**NPTEL**

**NPTEL ONLINE CERTIFICATION COURSE**

**Course**
**on**
**Laws of Thermodynamics**

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# Lecture 14: Second Law and its Corollaries (Part III)

Good afternoon and I welcome you all to this lecture section of the course laws of thermal. Now last class we discussed the connotes we discuss in the connotes to we arrived by logical detection of truth.

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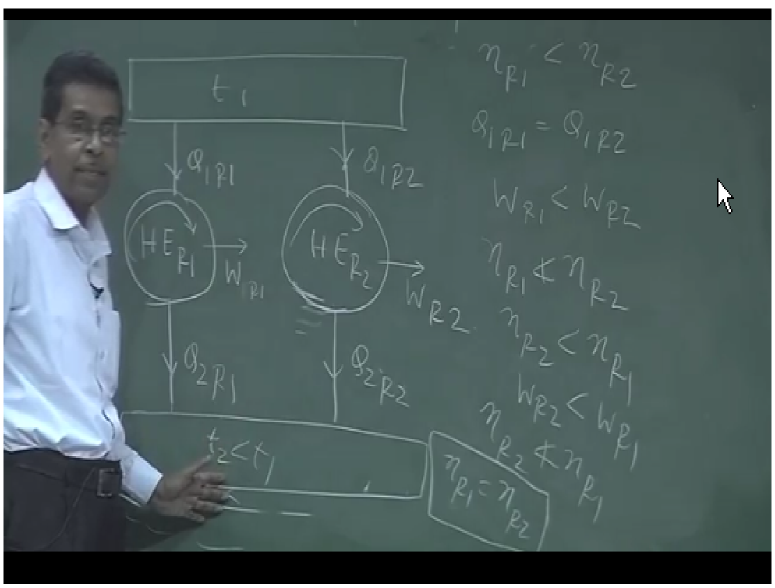

That reversible in the efficiency of reversibility is this higher than that we reversible engine operating in the…. Now the second statement is that efficiency of level civil engine operating same source in this.

How do you protect to how do you protect it is very simple hoe you put the first one it will automatically follow. That means there is two reversible engine R1 and R2 for the reversible engines R1 and R2 both the reversal we discussed earlier. One reversible and another will reversible. Let q1 arrow and is the taken by the reversible engine arrow one and Q1R2 is been reversible engine.

And these are the keep rejected by the reversible engine 1 and reversible engine 2. Accordingly these are this work never followed by the reversible engine1. This the work developed by the reversible engine 2 okay. Now let us consider the all with the earlier that $\eta_{R1} < \eta_{R2}$ $\eta_{R1}$ is less than our we consider this is reversible this was revisable. Then by designation of episame and you have the same time.

Consider that Q1R1 is similar with that means the hit taken by two reversible engines is but their rejection is different accordingly the work done is different. Because we do not accept for that efficiency is that. First we assume that $\eta_{R1}$ is less than $\eta_{R2}$. If I make this two operator is a hit pump reversible hit pump or refrigerator. Then all this quantity will be same in the opposite direction and it will demand then work WR1 from the surrounding and keep.

This is so WR1 is less that means the earlier proof W R1 is $<$ WR2 therefore the part of WR2 will be taken by WR1 and will gativinate work output of wR2 – WR1. Clear because last proof if recalled the last proof then you will see the WR2 is greater than WR1 so we take these and we designate. That means by reverse this we can proof that $\eta_{R1}$ then or to be less than $\eta_{R2}$, because in that it is will violetic element clustered.

We connect this and we proof, now the differences is that this is again in reversible engine now if we reverse this now $\eta_{R1}$ cannot be greater than it cannot be less than $\eta_{R2}$.let u consider $\eta_{R2}$ is less than $\eta_{R1}$. This is less than then what happen what we do? We just reverse. This is the reversibility engine and all this quantities will reveal by this same amount but the opposite direction then it will QR2 from it will QR1 or Qr2 here. And it will take WR2.

So if $\eta_R$ is less than $\eta_{R1}$ then WR2 in this case less than WR1 and we can connect this and then that case we get WR1 – WR2 and we connect this two, this means violetic we mean consider that means in that in this cas what we can do we can reverse this engine if we consider this efficiency of this less than this and will prove that the only I that prove her. The efficiency are and this will cannot be less than this otherwise the violet it will be consider by the this two.

Because this two and it is, if I consider $\eta_{R2} < \eta_{R1}$ then we reverse this and here we are that opportunity that advantage that seems it is a reversible engine if you reverse this quantity will be same. And in the opposite direction since in the case $WR2 < WR1$ to it is WR1 is the part of this and WR1 –WR2 is the main part of and will connect with this. So this so it will violet will be construct this. So therefore $\eta R2$ cannot be equal to $\eta R1$, so $\eta R1$ cannot be less than $\eta R2$.

$\eta R2$ cannot be less than sorry it will cannot be less than $\eta R1$. So only opportunity only solution is that $\eta R1$. That means this can be prove that for any reversible engine operating between the same source temperature and seen temperature. The same deserver operating between the same two hit reserves is same. And now you can add a question are what the differences between reversible engines are?

Yes the reversible engines two reversible engines may differ by the construction of their material of construction by their design the process will be different. Reversible process may not be that the reversible process can be constant pressure reversible process constant volume the reversible process, isothermal reversible process. So the process is that means the thermolinamic cycle may different for these two cases.

You working doing or working system may be different their material of prospection for the engine may be different, so that may many ways in these two different. But thermolinamic cycles on which be working system we can operate both the sides are have to be reverse. Then it will be revisable in this and they will be different reversibility. That means whatever will be the working system, whatever may be the processes in terms of the process caused.

But the keep the processes are all reversible that means the reversible cycle is reversible. Then the reversible of the different types then the same efficient the results in the same efficiency that will be the two temperatures. So therefore we can tell this thing is now you in this form that all reversible engines of the same efficiency which $\eta R$ and all engine will be reversible engines. And otherwise which where is in the working system material of construction processes.

But the reversible, not the all processes are revisable in the thermolinamic cycle. Thermolinamic cycle is revisable, the vary of this revisable that means all of u designs have engine in fact this will revisable engine technical engine then we will see the efficiency of the all the engines. Then we will see all the engines developed by this entire individual will be different. What may be smart enough to design efficiency in the engine 1.

Not that smart enough to revisable engine which is not that efficiency. That means all will revisable engine in the $\eta1$, $\eta2$, $\eta3$, $\eta4$ all may in define. Then $\eta1 \neq \eta2 \neq \eta3 \neq \eta4$ and so on is not that they are equal. That means the reversible engine may be deficiency may where we given in between the same source side. Which are but this is same and the highest of this efficiency or this reversible class of engines but the class of the reversible engines is less than $\eta R$.

That means $\eta_R > \eta_{highs}$ the highs value of the efficiency but one can achieve in practice are in the reversible or natural engines is less than $\eta$, that means the revisable engine efficiency is the highs put the performing this criteria for all the reversible engine. All the reversible engines when where we are using their efficiencies but the highs one is the reversible engine efficiency to this same for all reversible engines are in between same source and same temperature.

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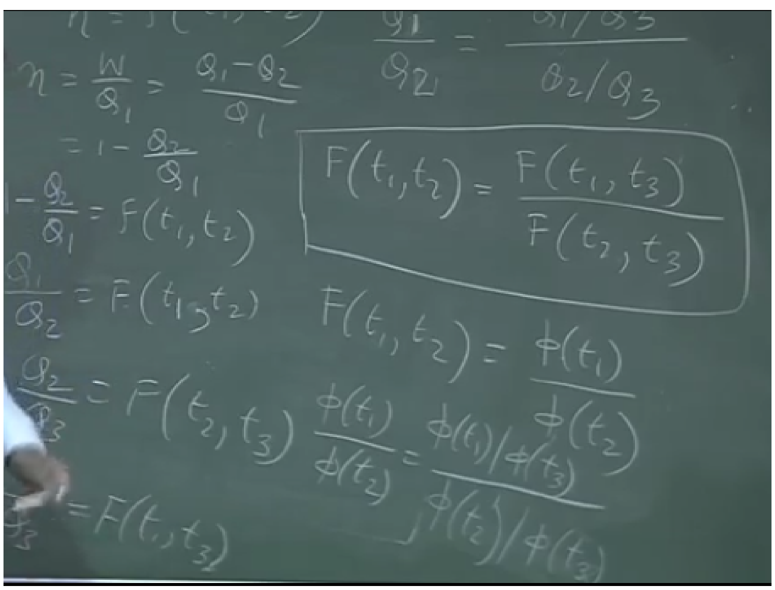


Now I will come to a very important concept or very important detection thermodynamics scale of absolute scale absolute thermodynamic scale of temperature, absolute thermodynamic scale of temperature. This is how do you define it was defined by lot scales in first. The absolute thermodynamic scale of temperature then it was in this. Now this definition of absolute thermodynamic scale of temperature comes for in directly or it is a direct comes directly from the Carnot's theorem or principle or it is the direct consequence of Carnot's theorem or principle.

Now let us see now if there is a heat engine operating between $t_1$ x8 $Q_1$ and rejects it $Q_2$ at a temperature $t_2$ and develops or we know if it is the reversible heat engine then we know efficiency is a function of temperature that means the Carnot's principle tells that all reversible engines at same efficiency working between the same two temperatures Thermal reservist $t_1$ and $t_2$ $t_1$ is greater than $t_2$

That means analytically you can express that η is a function of $t_1$ and $t_2$ because this depends only on temperature if you change that $t_1$ $t_2$ then the reversible engine efficiency will change but again with the same sink and source and sink same reservoir the efficiency of all reversible means that means for a given $t_1$ and $t_2$ as the source and sink temperature if we see this is a function of $t_1$ $t_2$ that we can write.

Now if we see in C can be written as W / $Q_1$ = $Q_1$ this has been done earlier $Q_2$ / Q 1 that means 1 - $Q_2$ / $Q_1$ so therefore one can write 1- $Q_2$ / $Q_1$ = function of $T_1$ that means this is a function of $T_1$ T this can be written in a different fashion that $Q_1$ /$Q_2$ is some other function of $T_1$ / $T_2$ that means $T_1$ and $T_2$ that means the ratio of heat interactions by the heat engine with the source sensing is a function of 2 temperature this some other function that means we just write in this fashion 1 - $Q_2$ / $Q_1$ is a function of $T_1$ and $T_2$ then $Q_1$ / $Q_2$ can be written as a function of $T_1$ and $T_2$ okay.

Now we will consider another heat engine let us consider this is heat engine number one this is heat engine number 2 which rejects takes heat from $T_2$ as $Q_2$ and rejects heat Q3 at a temperature T3 which is < than $T_2$ which is < $T_2$ that means $T_2$ is < $T_1$, $T_1$ < $T_2$ and $T_2$ $T_3$ is < $T_2$ and it develops another or let this work is W1 and this work is W2 heat engine 2 then for heat engine 2 we can write in the similar fashion that $Q_2$ / $Q_3$ is the same function of $T_2$ / $T_3$ because it is an unique function it is since the unique function who depends upon the temperature level if you substances these arguments $T_1$ $T_2$ it to it will give the value of η

Because it is dependent on $T_1$ $T_2$ for the same function but with $T_2$ and $T_3$ and if we consider the combination of two engines together $r_1$ and $r_2$ together which develops $W_1$ and $W_2$ amount of wall takes heat $Q_1$ from $t_1$ and rejects heat $Q_3$ to $T_3$ then with respect to the combined system we can write $Q_1$ / $Q_3$ is a function of $t_1$ $t_3$ okay same function now we can write this thing in this way but so long we do not know this functional form.

We only express in the form of an implicit function that $Q_1$ / $Q_2$ is some function of $t_1$ $t_2$ $Q_2$ / $Q_3$ is the same function of $t_2$ $t_3$ and $Q_1$ / $Q_2$ is the same function of $t_1$ $t_3$ okay, now if we write with certain algebraic manipulation $Q_2$ by $Q_1$ as $Q_1$ by $Q_2$ rather $Q_1$ / $Q_2$ ask $Q_1$ by $Q_3$ divided by $Q_2$ / $Q_3$ then we can write this $Q_1$ /$Q_2$ is $Q_1$/ $Q_3$ / $Q_2$ by Q so therefore we can write function of $t_1$ $t_2$ equals to function of $Q_1$ $t_1$ $t_3$ divided by the function of $t_2$ $t_3$ from here that means if I just make an algebraic rearrangement.
So that this gives some hints to the type of the function not the explicit form that explicit form of the function in terms of the two temperatures but at least they give some idea because of exploiting this relationship $Q_1$ / $Q_2$ function of $t_1$ $t_2$ $Q_2$ / $Q_3$ is a function of $t_2$ $t_3$ and $Q_1$/ $Q_3$ is the function of $Q_1$ T, so that we can write that function of $t_1$ $t_2$ is function of $t_1$ $t_3$ divided by the function of $t_2$ $t_3$ this is only possible that means t3it should be canceled out such a way that $t_3$ terms from these to function.

So that it results into the function of $t_1t_2$ and this is only possible provided the function is of this type $t_1$ $t_2$ can be expressed in terms of product or quotient however you can tell I write this way is a function of $t_1$ divided only in terms of that is a product form or a quotient type that if function of $t_1$ $t_2$ is function of $_{t1}$ / $t_2$ then it can happen because here it will be function of t1 by function of $t_3$ here it will be function of $k_2$ by function then what is happening that function of t1 by function of $t_2$ if the function can be expressed this way then only this is function of $t_1$ divided by the function of $t_3$.

So this function can be expressed is this way that is function of $t_2$divided by the function of $t_3$ that means the way in which the heat fluxes cancelled out $Q_3$ it becomes $Q_1$ / $Q_2$ the function t3 cancels out altogether so that it remains function of T 1/function of T 2 which is a function of T1 T 2 that means this function of two temperatures for the efficiency will be in this form, clear? So this now okay, now these function of T 1 and T 2, Ø T1 and Ø T 2 this is if I now I write.

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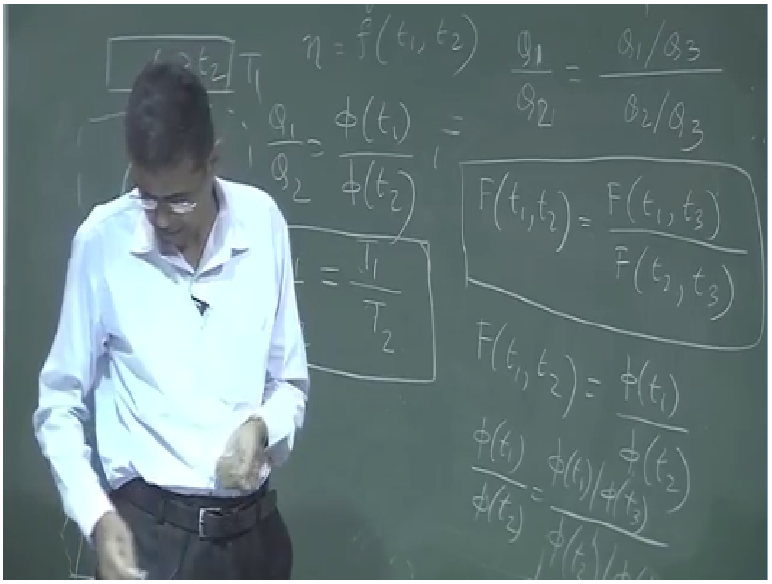


Q 1/Q2 so therefore we arrive this is some function of T1 by some function of T2, Now η is a function of T 1 and T 2 from which we derived that Q 1 / Q 2 is some function of T 1, T 2 and that has to be of this form from this deduction function of T 1 and T2 and this function is defined as T1 this function of T 1, T 1is temperature measured in any conventional scale existing earlier so in this absolute thermodynamic scale temperature was not discovered or was not deduced like this.

That means it is  temperature on any conventional scale this function itself is defined as the absolute thermodynamic temperature that absolute thermodynamic scale up temperature that means absolute thermodynamic scale of temperature, so the function itself is defined as T1 this function itself of T2 is defined as another temperature this is conventional scale temperature existing conventional scale this function is defined that temperature in some other scale which is the absolute thermodynamic scale and this is T2.

So therefore this gives the bath of absolute thermodynamic temperature scale and this is the definition of absolute thermodynamic temperature scale that the ratios of the temperatures equals to the ratios of the heat interactions by a reversible heat engine that means if q1 is the heat taken from temperature T1now if I express this and absolute temperature T1 and this is an absolute temperature T 2.

Then T1/T 2 = Q 1 the heat taken from T1 to that given to T 2, so therefore this is the definition of absolute thermodynamic scale of temperature that is the ratios of the temperature is equal to the ratio of the heat interactions by the reversibility. Now the question will come this is the concept these are the very routine logical deduction but concept is that, then to find out the absolute thermodynamic temperature scale we have to measure the heat interaction by a reversible engine.

But reversible engine does not occur in practice all natural or practical engines are irreversibly yes this is a good question we come but here the answer is that this heat Q1/ Q 2 that is the heat interaction by a reversible heat engine can be expressed in terms of other measurable properties by the thermodynamic property relations from where we can measure this, so therefore it is not always that it remains as a hypothetical since it is defined in terms of the heat transfer by reversible heat engine, okay, so this defines the absolute scale of absolute thermodynamic scale of temperature okay. Now we will define we will go to the definition of or the Carnot engine or Carnot cycle.

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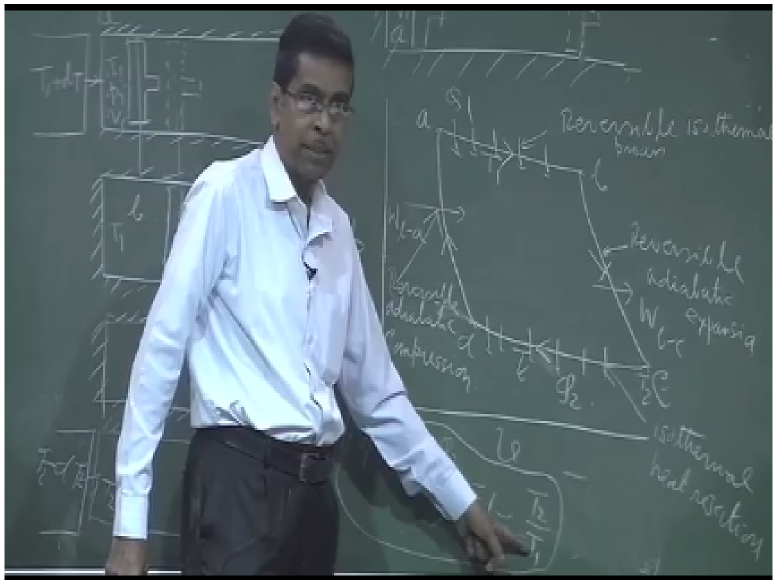

Now Carnot was the first man Carnot engine who first realized how we can contribute practice not in practice rather we can conceive physically a reversible engine, we can conceive physically a reversible engine that was first given by Carnot, the concept is like that he first took a cylinder and piston and some gash inside at a temperature T1and that if pressure P1 at a volume V1and he took a body whose temperature is T1+dT and heat is allowed to transfer to this through this if everything is insulated.

And while the heat is transferred since it is with infinite small temperature difference T1+dT to T1 this process is an isothermal heat transfer process in addition process slowly heat is coming and at the same way we make this temperature T1 fixed since T1+dT the source temperature is fixed for this we expand or we push the piston outside okay, and let us consider the piston has come to this state.

So this state is A and after this expansion the piston comes to this state, the piston comes to this state this is this state B. Now while the piston expands what happens even if the heat transfer is that it cannot raise the temperature because the gash expands and for expansion it cooling is there so that it makes a balance to make the temperature constant that is isothermal process is possible with heat transfer provided it does work so piston comes here and work is developed.

Now this is the system B now here we what we do we make everything insulated and allow the piston to go allow the piston to go to a position where the gas is expanded like this is the another position, this we can make dotted because it is the separate figure.

So from state a to state B then state B to state C here temperature remain same three one pressure is little bit reduced and volume is little bit reduced I am not showing it but here the pressure is tremendously reduced that in see and also temperature is reduced because this is insulated no heat transfer is there and we let the piston expand from this position to this position in which we get the work a greater amount of work we get.

Now here what happens after this, this is all insulated and this expansion we make extremely slowly where heat transfer was made extremely slowly piston move extremely slowly a little displacement is there for some amount of heat to be transferred then please turn of a very large displacement and expansion but very slowly it is an extremely slow process when everything is insulated no heat transfer is there.

Then at this state after reaching the state we remove the insulation and make the piston comes to a contact with this cache not the piston this gas comes into contact to a cold reservoir later this state temperature is $t_2$ which is much less than $t_1$, now I am writing this $t_1$ and $t_2$ in absolute thermodynamic temperature scale, so this is $T_2$ this is $T_2$ temperature, so therefore this will be $T_2$ - $D_T$ so that this temperature is very small compared to this $T_2$ that means the heat is transferred to this temperature this accessing where the temperature difference is infinite small.

That means the heat transfer takes place at reversible condition limiting reversible quasi irreversible condition and to make this $T_2$ constant just like the heating process we make a displacement of this system piston like this that means while it rejects it the piston pushes their rejection of heat will make the system cold that means this temperature may decrease but at the same time that piston pushes the air to raise the temperature so that balance is there because $T_2$ – $dt_2$ is kept fixed.

So if $t_2$ is going lowered then the temperature differential will be higher, so that we do not want to make the temperature differential higher that means it will be an isothermal heat rejection like that it is an isothermal heat addition do you want a system temperature escape constant here $t_2$ the system temperature is kept constant so this is the process of heat rejection when the piston moves here then at the end last profit after this.

We again just similar to that insolate everything take away the sink, take away the sink and make big piston from this position it could have been better if we could have drawn below it so that this is the this position from this position it again comes back to its initial position that means in this process what happened the gas is compressed a substantial compression of the gas but very slowly just like the expansion takes place very slowly from this position that is the position to this position.

Similarly from this position the gas is compressed to its initial state so that we regain again with $P_1$ $t_1$ and $t_1$ we remove this sink and make it insulated so that no heat transfer takes place so this way we cannot sort of physically a reversible engine or reversible cycle it consists of four processes you see this is an isothermal heat addition this is the way we consider that the some air is there it is in contact with the $T_1$+ DT where DT is very small and $T_1$ is kept constant so by expanding the gas to a little extent so that some heat is transferred at constant temperature t1and always that infinite small temperature difference reversible thermal heat transfer.

Then after reaching this position everything is insulated this is removed and this is expanded from this position to this position okay very slowly extremely slowly there is no heat transfer to the surroundings so question of irreversibility cannot come then this comes here after the expansion okay and we get work here, here also we get some work because of the expansion major work comes here and this is an reversible expansion process and the process is adiabatic because it is insulated then after this what happened just like heat addition.

We have to reject it by Kelvin-plank statement one reservoir engine cannot operate then here if the temperature is $t_2$ at this position that is $t_2$ then this thing has to be $t_2$-DT and to make the same infinite small temperature difference DT for heat to flow to the same we make it a constant temperature or isothermal heat rejection by pushing the piston slowly and it comes to this position when some heat is transferred.

Then at this position we again insulate it and very slowly compress the gas to its initial position this way we consider a Carnot cycle or Carnot engine if we draw this on $P_V$ diagram if we draw this on $P_V$ diagram you will see that state a let us like this $P_1$ $V_1$ and $t_1$ okay now state A to B to be C okay C to D and final state is E that is again a final status is or that is again A so A to B is an isothermal process it looks like that in a $P_V$ diagram where the volume is increased.

Then pressure is decreased due to this, for an ideal gas you know PV = RT or PV is equal to MRT, B is the total volume then a isothermal process gives in PV diagram a rectangular hyperbola, here P is the pressure P is the specific volume per unit. So this is the this is taking place at a constant temperature $T_1$ then from B to C is an slow expansion process to a very low pressure and temperature and this is a reversible adiabatic process.

So reversible isothermal process this is reversible adiabatic expansion why adiabatic insulated? No heat transfer then c to d again from c to d is a heat rejection but at an isothermal, that we see if this temperature is $t_2$ at states this remains at $t_2$, then again and this is isothermal heat rejection this process is isothermal heat rejection. This is isothermal heat rejection okay and then again from d to a. This is the direction of the process d to a is again this is the d state this is that this state you see this state this is the d state to a state again in the initial state.

This is adiabatic compression that means we see the Carnot cycle consists of two isothermal process at $t_1$ and $t_2$ two temperatures t1 is higher than $t_2$ and two adiabatic process reversible adiabatic process adiabatic expansion and reversal sorry reversible adiabatic compression, now at this temperature heat is added let $Q_1$ and at this temperature heat is rejected net key and in this $W_{bc}$ work from b to c, we get and here we give our $W_B$ to a, $W_B$ to a.

So this way a Carnot cycle is concept and if we write the efficiency of the Carnot cycle as we know is 1 - $Q_2$ / $Q_1$ this is because this is the network if $W_{BC}$ is higher than $W_{ba}$ so $W_{bc}$ - $W_b$ okay divided / $Q_1$ that means and this = $Q_1$- $Q_2$ $W_{bc}$ - W = $Q_1$- $Q_2$, so 1 - $Q_2$ by Q as you have already seen for a reversible heat engine. So this so if you write and with the definition of the absolute temperature we can write $t_2$ by $t_1$, so therefore the efficiency of any reversible engine can now be expressed in terms of absolute temperatures as 1- $t_2$ / $t_1$ because $Q_2$ by $Q_1$ is $t_2$ / 2 and all it is proof and this is by the definition of thermodynamic scale of temperature.

We have deduced from the directly from the Carnot's principle or theorem that the absolute thermodynamic temperature scale is defined as that the ratio of the temperatures in that scale is the ratio of the heat interactions by a reversible engine with the thermal reservoir, so Q2 by Q1 is t and this is not for this type of reversible engine as conceived by car nodes for any reversible engine working between a sink temperature $t_2$ and source temperature $t_1$ its efficiency is given by 1 - $t_2$ by $t_1$ okay this is the way car nodes first consider a reversible heat engine okay thank you for this model.