

welcome to this lecture of ah thermodynamics and this concludes the discussion we have been having on kinetic theory and later on thermodynamics so again as usual i shall start by recapitulating what we have learnt in the last lecture and then i will give you some topics discuss some special topics which could be slightly advanced but at the same same time they will help you to have a deeper understanding of whatever thermodynamics i have discussed in last four lectures so again recall second law of thermodynamics that's what the essence of last lecture two statements which are equivalent one is kelvin planck statement kelvin planck statement refers to engine and tells us that we cannot have an engine whose efficiency is one okay so it says no cyclic process is possible whose sole result is the absorption of heat from a resorb wire and the complete conversion of it to the walk that means output always be less than the input okay secondly clausius statement which again refers to another version of second law which is equivalent to this kelvin klong statement i have written here but it refers to the refrigerator it tells us that i cannot have a refrigerator whose coefficient of performance is infinity that means i cannot construct a is our refrigerator which absorbs heat from a cold reservoir and dumps the entire amount of heat to a hot reservoir its not possible i have to do some work on the refrigerator to make it work in a closed cycle ok then i talked about carbon engine which is a reversible engine i told you repeatedly what do i mean by reversible engine dissipation less working substance i chose to be one mole of ideal gas but also we discussed this is not essential ideal gas specific heat is independent of volume and temperature and any other quantities its three by two n k if i consider one mole of mono atomic ideal gas in that case calculation becomes very simple okay engine works in a complete cycle what was important there was a hot reservoir at a temperature  $t_1$  and a cold reservoir at a temperature  $t_2$  efficiency should be maximum but we calculated the efficiency it was not unity ok let us proceed so carbon engine was operating in force processes isothermal expansion adiabatic expansion isothermal compression adiabatic compression this brings me back from  $p_1 v_1 t_1$  to  $p_1 v_2 t_1$  i complete a closed loop in my p v diagram a closed loop and there were few comments these processes can be executed in any order ensuring the initial and final states are the same p

one  $v$  one  $t$  one  
 initially  $p$  one  $v$  one  $t$  one finally we calculated the work done and heat  
 absorbed and internal energy  
 being a state function its change is zero  
 so we did not really care about the internal energy ok so  
 what did we find out what is a remarkable result remarkable result is the  
 following that  
 efficiency is  $1 - \frac{t_2}{t_1}$  what was  $t_1$   $t_1$  is the temperature of  
 the hot reservoir  
 $t_2$  is the temperature of the cold reservoir and the engine is operating in  
 a closed  
 loop extracting heat from the hot reservoir dumping heat to the cold  
 reservoir  
 in the process doing work  $w$  ok and this efficiency cannot be unity because  
 then  
 you have to say  $t_2$  is equal to zero and  $t_2$  is equal to zero you cannot  
 set and that is  
 why efficiency is finite but it is maximum  
 so then we proceeded to discuss  
 carnot theorem given two heat reservoirs or wires which means  $t_2$  and  $t_1$   
 fixed  
 a carnot engine has the maximum efficiency any irreversible engine will have  
 less efficiency  
 than the carnot engine ok furthermore efficiency of all reversible engines  
 working between  
 two given reservoirs that means  $t_1$   $t_2$  fixed is the same secondly it is  
 independent of the  
 working substance or the operational details the way i executed my  
 thermodynamic operations  
 this is what i called carnot carnot theorem and i gave you some argument regarding  
 this  
 carnot theorem that is the following i had two given reservoirs which is having  
 temperature  
 $t_1$   $t_2$  this one is hot this one is cold i grant two engines one is carnot  
 carnot  
 was being operated as a refrigerator and then parallelly within the same  
 reservoirs i had an irreversible engine okay this picture reminds us what you  
 are doing carnot  
 operated as a refrigerator which is absorbing  $q_2$  amount of heat  
 from this reservoir  
 dumps a  $q_1$  amount of heat to the hot reservoir whereas the irreversible  
 engine irreversible  
 engine it extracts  $q_1$  amount of heat from the hot reservoir  $w$  amount of work  
 it does and rest  
 of the heat  $q_1 - w$  it releases to the cold reservoir  
 so that was the situation i  
 argued that these two taken together actually works as an engine which  
 absorbs  $w$  amount of heat from  
 this reservoir and converts it entirely to work then we are good it is not  
 possible it is violating second law if i assume  $w$  is greater than  
 $w$   
 so argument was  $w$  cannot be greater than the blue  
 so  $w$  is never  
 greater than  $w$  if  $w$  is greater than  $w$  i violate second law this system

violates second law this was the argument once we convinced ourselves that  $w_{\text{prime}}$  cannot be greater than  $w$  we proceeded and series of mathematical arguments told us that efficiency of Carnot engine is greater than efficiency of the reversible engine that is the summary so we cannot have  $w_{\text{prime}}$  greater than  $w$  because that makes second law violated we cannot do that hence  $\eta_c$  must always be greater than  $\eta_{\text{irreversible}}$  that is the summary of whatever we did in the last lecture let me now proceed and give you some concepts some notions which are different slightly advanced but I told you in the beginning these topics like I am going to introduce entropy will be very useful for further studies and of course understanding thermodynamics by heart ok entropy so far we have been talking about thermodynamic variables  $u$  internal energy volume temperature pressure some of them extensive we discussed what do I mean by extensive at length these are intensive ok now I bring in a new thermodynamic variable which I call entropy is an extensive thermodynamic variable entropy if I consider usually let's say isolated system is just a name do not get baffled by these names what an isolated system mean it means my system plus reservoir system and reservoir taken together constitute an isolated system so entropy is can be written as a function of  $u$  internal energy  $n$  number of particles and volume of the container so this is entropy I will give you more mathematical form soon but it can always be expressed as a function of pressure temperature and so on ok given an equilibrium thermodynamic state I know equilibrium dynamic state is characterized by pressure volume and temperature and similarly if I have an equilibrium thermodynamic state whenever I am in equilibrium state has a definite value of entropy ok this is important and entropy is a state function what does it mean entropy depends upon the state of the system  $p$   $v$   $t$  etcetera as was internal energy if you remember I always told you heat absorbed or heat released depend upon the thermodynamic path thermodynamic processes I execute work done heat absorbed that is why I was always writing them as  $\Delta q$   $\Delta w$  but I was writing  $d u$  all the time because if I do a thermodynamic process then change in internal energy only depends upon the initial and final state difference between the final value and the initial value of the internal energy so in that sense entropy is also a state function ok but there is a difference between internal

energy and entropy i told you that when you talk about internal energy you really do not care where do you set your zero of energy this is not true for entropy in the limit of absolute zero temperature entropy vanishes ok entropy goes to 0 if temperature goes to the absolute zero these is sometimes referred to as third law of thermodynamics now i will consider reversible process let us consider that a small amount of heat transferred to a system which is at a temperature t very small amount you can ask the question what is the change in the entropy of the system this is the change you see its  $\Delta q$  over  $\Delta t$  amount of heat sorry this  $\Delta$  should not be there i raise it its  $\Delta q$  over t this is the amount of heat supplied and this is the t temperature at which the system is maintained in equilibrium that means here i am assuming  $\Delta q$  tends to zero ok this is the small change in entropy in this process which have said is a reversible process but in general i can have heat exchange which takes the system from  $t_1$  to  $t_2$  then the expression or change in entropy will be like this  $s_f$  minus  $s_i$  final value minus the initial value which refers to change but this is a finite process this was an infinite decimal process but both reversible this is the expression  $\Delta q$  over t integrated from  $t_1$  to  $t_2$  this is my change in entropy see entropy change does not require that t is to be fixed it need not be an isothermal process ok that is why i cannot simply write is as a total change by the temperature ok i have to integrate from  $t_1$  to  $t_2$  ok now what you clearly see that  $\Delta q$  is important it is important that system absorbs heat or system releases heat to its entropy so that its entropy changes so in an adiabatic process we know  $\Delta q$  is equal to zero in an adiabatic process hence entropy change is zero ok often i will refer to adiabatic processes as isentropic process we know isothermal which keeps temperature fixed isobaric isochoric and adiabatic now onwards i will refer to as isentropic because in an adiabatic process change in entropy is equal to zero any irreversible process you may have in mind you can argue that this quantity  $s_f$  minus  $s_i$  is always greater than the quantity i calculated for a reversible process so i can think of a reversible process between temperature  $t_1$  and temperature  $t_2$  i can calculate the entropy change irreversible process i go from  $t_1$  to  $t_2$

two same values but entropy change will be more  
 so this is summary of entropy entropy  
 is a is an extensive thermodynamic variable given a thermodynamic equilibrium  
 state there  
 is a definite value of entropy if i consider reversible processes and a small  
 amount  $\delta q$   
 tending to zero heat is provided to the system then there is a change in  
 entropy rather  
 increasing entropy if i provide heat maintaining a temperature  $t$  then change  
 in entropy will be  $\delta q$   
 $\int \frac{dq}{t}$  in general i will have an integral from the initial temperature to  
 the final temperature  
 that will give me the change in entropy but if i have an adiabatic process  
 there is  
 no heat exchange as a result entropy change is zero ok and i shall call it  
 isentropic  
 process ok in any reversible process entropy change will be more than the  
 entropy change  
 in corresponding reversible process ok some sense you will find out the  
 statement  
 that entropy is very loosely speaking related to the randomness or  
 disorder of the system and we lose information about the system when entropy  
 increases what do i mean by that ok let us take three levels energy levels if  
 you like you know both theory  
 a little bit of ok you can think of three bohr levels which electron can  
 occupy if i know  
 with probability one that electron in level one okay with probability one then  
 entropy will  
 be zero but if there is a finite probability of electron being in level 1  
 level 2 level 3 then  
 entropy is greater than zero its a positive value but at the same time i am  
 losing  
 information when i was knowing for certain that system or the electron is in  
 the level one  
 entropy was zero the probability of occupying other states increase entropy  
 increases that is  
 why i say we lose the information about the system when the entropy increases  
 ok now there  
 comes a very fundamental law of nature this is how one proposes the second law  
 in  
 modern books consider an isolated system system plus reservoir ok that is my  
 isolated  
 system in any allowed thermodynamic process ok  $\Delta S$  will always be greater  
 than  $0$   
 $\Delta S$  refers to the change of entropy of the system plus the change of entropy of  
 the  
 reservoir  
 so  $\Delta S$  of system plus  $\Delta S$  reservoir these two taken together  
 must be greater than equal to zero this is the second law of thermodynamics  
 everything  
 what we have learnt about second law is encoded in this simple mathematical  
 expression  $\Delta S$  if you like i write a total  
 so that you do not lose track with system and  
 reservoir

so this is as total total entropy change is greater than equal to zero ok  
 what does it mean  
 and when does the equality sign hold equality sign holds only when there is  
 a reverse level process ok its only in a reverse level process any irreversible  
 process you may have  
 in mind total entropy always increases ok entropy cannot be dissipated once  
 entropy is generated it is there for an isolated system ok now you may often  
 heard this statement entropy of the universe is increasing this is what is  
 implied here which means if you consider  
 universe to be an isolated system there are plenty of processes which generate  
 entropy but  
 entropy cannot be dissipated and hence total entropy of the universe is always  
 increasing so  
 two things in this slide i would like to summarize entropy increase means loss  
 of information as  
 i have illustrated giving these three levels if i know system is in any one  
 level with  
 probability one entropy zero if it is distributed over different levels  
 entropy increases  
 secondly second law you can write in the form  $\Delta S_{\text{total}}$  is always greater  
 than equal to zero in any thermodynamic process reversible process  
 $\Delta S_{\text{total}}$  is equal to zero and entropies of the universe is always  
 increasing because you can  
 generate entropy but you cannot dissipate entropy this is very very  
 fundamental form of second law  
 now i would like to say briefly one more thing remember entropy is a state  
 function and  
 what was our first draw first law was  $du + pdv$  and i am talking about  
 reversible  
 processes what is  $dq$  we have already seen  $dq_{\text{rev}} = T ds$  remember i am  
 writing  $dS$  because  
 $S$  is a state function i told you repeatedly  
 so i can write my first law in the following form  $T ds$   
 is equal to  $du + pdv$   
 so this is often called the second law of thermodynamics in the  
 mathematical form which is nothing but the first law but i have brought in the  
 concept of entropy  
 which is a state function and replace  $\Delta q$  which is a path dependent  
 function thermodynamic  
 process dependent function with entropy  
 so i have this equation now  $T ds$  is equal to  $du + pdv$   
 $v$  where this is mechanical work done i am assuming everything mechanical walk  
 everything reversible  
 of course was static  
 so this is all about entropy i wanted to say then i will talk about  
 something  
 called  $Ts$  diagram okay that means thermodynamic processes are to be drawn on  $T$   
 $S$  plane rather  
 than  $PV$  diagram or  $VT$  diagram its useful you can see why it is useful it is  
 useful  
 because we have talked about two processes  
 so far at least in the context of carnie gene ok  
 what are these two processes isothermal isothermal means temperature is fixed  
 so this

is isothermal its a parallel line temperature fixed and secondly isentropic  
 adiabatic  
 which means entropy is fixed ok  
 so this is this represents an  
 isothermal process isothermal this is adiabatic which i shall call isentropic ok  
 now ts diagram is useful in the following  
 sense which i will argue pv diagram area under the curve provides the work  
 done on or by the system that we have learnt ts diagram  
 on the other hand as you will see in a closed loop in a closed loop in t s  
 diagram will  
 provide you the net heat exchange this you can easily argue which i will not  
 show the  
 argument i have already told you adiabatic process isotropic process  
 isothermal process entropy  
 changes keeping temperature fixed okay remember this is very important change of  
 entropy  
 of the system and the resolver both taken together is zero in a reversible  
 process ok so  
 with this input will start to proceed carnotine gene and draw the ts diagram  
 for a  
 carnot engine lets recall the pv diagram ok  
 so this is my pv diagram this was my step one step two step three step four  
 i  
 was starting from  $p_1$   $v_1$   $t_1$  this is an isothermal process that takes b  
 $p_2$   $v_2$   $t_1$  followed by an adiabatic  
 or isentropic process  
 so that takes me to  $p_3$   $v_3$   $t_2$  here i reach  
 the temperature of the code is over then there is a contraction which takes me  
 to  
 $p_4$  for  $v_4$  for this is again isothermal process this is  $t_2$  then an adiabatic  
 contraction takes  
 me back to  $p_1$   $v_1$  and  $t_1$   
 so this is my isothermal this is my adiabatic again isothermal again  
 adiabatic heat absorbed  $q_1$  and heat released is  $q_2$   
 ok now we will draw the ts diagram for this corresponding carnotine ok we  
 should proceed  
 to draw the ts diagram for this carnot chain ok  
 so this is your t this is your s i am plotting  
 temperature as a function of entropy or the other way around  
 so first process was isothermal  
 so let  
 us fix two temperatures that  $b$   $t_1$  this  $b$   $t_2$  ok first process was  
 isothermal in  
 which entropy changes in this case system is absorbing heat  $q_1$  amount  
 of it  
 so entropy will increase ok then followed by an adiabatic expansion in  
 which entropy cannot change  
 so this is this is step one this is the step one here this is step  
 two which corresponds to step two here  
 so one two this is step three this is the step three here isothermal process  
 but it was a compression that is why heat was released  $q_2$  amount of heat  
 and step three  
 that is why entropy decreases but comes back to this value and then you have  
 an isentropic or

adiabatic process which is step four here this gives me the step four here ok  
 i should write here rather ok  
 so you see that the  $t-s$  diagram for a Carnot engine this is the  $p-v$  diagram and this is the  $t-s$  diagram of the Carnot engine ok  $t-s$  diagram you see  $t-s$  diagram looks much simpler only because of the fact isentropic processes are straight lines like this and isothermal processes are straight lines like this you see you have a rectangle you had a complicated geometry here instead in  $t-s$  diagram you have a rectangle ok so now how can you calculate the efficiency ok you see remember this this curve and this curve these two there is no entropy change ok two and four there is no entropy change because these are adiabatic processes and there is no heat exchange ok so now step one heat absorbed is  $q_1$  temperature was maintained at  $t_1$  is the temperature of the hot reservoir so  $\Delta s_1$  is equal to  $q_1$  by  $t_1$  ok adiabatic process steps two and four  $\Delta s$  is zero we do not have to care about these two processes step four on the other hand step four is here ok equivalent you see this step four is again adiabatic but step three one has to be very careful ok so step three one has to calculate step three heat absorbed is  $q_2$  and temperature is  $t_2$  so  $\Delta s_2$  let me call it is minus  $q_2$  by  $t_2$  so heat absorbed in this process entropy change  $\Delta s_3$  is  $q_2$  by  $t_2$  and four adiabatic processes  $\Delta s$  is zero step three heat released i wrote absorbed because i gave a minus sign here let me clarify heat release  $q_2$  at a temperature  $t_2$   $\Delta s_4$  is minus  $q_2$  by  $t_2$  now remember i should tell one statement very clearly we are focusing on the system in any process the net change in the entropy of the system plus reservoir is zero that means here entropy of the system is increasing but reservoir is losing its entropy is decreasing and total entropy change is zero because it is a reversible process similarly here entropy of the system is decreasing but entropy of the reservoir is increasing because system is releasing heat to the reservoir okay so but it is a closed loop so  $t-s$  diagram was giving me a closed look i come back to the same position ok so in the closed loop net change of the system is zero also is zero and add them you will always find out total change of the system plus this or wired is equal to zero

so the total of this system is  
 $q_1 - q_2 = 0$  so  
 $q_1 = q_2$  is equal to  $t_1 - t_2$

so what is the efficiency efficiency is  $1 - \frac{q_2}{q_1}$  which immediately gives me  $1 - \frac{t_2}{t_1}$  so that is the purpose of this discussion I told you that if I use the  $t-s$  diagram instead of  $p-v$  diagram I have these processes represented by straight lines in the  $t-s$  diagram ok and then immediately I can work out the efficiency of a Carnot engine

which is given by  $1 - \frac{t_2}{t_1}$

so same result we obtained using the  $t-s$  diagram ok this is all I wanted to say about entropy but today's lecture still we have some time left

I would like to do some problems for you and give you some food for thought so that you

can learn on your own few advanced topics

so first let us do a problem this problem is a quite an illustrative problem which involves an imaginary ideal gas engine ok and the assumption I will make

$C_p$  and  $C_v$  are always constant constant ok and now let us draw the corresponding  $p-v$  diagram and

I leave it to you to construct the  $t-s$  diagram ok

so  $p-v$  diagram is the following there is a  $v_1$  there is a  $v_2$  there is a  $p_1$  let us say  $p_1$  and  $p_2$  there is a process which is like this and there is a process which is like this and there is a process which connects these two the slope should be monotonic and my drawing is bad rather it should be like this I raise the upper curve ok

so immediately see that ah what is this ah processes this keeps your pressure constant

so this is isobaric this is obviously volume constant we know what is this this is isochoric and finally this is my isentropic or adiabatic process I ask you the question I put the arrows like this isobaric followed by

isochoric and then finally adiabatic I ask you the question very simple question that calculate

the efficiency of this ok calculating efficiency is not difficult you have to calculate

the work done first remember this process  $v$  is kept fixed

so work done is

zero ok whatever work done will be here and here ok but I will not calculate the work done that I also leave for you to check out what is the work done because we

know the work done how to calculate it for both isobaric and adiabatic processes I would rather

calculate  $q_1$  and  $q_2$  let's see heat absorbed ok heat absorbed in which process here you see

pressure is increasing which means temperature is increasing let us call this temperature  $t_1$  this

temperature  $t_2$  this temperature is  $t_3$  ok now in this process how much heat will be absorbed

$C_v$  volume is kept fixed  $C_v (t_3 - t_2)$   $t_3$  must be greater than

$T_2$  because pressure is increasing  $T_3$  greater than  $T_2$  because pressure is increasing keeping volume fixed  
 so this is the process which is involved in heat absorption now heat released should be this process heat released ok i am referring to the magnitude of it ok should be pressure is kept constant  
 so  $C_p$  and  $T_1 - T_2$  its negative  $T_2 - T_1$  but i am referring to the magnitude only  
 so remember this is heat released ok now once i have it absorbed and it released i can immediately calculate what is the efficiency of my engine ok  
 efficiency will then be given by  $1 - \frac{Q_2}{Q_1}$  this is my  $Q_2$  remember again it is the magnitude ok  
 so remember what is the engine ideal gas engine ok and then  $C_p$  i have assumed constant does not depend on anything as happens for ideal gas as you know  
 so now you have one isobaric process one isochoric process one adiabatic process i asked you calculate the work done that will be in this process and this process  
 this process no volume is kept fixed ok second find out the  $T$ - $S$  diagram  $P$ - $V$  diagram i have given  
 so i calculated heat absorbed it is absorbed in this process because keeping volume fixed i am changing pressure you know if i keep volume fixed  $P$  is proportional to  $T$  pressure increases mean temperature increases and the heat absorbed will be  $C_v (T_3 - T_2)$  i have assigned temperatures  
 ok now heat is released in this process because it is isobaric volume is decreasing keeping pressure constant  
 so  $T_2$  will be less than  $T_1$  i have written the magnitude of the heat released  
 at  $C_p (T_1 - T_2)$  which is  $Q_2$  now let me try to calculate the efficiency  $1 - \frac{Q_2}{Q_1}$   
 $1 - \frac{C_p (T_1 - T_2)}{C_v (T_3 - T_2)}$  which is nothing but  $1 - \frac{C_p (T_1 - T_2)}{C_v (T_3 - T_2)}$  this gives me the answer but its not a very good answer because the problem gives me  $V_1, V_2, P_1, P_2$   
 one it does not give me  $T_1, T_2, T_3$   
 so i should be able to express everything in terms of given quantities in the problem  
 so let us proceed efficiency i can write as  $1 - \frac{C_p (T_1 - T_2)}{C_v (T_3 - T_2)}$  which i can simplify as  $1 - \frac{\gamma (T_1 - T_2)}{T_3 - T_2}$   
 three by  $T_2$  ok these we have written previously but this does not give me very nice result  
 as i told you i have to express in terms of  $P_1, P_2, V_1, V_2$  you can easily see from here  $T_1$  it ideal gas  
 so i will always have  $P_1 V_1 = n R T_1$  satisfied  
 so i will have  $T_1 = \frac{P_1 V_1}{n R}$   
 one is equal to i will be careful  $P_1 V_1 = n R T_1$  ok similarly if you look at  $T_2$   
 $T_2 = \frac{P_2 V_2}{n R}$  i can write as  $P_2 V_2$  sorry it should be  $P_1 V_1 = n R T_3$  similarly i can

write as  $p_2 v_1$   
 over  $r$  i am going to substitute this see this is  $p_2 v_2$  as per my notation  
 this is  $p_1 v_2$  by  $r$   
 this is  $p_1 v_1$  by  $r$   
 so let me substitute in this expression and see what i get  
 so efficiency  $\eta$   
 will be given by  $1 - \gamma \frac{p_1 v_1 - p_2 v_2}{p_2 v_2 - p_1 v_1}$   
 so all i have done i have  
 replaced temperature substituted for temperature for one mole of ideal gas i  
 always have  $p v$  is  
 equal to  $r t$  satisfied and i know coordinates of the point which are denoted  
 by temperature  $t$   
 $t_1$  and  $t_2$  respectively  
 so immediately one can simplify life and one can write out the  
 final expression which is  $1 - \frac{p_2 v_2}{p_1 v_1}$   
 so this is the  
 efficiency of the engine i have been talking about okay this is one example of  
 doing some problem  
 using the simple  $p v$  diagram to end this discussion i will have two more  
 comments and i will  
 leave two problems for you to do for example if i give you a  $t s$  diagram ok now  
 it is a  
 $t s$  diagram not  $p v$  diagram this you can say problem 2 ok here you have a  $t s$   
 diagram  
 and i give you three processes all these are straight lines ok so  
 lets say my arrows go like this this the yes and this i ask you identify  
 the processes ok  
 so this one you immediately know entropy is not changing  
 temperature is  
 so this is adiabatic or isentropic what about this one this one we can easily  
 find  
 out because temperature is constant is isothermal this process what is this  
 process this is not  
 adiabatic its a straight line i have drawn ok  
 so this process can be isochoric or isobaric or it could be any other process a  
 composite  
 process for example which you can figure out from the corresponding  $p v$  diagram  
 however  
 what is important here given this cycle calculate the efficiency of this  
 engine that  
 you should be able to do from the  $t s$  diagram itself now you may ask me how to  
 distinguish  
 between an isobaric and an isochoric process on a  $t s$  diagram this is what i am  
 going to discuss now  
 in a  $p v$  diagram you can always identify which one is adiabatic which one is  
 isothermal by looking at  
 the slope question is in  $t s$  diagram identifying isothermal or adiabatic  
 isentropic is very easy  
 what about isochoric and isobaric ok they will have different show  
 so the comment i would like to  
 make that you should note these following things that a isochoric curve  
 remember i am talking  
 about isochoric curve if you calculate the slope slope its  $t$  over  $c v$  isobaric

curve slope will be  $\frac{t}{c_p}$  remember this is with respect to the  $t-s$  diagram

so  $t-s$  diagram  $\frac{\Delta t}{\Delta s}$  change in temperature with entropy if volume fixed is greater than  $\frac{\Delta t}{\Delta s}$  over  $p$  ok slope of this isochoric is higher because  $c_v$  is smaller than  $c_p$  ok

so if i give you two curves you should be immediately able to tell me that this is isochoric this is isobaric remember i am referring to  $t-s$  diagram

so problem 2 involves

$t-s$  diagram identify processes in  $t-s$  diagram calculate the quantities adiabatic and isothermal

very easy to find out whereas isochoric and isobaric once again draw two curves look at the

intersection and find out the slope from this slope see whether this condition is satisfied

or not if it is you know this one having higher slope steeper slope ok will be your isochoric

process to summarize if i have a  $t-s$  diagram this horizontal curve obviously isothermal this one is isobaric and isochoric there will be isobaric and isochoric

so this will be the isobaric and this will be the isochoric that's what i have discussed based on the argument i have given previously

so let me conclude

by giving you one more cycle in the  $t-s$  plane which is following very close to the cycle i

drew in the previous slide again the question will be

calculate the efficiency calculate the efficiency from the  $t-s$  diagram itself i can say

this is  $t$  one if you like this is  $t$  two

so this is where i would like to end this set of

lectures of kinetic theory and thermodynamics i have followed two books one is the NCIT book

other is book by professor A.C. Verma and these two books and also something not covered

in your standard books but i wanted to give you some insight in the problems and some of

the problems i discussed are very deep if you understand them by heart you will learn the

subject better okay

so purpose was to tell you the microscopic origin of kinetic theory and macroscopic origin of thermodynamics but eventually all lead to should lead to same set of results we have been using  $pV = nRT$  for one mole of ideal gas always

so two different approach but fundamentally we want to get the same set of results which are experimentally verified and which are reproducible in our laboratories

so this ends our class lecture sessions on kinetic theory and thermodynamics i thank

you all very much for your attention you