long as you are in the linear region then you can choose any point as your reference point and then calculate the temperature ρ_t resistance ρ at a temperature t we are starting from your reference temperature resistance the last thing that we also did is to talk about the color coding in carbon registers this is these are standard registers which are available in the laboratories and sold in the market and on them they have a color band usually having four bands out of this out of which the first three represent the value of the resistance and the fourth one represents what is the tolerance that is the \pm to what extent you can take those values to be correct the error bars and that is what you from that you can read out the value of the resistance that is available in the laboratory and I had also talked about some ah quick mnemonic one remember uh these color coding now before we proceed let's talk about a few examples and for instance last time just before we concluded the lecture we wanted to find out that given alpha value of alpha which is about 0.004 .

0.004 per degree kelvin or centigrade doesn't matter for copper at what temperature at what temperature ρ will double its of course fairly trivial but so what I want is ρ must have twice its zero temperature value and that is given by $\rho_{t_0} [1 + \alpha \Delta t]$

so which tells me immediately that 1 is equal to $\alpha \Delta t$ or in other words Δt is equal to $1/\alpha$ which is $1/0.004$.

0.004 and that is 250 degree centigrade well assuming my ρ_{t_0} is resistance at 0 degree centigrade the usefulness of this linear relationship particularly in substances such as platinum or necron which have admirable linear relationship or variation of resistance with temperature is that you can use this to find out uh the temperature of an of an unknown unknown temperature of a heat bath and that is simply finding out that uh what is the resistance like at the temperature at which you do not know and comparing it as its resistance with a uh normal level

so these are the things that we talked about aspect let us look at a slightly different aspect of the coefficient temperature coefficient of register now we

know that when we apply heat or that it increase the temperature of let us say a and wire now we have of course made a statement that its resistance increases but we also know from our discussion of heat that not only the resistance increases whenever increase the temperature of a substance the length also increases

so there is a there is a change in the length there is also a change in the volume which means there is a change in the cross section now that would simply imply that our relationship where we said that resistance are for a given material is simply given by given by R_0 into one plus alpha t if resistivity follows this formula resistance for a sample will also follow the same formula now the question then is that why is it that we do not talk about the change in the lengths which are associated with the increase in temperature of a material now before we go to that try to let us recall our discussion of heat

so we know that since we have used alpha as the temperature coefficient of resistivity which is also normally used in our heat and thermodynamic scores as temperature coefficient of increase in dimensions but let me say that we will use that as the beta

so beta let it be the temperature coefficient of linear expanse that is l is equal to l_0 into 1 plus beta t i know that the volume also increases and the corresponding expression for the volume increase is v_0 into 1 plus gamma times delta t where gamma is the temperature coefficient of volume expansion and two if you substitute the relationship between the volume and the length now this can be written as ah supposing i take a rectangular parallelepiped as my material i can write this as l_0 cube into 1 plus well

so l_0 cube 1 plus gamma times delta t is also this quantity cube

so that gives me that gamma to be equal to 3 beta this is actually something which you have done in your discussion of heat and thermodynamics now that immediately tells me that the area of cross section which is another quantity which is of importance when we discuss the resistance of material because we had seen that the resistance is linearly proportional to the length and inversely to the cross sectional area

so my area then becomes this quantity divided by that quantity which is l_0 square into 1 plus 3 beta delta t divided by 1 plus beta delta t which is approximately if you expand the denominator in terms of the binomial and this is approximately equal to a 0 into 1 plus 2 beta delta t

so thus with the increase in temperature my length increases by this formula my area increases by that formula but if you recall when we wrote down the temperature coefficient and calculated change in the resistance when i increase the temperature we did not worry about these things now what is the reason for that and is it always justified

so let us look at that part

so first thing is let us look at the resistance to be equal to ρl divided by a this relationship now

so therefore if i can consider what is the change in the resistance when i increase the temperature

so let us say that the change in the resistance is delta r now which is delta of this right hand side now this i can write as l by a into delta rho plus rho by a into delta l this is just a normal chain rule differentiation type then rho l delta of 1 over a

so that's equal to minus delta a divided by a square because a is in the denominator

so that is simply l by a delta rho plus rho by a delta l minus delta a rho l delta a by a square

so let me divide both sides by well this is let me divide both sides by r

so that guy i get Δr by r now remember all that i am doing is to divide both sides by ρl by a

so i get uh three terms as uh from there i get $\Delta \rho$ by ρ and this term will give me Δl by l and this term will give me $-\Delta a$ by a^2

so if you want to consider all the three components together that is change in the length change in the area and everything then this is the expression that you must talk about but why is it that it is justified in most of our deliberations to neglect these two terms now that's easily realized by looking at the relative magnitude of these things

so let's look at for example for what happens in case of copper i get $\Delta \rho$ by ρ and that is supposing my temperature coefficient is α and i am looking at a temperature Δt more than my reference temperature then i get that this is $\frac{\rho_0}{\rho} (1 + \alpha \Delta t)$ minus ρ_0 divided by ρ_0 and this is approximately equal to $\alpha \Delta t$ and if you know what is the magnitude of α which you can look up from your standard tables this is about 4.3×10^{-3} now if you look at the corresponding thermal expansion coefficient of length for copper then you find that this quantity your β it's much smaller actually α as i said is 4.3×10^{-3} but β typically is of the order of 2.5×10^{-5}

so that tells me that my Δl by l is of the order of two point five into ten to the power minus five and if you look at Δa by a^2 that happens to be about five into ten square minus five and that is the reason why we usually neglect these two contributions but that doesn't mean there are no situations where these are actually negligible for instance if you look at a column of mercury supposing i have a column of mercury in a glass tube and let us just for fixing our ideas let's suppose this is a 10 centimeter height now if you look at the corresponding numbers for α and β for mercury you find that α that is the temperature coefficient of resistivity this is for mercury is about 0.309 and β is smaller than α but nevertheless it's still 1.8×10^{-4} which is about 50 percent of that value now i don't really need to worry about the Δa part because the base roughly remains constant because i am not really considering expansion of the mercury here but i am actually going to because the mercury is contained in a glass tube

so therefore the base being made of glass it the cross section remains the same so therefore what i have to do is to only consider the two terms that we talked about namely Δr by r is $\Delta \rho$ by ρ plus Δa

so so this is the point here now i can calculate given β what is the new length what is the this length like so this is given by your $\alpha \Delta t$ plus $\beta \Delta t$ now look in this situation where α and β are comparable quantities though β is much smaller than α in this case now i will still have a contribution from this term because this is small but not that small this is just half of that so therefore in situations like this one should also worry about what happens in this particular case to the change in the length of course the since this is a very special case of a liquid metal and the its container is glass which is an insulator i do not worry about the cross section expansion at all while discussing the analogy with the water water in a tube we said that it is necessary that i need a mechanism see for example i gave the example of a tube which was closed at one end and and there was water flowing in the pipe this is what happens in a municipal piping system that the water is supplied to your home which is continuously there right at the tip of your water faucet but no water flows out until you actually open your tap now just like that you need to

so therefore what i have to do is to only consider the two terms that we talked about namely Δr by r is $\Delta \rho$ by ρ plus Δa

so so this is the point here now i can calculate given β what is the new length what is the this length like so this is given by your $\alpha \Delta t$ plus $\beta \Delta t$ now look in this situation where α and β are comparable quantities though β is much smaller than α in this case now i will still have a contribution from this term because this is small but not that small this is just half of that so therefore in situations like this one should also worry about what happens in this particular case to the change in the length of course the since this is a very special case of a liquid metal and the its container is glass which is an insulator i do not worry about the cross section expansion at all while discussing the analogy with the water water in a tube we said that it is necessary that i need a mechanism see for example i gave the example of a tube which was closed at one end and and there was water flowing in the pipe this is what happens in a municipal piping system that the water is supplied to your home which is continuously there right at the tip of your water faucet but no water flows out until you actually open your tap now just like that you need to

so therefore what i have to do is to only consider the two terms that we talked about namely Δr by r is $\Delta \rho$ by ρ plus Δa

so so this is the point here now i can calculate given β what is the new length what is the this length like

so this is given by your $\alpha \Delta t$ plus $\beta \Delta t$ now look in this situation where α and β are comparable quantities though β is much smaller than α in this case now i will still have a contribution from this term because this is small but not that small this is just half of that

so therefore in situations like this one should also worry about what happens in this particular case to the change in the length of course the since this is a very special case of a liquid metal and the its container is glass which is an insulator i do not worry about the cross section expansion at all while discussing the analogy with the water water in a tube we said that it is necessary that i need a mechanism see for example i gave the example of a tube which was closed at one end and and there was water flowing in the pipe this is what happens in a municipal piping system that the water is supplied to your home which is continuously there right at the tip of your water faucet but no water flows out until you actually open your tap now just like that you need to

provide a mechanism for pushing these electrodes

so that when you put your switch on which is equivalent to opening up a cap what you find is that the current or the electrons in this case will start flowing now the question is this that what was supplied by a water pump there what is the corresponding quantity here now for instance one of the mechanisms by which this is done is by having a battery in a circuit

so basically what happens is this that like I have a pump which is pushing the water now in order to establish a current I need something which will actually push it now let us see what actually happens

so what I have is a battery which provides this mechanism I will briefly discuss how this is done but it is something like an electrolytic cell usually a dry cell but where there are two terminals now what actually happens you have seen your standard batteries at home the 1.5 volt double A batteries or AAA batteries now what you find is that there is an end which is marked with a positive that's a positive terminal and this side is a negative terminal now actually inside this there are two electrodes and one of them

so what is known as cathode is connected to this positive electrode I must alert you at this stage that in your discussion on electrolysis you have heard that cathode is the negative electrode and this is this causes a lot of confusion because that is true in case of electrolysis where we pass the electricity to split the you know the solution into its ions now what happens in this case it is the chemical which splits and approach these things

so because of that the nomenclature cathode and anode have slightly different context meaning in both these cases it's much better because of that to stick to our nomenclature one is a positive terminal and the other one is a negative terminal

so so this is let us say the positive terminal that I have now so the positive terminal is that terminal when you connect it to an outside and this is passing through some resistances let us call it load for the moment and this is your seat of the pumping mechanism which we have called that now the current flows from the positive terminal through the load and comes there what actually happens is that since I know that the charges which flow are actually electrons

so basically instead of the positive terminal being a point from where the positive charges flow out actually this is where the electrons actually enter in now

so what actually happens is this

so let's still stick to our nomenclature of the positive charges carrying a current I mean all that you know is that direction of electrons would be exactly opposite but supposing we still talk in that language now you see what happens is this that when this positive terminal when these positive charges flow from the positive terminal through the load and they can come and come at the other end which is the negative now at that stage these charges have to be pushed up up the potential hill see because they they have come down the potential and let us not worry about at this moment what the load does but it has come there now if you want to maintain a current then what you have to do is to inside the battery you have to push them upward now a mechanical analogy will help

so suppose I have this following situation supposing I have some marbles which are at a certain height it's moving there and let's suppose there is a small orifice through which the marbles drop down

so since the marbles are continuously coming in as long as you are pushing from here the marbles will come through this but once it has come to the ground there is no way it is going to return back

so what we do is this that we have a person who is standing at the ground who actually picks up these marbles and put them up there and that is the only way you can continue a regular circulation of marbles in this mechanical analog that we have given

so battery does exactly the same

so what it does is these positive charges which flow there and arrive there so it needs to provide additional potential energy to it

so increase its potential from here to there and that's the job of a pump

so the this is this is the job of a battery and this quantity the battery is there which because of this analogy that i have given it looks like there is some force which is pushing it up and because of this unfortunate analogy this came to be known as a seat of what is known as the electromotive force insert emf in tune with our analogy this source of emf will do work because it is removable lifting it up or increasing its potential energy by moving the um charges from a lower potential to the upper potential to a higher potential

so so the short this moves charges in this case positive charges from lower potential to higher potential and

so therefore this source it has to do work and and if you define the emf as the amount of work you need to do to lift a unique unit charge then i define my emf as work done per unit charge now notice this is doesn't even have the dimension of a force but nevertheless this is called electromotive force

so this is equal to this is equal to suppose work is represented by w

so this is dw by dq and who the units as you can see this is work

so therefore it is joule per coulomb which is called a volt

so this emf is not a force but emf provides a mechanism to continuously lift the potential energy of the positive charge

so that it can start continuously flowing

so therefore let us quickly summarize what we have learnt regarding our flow of current in a through a resistance

so consider a typical resistor of length l

so supposing the electric field direction is this by that i mean this is at the higher potential and this is at a lower potential of course the current density direction is also this the various relationships that i have got are the following i have e equal to v divided by l which is simply the electric field being potential difference per unit length the current density is related to the electric field by j being equal to σ times e alternatively my e is equal to ρ times j now i know that the current i is related to the current density by j times the area

so if we look at these relationship we get the following we get e equal to v by l but e is also equal to ρj these are magnitudes i am writing down and

so this is equal to ρj j is current i divided by a

so therefore my potential difference is related to the current by this relationship that is given by ρl over a let's put this dimensional quantities and quantities specific to the sample dimensions times i now this is the quantity which you call as the resistance and is usually denoted by r

so i find that r is equal to ρl over a that is the resistance of a sample is proportional to the length of the sample and is inversely proportional to the cross section then ideal source of emf provides a constant potential difference or constant voltage across its terminals now this is irrespective of how much of current flows there

so let me look at this section of a circuit supposing i have a source of emf and let's say there is an internal resistance and this is my battery

so let me represent it the way i have been doing

so this is emf e this is the internal resistance r this is the point a and this

is point b for definitiveness let me take that this emf is 10 volts

so this is the positive end of the battery this is the negative end and suppose i am interested in finding out what is the potential difference between the points a and b

so what is ΔV_{ab} let me define an intermediate point which is c it really doesn't matter whether you put the internal resistance to the left of the battery or the right of the vector for the purpose of illustration the result turns out to be still the same now clearly the potential difference across a b is the sum of the potential difference across ac and c

so let me write this that ΔV_{ab} is ΔV_{ac} plus ΔV_{cb} now had there been a current in the circuit and suppose that this is the current which is flowing from the positive terminal out then this would have been this term would have been i times r plus of course ΔV_{ac} ΔV_{cb} but because there is no current

so this term is 0

so i am left with simply ΔV_{cb} but that is nothing but 10 volts now whatever i have said is true provided there is no current in the circuit in other words if it is an open circuit if the circuit is open

so the open circuit voltage is 10 volts of course if there were current in the circuit the voltage that will be available across the point a and b will be smaller by the amount i times the internal resistance r let me take a specific example i take the same battery but let us say that this is my source there is an internal resistance here

so let me just mark it with a block to show this is my battery and there is a load that is the outside resistance through which i am connecting this let us just call this r_l this is the load let me give some numbers supposing the internal resistance is 1 ohm and let us say the battery provides 10 volts open circuit voltage then \mathcal{E} and let me let me say that this load is 4 ohms now look at what happens there

so the net potential difference now is i can go from any point to come through it

so therefore V will be equal to i times r total now notice that since i am essentially in the same path the current cannot change in that path

so whatever is the current it will first true go through r_l then through this

so therefore this will be equal to i times r_l plus r and that's equal to 10

so therefore my current is 10 divided by 4 plus 1 is 5 which is equal to 2 amperes coming back to what is the difference between potential difference between the point a and the point b

so you not notice what has happened there

so \mathcal{E} since a 2 ampere current is passing the i have an additional drop of 2 amperes multiplied by that

so the the

so therefore this is V_{ab} is i times r_l if you like you can do that and that's equal to 8 because i is 2 amperes r_l is 4 now another way of looking at it is you go to this intermediate point c that i talked about

so then we say that look V_{ab} is V_{cb} minus V_{ac} and that's equal to 10 minus 2 into 1 because 1 ohm is the internal resistance which is also 8 as it would be

so let me continue with this and try to tell you how does one find the potential and this is very important because lots of students have confusion on how to go about let me do that by an example

so once again i take a battery internal resistance

so let's suppose the internal distance 3 ohms and my battery as before is supplying 10 volts and let us suppose that i have a current this i have actually measured and there is a load there through which the current that passes okay is

let us say θ .

5 ampere

so look at what happens there the potential difference that exists between the two ends of r_1 is also the potential difference between that exists between these two because these wires are supposed to be resistance

so therefore if the current passing through is θ .

$5 i$ times r is the potential drop here which is 3 into θ .

5 which is 1 .

5

so that potential drop between these two points is 8 .

5 volts but you see it is the same current which is passing through r_m

so therefore 8 .

5 volts divided by r_1 is equal to θ .

5 which tells me that the load must have been 17 ohms how does one do it systematically

so the way to do it systematically is the following

so let us repeat that problem in a slightly different manner

so i have suppose i have a circuit of this type i have two resistances r_1 and r_2 and these are in series and connected with the battery battery may have an internal resistance but they are not particularly worried about that and

so this is my battery which provides an emf e

so let us look at what happens when i look at various points like $abcd$ and try to find out what is the potential of a particular point related to the other point let us suppose we are going against the direction of the current now in this particular case because there is a single battery and this is the positive terminal the current is obviously moving like this

so let me start at the point c and start moving in the direction opposite to the current

so notice this that as i cross r_2 reach the point b my potential will rise by an amount i times

so let me write this way that v_c plus i times r_2 is equal to v_b continuing like this let me go to the point a

so my v_b plus i times r_1 that is the rise in the potential as you move from b to a and that is equal to v_a

so therefore what i get is v_c plus i times r_2 equal to v_b but v_b is v_a minus i times r_1

so that tells me that v_c minus v_a or rather i should say v_a minus v_c is i times r_1 plus r_2

so therefore the current i is given by v_a minus v_c divided by r_1 plus r_2 but you observe that v_a minus v_c since these are connected to the battery by the resistance wire

so this is equal to whatever emf is supplied by the battery this is not exactly the open circuit here because there is a current in the circuit

so there would be a drop through the internal resistance but this is given by the emf available to the circuit divided by r_1 plus r_2 and as i have pointed out if instead of going in a direction opposite to the current if you travel in the direction of current all that you have to do is to do a similar exercise by saying every time you cross a resistance the potential drops

so what is the effect of the internal resistance

so the internal resistance of the battery reduces the voltage that a battery may be able to supply by an amount i times the value of the internal resistance and obviously this means that if a battery is in a circuit which has a current flowing through it the effective voltage that it provides becomes reduced

so let me give an example where we calculate this on a slightly different

problem

so let me take an example where i have two batteries

so this is one battery this is the internal resistance is r_1 there is another battery but this time i have written it in a slightly different way that is the polarities are different and

so this is second battery

so let us call this r_2 and normally a seat of emf is shown in pictures in this fashion going from negative towards positive because you are increasing the potential energy

so therefore let us call this e_1 which is equal to 2 volts battery and e_2 is equal to 4 volts and i have given some data let me take r_1 to be 1 ohm and r_2 to be 1.

5 and this whole thing passes through a load resistance r_1 and let us take this to be equal to 5.

5 now let us look at this problem this is a problem where i am interested in finding out how much is the current now there is no particular place where i can start with

so let me start here now having done that i would go look at this situation here this is purely intuitive i have a four volt battery here and a two volt battery here this terminal is positive

so i expect the current to go in this direction let me not put the direction directly but i say that let this be the assumed direction of the current and this is purely because the positive terminal of a higher potential higher voltage battery is going to provide me current in this direction i need not really have assumed it but we'll show that in a problem

so let me do the following let me start from the point a and proceed in a direction opposite to okay in the direction of the direction opposite to the current

so what i do is this we say v_a now minus because my potential is dropping here there's a positive 2 negative minus e_2 let's assume the current to be equal to i

so plus ir_2 about whenever you assume that there is a current flowing through a potential resistance the potential drops

so plus ir_2 plus ir_1 plus e_1 well plus $i r_1$ plus e_1 now you see i am back at a

so therefore this must be v_a i have simply completed the same circuit from here to there here there from this path there is no potential drop here and this

so i have traveled like this and

so this tells me that i times r_1 plus r_2 plus r_1 plus e_1 minus e_2 is equal to zero let's put in the numbers

so i've got $i r_1$ is one r_2 is one point five this is five point five

so i add this up

so i get i times 8 e_1 minus e_2 is minus 2 i can take it to the other side and write this is equal to 2

so that tells me i is equal to 1 by 4 ampere now this is what i would do if i knew the direction of the current now supposing i do not i a priori have assumed that this to be see i done this way but let me do the other way now then what happens is the following that i proceed through essentially the same set of equations and then let us look at what happens

so we go to v_a let me go back here v_a now here minus e_1 see i am again like in the other case i am going from the positive terminal to the negative terminal

so minus e_1 drop plus ir_1 drop ir_1 and exactly the same way you will come back to the point a what will happen now everything here has the e_1 and e_2 sign has changed

so i will get i equal to minus 1 by 4 ampere saying that my original assumption

that the current was in a given direction was wrong and the current is should be in this direction and this is the way you can always find out the potential difference between any two points

so for example supposing i ask you the question what is the potential difference between these two parts a and b well it's the same thing again since you have now calculated the current to be equal to one fourth of an ampere assuming the direction of the current to be that

so what we do is we say v_b is equal to v_a minus e_2 plus ir_2 but that's the only resistance through it is passing substitute the numbers you find v_b minus v_a is equal to minus 3.

625 i will return back to this problem in the next lecture but we will calculate again show that how i calculate the potential difference between these points assuming the current to be in an arbitrary direction you