# Engineering Thermodynamics

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## Lecture 30

## Carnot principles, thermodynamic temperature scale, Carnot HE and HP

Welcome back, we are discussing the second law of thermodynamics, and in this last few lectures we described Kelvin Planck statement of second law of Thermodynamics.

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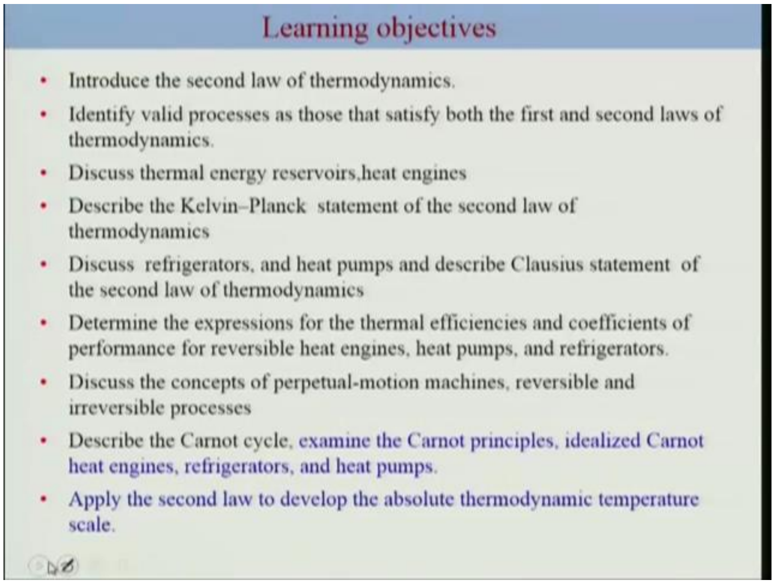

Learning objectives

- Introduce the second law of thermodynamics.
- Identify valid processes as those that satisfy both the first and second laws of thermodynamics.
- Discuss thermal energy reservoirs,heat engines
- Describe the Kelvin–Planck statement of the second law of thermodynamics
- Discuss refrigerators, and heat pumps and describe Clausius statement of the second law of thermodynamics
- Determine the expressions for the thermal efficiencies and coefficients of performance for reversible heat engines, heat pumps, and refrigerators.
- Discuss the concepts of perpetual-motion machines, reversible and irreversible processes
- Describe the Carnot cycle, examine the Carnot principles, idealized Carnot heat engines, refrigerators, and heat pumps.
- Apply the second law to develop the absolute thermodynamic temperature scale.

In this lecture we will be examining the Carnot principles, idealized Carnot heat engines, refrigerators, and heat pumps. At the end we will be developing the absolute temperature scales, and finishing up this second module of second law of Thermodynamics with an example.

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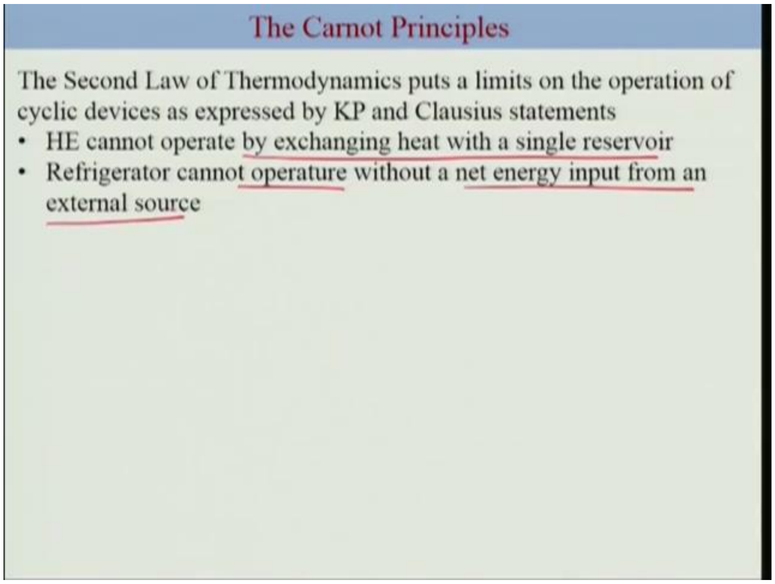

## The Carnot Principles

The Second Law of Thermodynamics puts a limits on the operation of cyclic devices as expressed by KP and Clausius statements

- HE cannot operate by exchanging heat with a single reservoir
- Refrigerator cannot operature without a net energy input from an external source

Let me just go through a bit of what are the limits which are being put on the operation of cyclic devices. So we have Kelvin Planck and Clausius statement. This statement does put some conditions or limitations or the operation of cyclic device. It states the following that heat engine cannot operate by exchanging heat with a single reservoir that is one statement comes from Kelvin Planck statement. And refrigerator cannot operate without a net input from an external source. Okay, so based on the statement we can draw conclusions, and these conclusions can be summarized in the following form.

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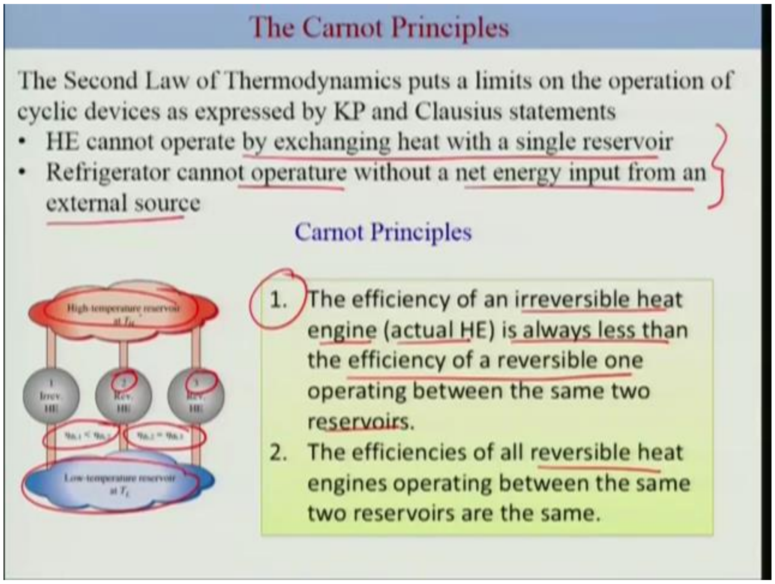

## The Carnot Principles

The Second Law of Thermodynamics puts a limits on the operation of cyclic devices as expressed by KP and Clausius statements

- HE cannot operate by exchanging heat with a single reservoir
- Refrigerator cannot operature without a net energy input from an external source

### Carnot Principles

1. The efficiency of an irreversible heat engine (actual HE) is always less than the efficiency of a reversible one operating between the same two reservoirs.
2. The efficiencies of all reversible heat engines operating between the same two reservoirs are the same.

So that is something we are going to state as Carnot Principle. These conclusions are the following, if the efficiency of an irreversible heat engine which should be the actual heat engine is always less than the efficiency of a reversible one operating between the same two reservoirs.

So that is the first statement which is the conclusion based on this statement Kelvin Planck and Clausius statement. The efficiencies of all reversible heat engines operating between the same two reservoirs are the same. Okay, and this essentially we are going to state that these are the principles which we are going to call it Carnot Principle.

Okay, so that is let us examine here. Based on this principle that you have a one high temperature reservoir at temperature Th, and low temperature reservoir is at temperature Tl. Where the statement here is first statement states that the reversible heat engine will always have higher thermal efficiency compared to the irreversible heat engine, which essentially means that efficiency of irreversible heat engine will always be less than the reversible heat engine.

And if we have two particular heat engines which are operating between the same reservoir, here is another example heat engine 2, and heat engine 3 which are reversible heat engine operating between these two reservoirs having temperature Tl and Th, they will have same efficiency. Okay, so that is what we are going to summarize as Carnot Principle.

So we can prove this principle, we can assume that let us say that Carnot principle one is violated.

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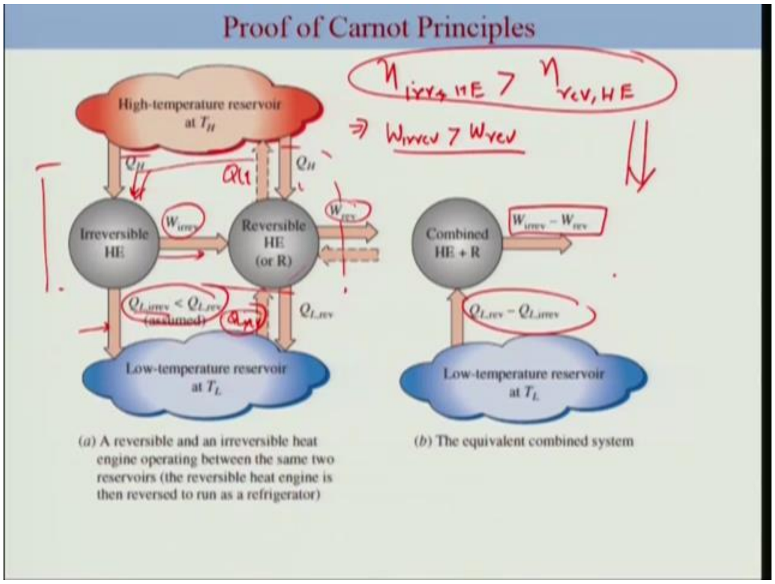

Proof of Carnot Principles

$\eta_{irrv,HE} > \eta_{rev,HE}$

$\Rightarrow W_{irrev} > W_{rev}$

(*a*) A reversible and an irreversible heat engine operating between the same two reservoirs (the reversible heat engine is then reversed to run as a refrigerator)

(*b*) The equivalent combined system

So this would be the example. We are going to try to prove the Carnot principle. Here we are going to assume that irreversible heat engine, efficiency of irreversible heat engine is greater than the reversible one. Let us assume that.

So what does that mean here is that the following essential work output here, okay would be more than for the corresponding reversible one. Okay, in the other word the heat rejected here for the case of irreversible heat engine would be a less compared to that rejected for the case of reversible heat engine, okay.

Now what we can do is we can reverse this second heat engine and make it refrigerator. So now essentially what you have done is you have reversed it, and this is rejecting Qh to the reservoir. And here this was the work output for the reversible heat engine. Now you have to reverse the cycle, and hence this becomes an input.

Okay, now this particular heat which is being extracted here to irreversible reservoir, and rejected to the high temperature reservoir, this can directly be sent here to the reversible. Thus this will eliminate each other in the sense when you can consider as one particular device. So this could be combined in this form, so this cancels out this particular heat Qh could be the part of the internal mechanism.

And what remains here is the following that this essentially is the work output, and this is the work input W reversible. Thus overall work output considering that W irreversible is greater than W reversible can now be summarized in this form. And similarly for the case of Q to the low temperature reservoir can be now written in this form, okay. Considering that we have reversed the directions. So it will be Ql minus Ql reversible.

So now what you have is a device where essentially it is extracting heat from a single reservoir, and producing a network which essentially is violating the second law of Thermodynamics. So considering the fact that you have violated the first of Carnot Principle is equivalent to stating that you have violated the second law of Thermodynamics. In a similar you can also prove the second Carnot principle.

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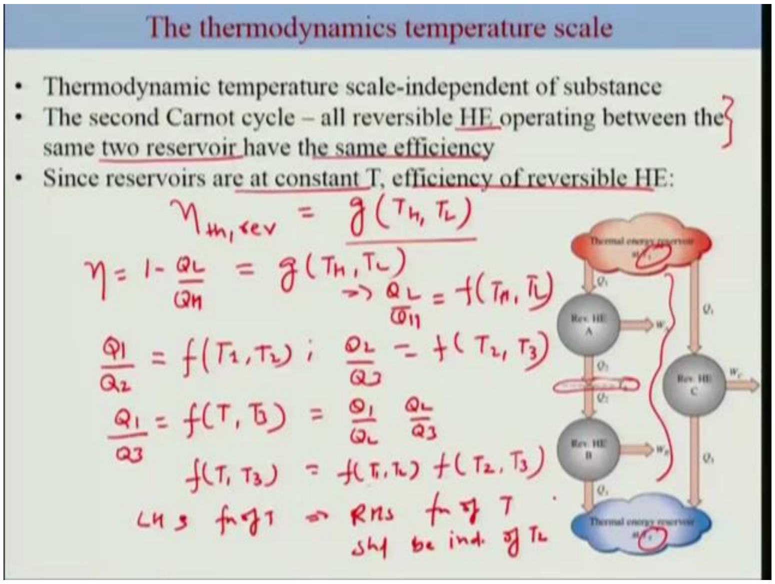

The thermodynamics temperature scale

- Thermodynamic temperature scale-independent of substance
- The second Carnot cycle – all reversible HE operating between the same two reservoir have the same efficiency
- Since reservoirs are at constant T, efficiency of reversible HE:

$$\eta_{th,rev} = g(T_H, T_L)$$

$$\eta = 1 - \frac{Q_L}{Q_H} = g(T_H, T_L) \Rightarrow \frac{Q_L}{Q_H} = f(T_H, T_L)$$

$$\frac{Q_1}{Q_2} = f(T_1, T_2) ; \quad \frac{Q_2}{Q_3} = f(T_2, T_3)$$

$$\frac{Q_1}{Q_3} = f(T_1, T_3) = \frac{Q_1}{Q_2} \frac{Q_2}{Q_3}$$

$$f(T_1, T_3) = f(T_1, T_2) f(T_2, T_3)$$

LHS fn of T ⇒ RHS fn of T shd be ind. of $T_2$

Let us now look at specifically Thermodynamic temperature scale, okay, which essentially we have discussed much earlier (())(05:12) part of this course, and we have said that Thermodynamic temperature scale is nothing but is an independent substance. Okay, what we know that all reversible heat engine operating between the same two reservoir have the same efficiency. Okay, so that is the Carnot principle states that, okay.

Since reservoirs are at constant temperature, efficiency of reversible heat engine can be written as this form. So this is heat engine efficiency which can be written as a function of these two temperature, considering that reservoir are at a constant temperature. And considering that all reversible heat engine operating between two reservoir, they must have the same efficiency.

So this is the Carnot principle which you are making use of it. You are also making use of the fact that reservoir operate at a constant temperature thus efficiency of reversible heat engine should be a function of Th and Tl.

Okay, now we know that your heat engine efficiency can be written as 1 minus Ql by Qh. Okay that is the work out divided by heat in. Okay, for the case of reversible one this is essentially GTh Tl, so this we can conclude that Ql by Qh is also a function of Th Tl.

Okay, now consider this particular illustration here you have two thermal reservoir, one operating at T1, and other is T3, and here we are considering another kind of reservoir which is at T2. Okay, now you have three specific heat engine, and uuh the corresponding work output heat input and rejections are given.

So let us start with reversible heat engine A, and I am going to write this as Q1 by Q2 as a ratio of 1 and 2. This can be the function of corresponding temperature, T1 and T2. Okay, I can also write Q2 Q3 for the case of the second reversible heat engine as function of T2 T3, okay. And for the third or C reversible heat engine, it can be written as Q1 Q3 F (T1 T3).

Reversible heat engine is basically equivalent of these two intimidate reversible engine. Okay, so now we have this information based on the Carnot principle, based on the definition or efficiency. You can now write Q1 Q3 as Q1 Q2 Q2 by Q3, and this essentially is F T1 T2 F T3, okay.

Now you have left hand side which function of temperature okay and this right hand side should also be function of temperature, okay, and should be independent of T2. Okay, so this is something we can conclude based on this analysis on your efficiency and definition of Carnot Principle.

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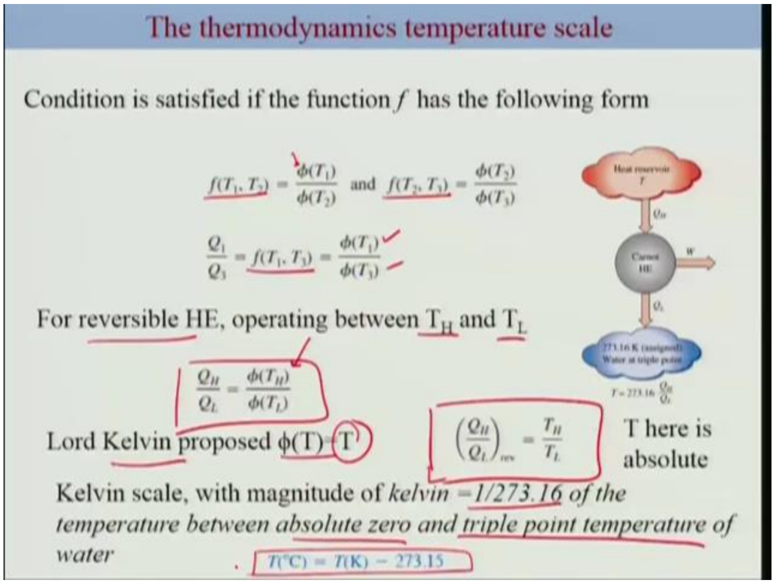

## The thermodynamics temperature scale

Condition is satisfied if the function $f$ has the following form

$$f(T_1, T_2) = \frac{\phi(T_1)}{\phi(T_2)} \quad \text{and} \quad f(T_2, T_3) = \frac{\phi(T_2)}{\phi(T_3)}$$

$$\frac{Q_1}{Q_3} = f(T_1, T_3) = \frac{\phi(T_1)}{\phi(T_3)}$$

For reversible HE, operating between $T_H$ and $T_L$

$$\boxed{\frac{Q_H}{Q_L} = \frac{\phi(T_H)}{\phi(T_L)}}$$

Lord Kelvin proposed $\phi(T) = T$

$$\boxed{\left(\frac{Q_H}{Q_L}\right)_{rev} = \frac{T_H}{T_L}}$$

T here is absolute

Kelvin scale, with magnitude of *kelvin = 1/273.16 of the temperature between absolute zero and triple point temperature of water*

$$\boxed{T(°C) = T(K) - 273.15}$$

Let me further get into this what we have written here and define what kind of functions we can consider. So the function which we are talking here is a function that could be many forms, so what we are making use the fact that this particular expression based on which you can conclude this. So what we can come up with the function F which is simply the ratio of this function Phi will be the one which will satisfy the previous statement.

So here what we have done here is that this function is simply a ratio of Phi which depends only the temperature, and similarly F T2 T3 can be simply the ratio of Phi T2 and T3. Okay, thus Q1 by Q3 which is a function of T1 and T3 independent of T2 can be simply written as Phi T1 divided by Phi T3. So this is one of the function which satisfy the previous conclusion.

Now our reversible heat engine which operates between Th and Tl, you can write Qh by Ql as simply Phi Th by Tl. Now there are many functions which would satisfy this, one of the function which was proposed by Kelvin was simply replacing Phi T by simply the temperature in absolute term. So in other word based on Kelvin proposal we can write Qh by Ql for the reversible heat engine as simply the ratio of Th by Tl. This on the basis of Kelvin Thermodynamic scale, okay, or Kelvin scale.

So, in the Kelvin scale triple point is fixed at 273 point 16 Kelvin, and the magnitude of Kelvin is basically 1 by simply 273 point 16, that becomes the Kelvin Unit, okay. So which is nothing but the temperature between absolute zero and triple point temperature of water. Okay, the temperature (())(10:29) to you in this form which we have already discussed.

Now this is very cumbersome way to calculate temperature or to measure the temperature. Better way off course is to make use of constant volume gas thermometer. Okay, but what we are going to make use of it is expression of Qh by Ql for reversible heat engine as simply as Th by Tl. Okay, and this particular kind of hypothetical heat engine which operates reversible Carnot Cycle would be called Carnot Heat engine.

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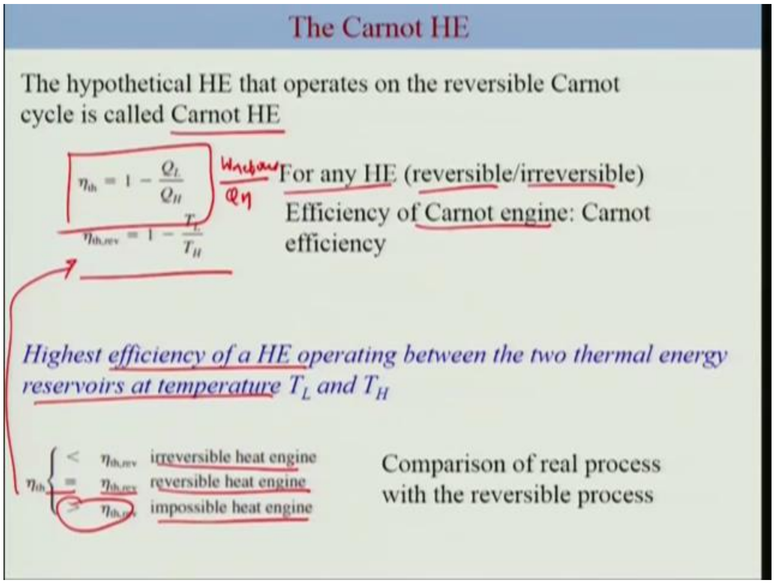

### The Carnot HE

The hypothetical HE that operates on the reversible Carnot cycle is called Carnot HE

$$\boxed{\eta_{th} = 1 - \frac{Q_L}{Q_H}} \quad \frac{W_{net,out}}{Q_H}$$

For any HE (reversible/irreversible)

$$\eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

Efficiency of Carnot engine: Carnot efficiency

*Highest efficiency of a HE operating between the two thermal energy reservoirs at temperature* $T_L$ *and* $T_H$

$$\eta_{th} \begin{cases} < \eta_{th,rev} & \text{irreversible heat engine} \\ = \eta_{th,rev} & \text{reversible heat engine} \\ > \eta_{th,rev} & \text{impossible heat engine} \end{cases}$$

Comparison of real process with the reversible process

So let me just describe a bit more here. Okay, so for any heat engine reversible or irreversible we know that the N efficiency is 1 minus Ql by Qh, or W net out divided by Qy. If you are assuming that your heat engine operates on a reversible Carnot cycle, what you can do is that you can replace Ql by Qh simply by Tl by Th. So this is the efficiency of a Carnot Engine, okay, or you can call Carnot Efficiency. So this will be the highest efficiency of heat engine which operates between two thermal energy reservoir at temperature Tl and Th.

Okay, so you can clearly see that if you increase the temperature of the high temperature reservoir, the efficiency will increase. All the way around if you can decrease the temperature of lower or can sink the temperature then the thermal efficiency will increase.

Now you can compare the real process with the reversible process. Reversible heat engine is defined as this as we have already mentioned, okay, that is your this definition. So, efficiency of irreversible heat engine should be, the efficiency of irreversible heat engine should be low compared to the reversible one, and this would be impossible, you cannot have any heat engine which can be greater than efficiency of the reversible one, okay. So that is the comparison of Carnot heat engine.

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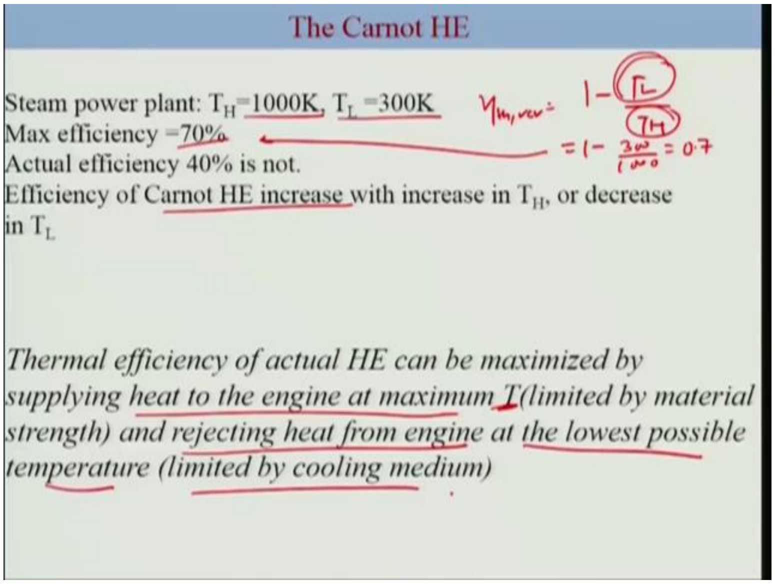

## The Carnot HE

Steam power plant: $T_H$=1000K, $T_L$ =300K

Max efficiency =70%

Actual efficiency 40% is not.

Efficiency of Carnot HE increase with increase in $T_H$, or decrease in $T_L$

$\eta_{th,rev} = 1 - \frac{T_L}{T_H}$

$= 1 - \frac{300}{1000} = 0.7$

*Thermal efficiency of actual HE can be maximized by supplying heat to the engine at maximum T(limited by material strength) and rejecting heat from engine at the lowest possible temperature (limited by cooling medium)*

So, let us take a simple example. Example of a steam power plant, where Th can be 1000 Kelvin, and Tl as a room temperature 300 Kelvin. So the maximum efficiency based on Eta Theta reversible 1 minus Tl by Th or 1 minus 300 by 1000 is equal to be point 7, or 70 percent, okay, and actual efficiency would be much lower 40 percent approximately. As we have already mentioned the efficiency of heat engine increases with decrease in Tl or increase in Th.

So Thermal efficiency of actual heat engine can be maximized by supplying heat to the engine at maximum temperature which will be limited by the material strength of heat engine, and rejecting heat from engine at a lowest possible temperature which will be limited by the cooling medium.

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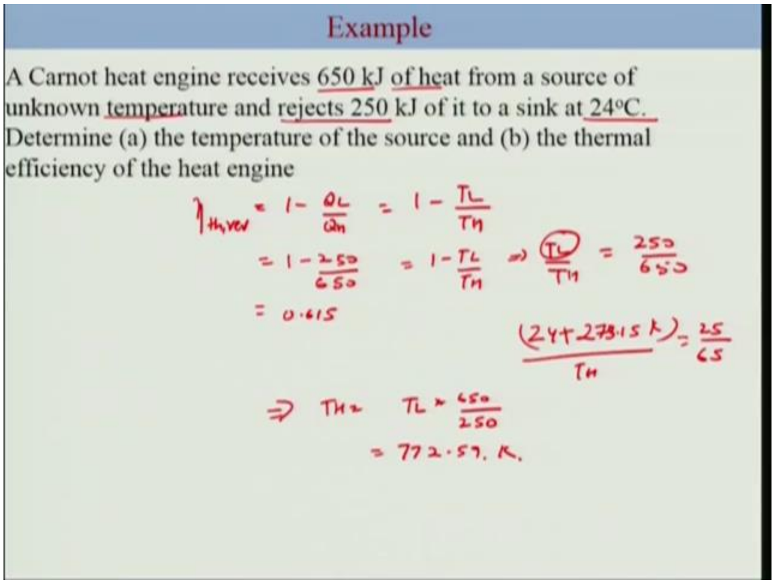

## Example

A Carnot heat engine receives 650 kJ of heat from a source of unknown temperature and rejects 250 kJ of it to a sink at 24°C. Determine (a) the temperature of the source and (b) the thermal efficiency of the heat engine

$$\eta_{th,rev} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

$$= 1 - \frac{250}{650} \quad = 1 - \frac{T_L}{T_H} \Rightarrow \frac{\boxed{T_L}}{T_H} = \frac{250}{650}$$

$$= 0.615$$

$$\frac{(24 + 273.15\ K)}{T_H} = \frac{25}{65}$$

$$\Rightarrow T_H = T_L \times \frac{650}{250}$$

$$= 772.57.\ K.$$

So, let me take an example to the learning of Carnot Heat Engine. This is an example of Carnot Heat engine which receives 650 kilo Joule of heat from a source of unknown temperature, and rejects 250 kilo joule or it to sink at 24 degree Celsius, and we have to determine the temperature of the source, and the thermal efficiency of the heat engine.

So, let us start with the first definition of Eta, okay, so Eta thermal reversible 1 minus Ql by Qh this would be 1 minus Tl by Th. So this is nothing but 1 minus 250 by 650, or this would be 0.615. So that would be your efficiency. This is also equal to Tl by Th which is essentially based on Tl by Th is nothing but 250 by 650, okay. So we already know that temperature Tl is known.

Now this Tl has to be in absolute term. This should be 24 plus 273 point 15 Kelvin and TL 25 by 65, okay. So you can calculate your Th as Tl into 650 by 250, or in other words this would come out to be Kelvin. So this is simple exercise which make use of the definition of Thermal Efficiency of Carnot Heat Engine, okay, where we have replaced 1 minus Ql by Qh is equal to 1 minus Tl by Th.

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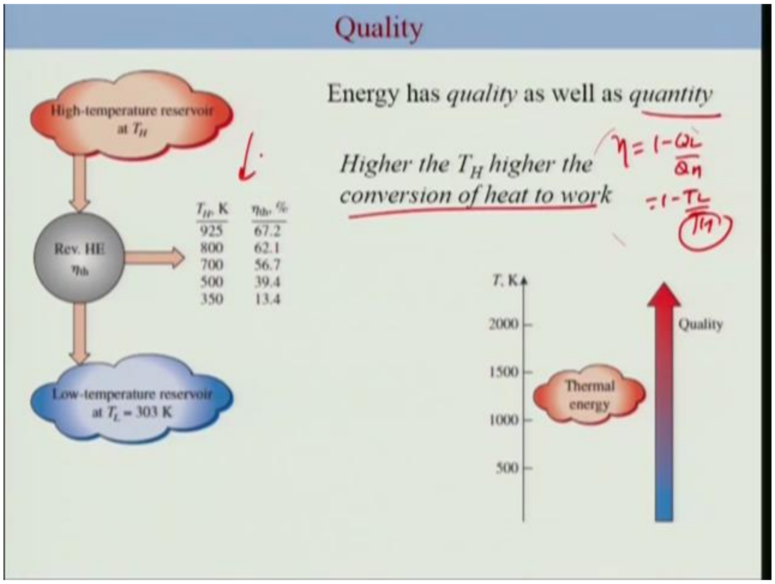

Quality

Energy has *quality* as well as *quantity*

*Higher the $T_H$ higher the conversion of heat to work*

$$\eta = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{\boxed{T_H}}$$

| $T_H$, K | $\eta_{th}$, % |
|---|---|
| 925 | 67.2 |
| 800 | 62.1 |
| 700 | 56.7 |
| 500 | 39.4 |
| 350 | 13.4 |

Now let me just describe a bit of this understanding that you can for the case of Carnot Heat Engine, we have written already this. And we have already mentioned that higher the temperature Tl, higher is the efficiency which essentially means that the conversion is equal to be higher of heat to work, okay. So energy has a quality as well as quantity, and this particular aspect of your Eta and the conversion of Ql by Qh by Tl by Th suggests clearly that your heat efficiency decreases the temperature which is shown in this form.

So in another words you can have higher conversion of heat to work at higher temperature. So in some sense the quality of the energy is much higher at higher temperature, and this is something which is illustrated in this form that the quality increases as temperature thermal energy increases, okay.

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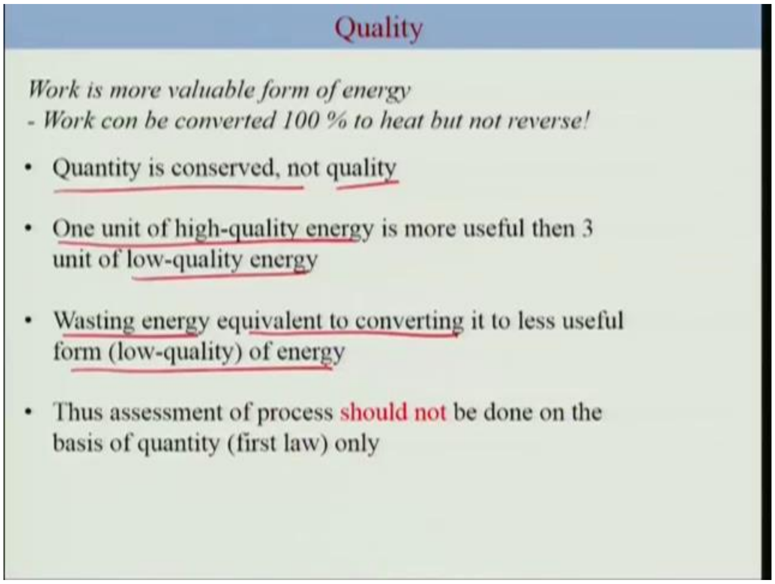

Quality

*Work is more valuable form of energy*
*- Work con be converted 100 % to heat but not reverse!*

- Quantity is conserved, not quality
- One unit of high-quality energy is more useful then 3 unit of low-quality energy
- Wasting energy equivalent to converting it to less useful form (low-quality) of energy
- Thus assessment of process should not be done on the basis of quantity (first law) only

So let me summarize this aspect, that work is more valuable form of energy. We already have discussed this fact work can be completely converted to heat, but not the reverse, and thus your work is of high quality compared to heat, okay. So quantity as we already know can be conserved, but you cannot conserve the quality. So that means heat cannot be completely converted to work which means quality is not conserved, there is a different quality of work and heat.

In a sense we can say that 1 unit of high quality energy is more useful then say 3 units of low quality energy, okay. Or typically in heat engine when we waste energy, this would be equivalent of converting it to less useful low form of quality energy. Thus it is important that whenever we look at the process we should not just talk about the conservation of the quantity, we should also look at the quality aspect.

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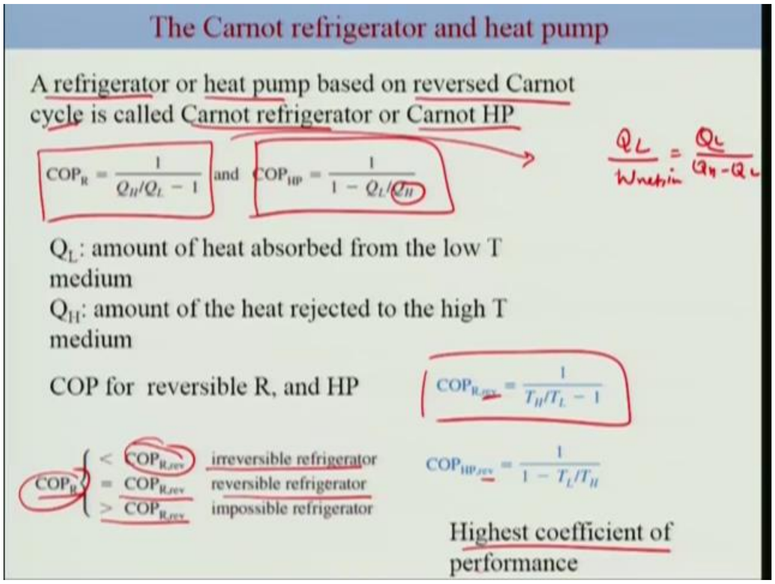

## The Carnot refrigerator and heat pump

A refrigerator or heat pump based on reversed Carnot cycle is called Carnot refrigerator or Carnot HP

$$\boxed{COP_R = \frac{1}{Q_H/Q_L - 1}} \text{ and } \boxed{COP_{HP} = \frac{1}{1 - Q_L/Q_H}}$$

$$\frac{Q_L}{W_{net,in}} = \frac{Q_L}{Q_H - Q_L}$$

$Q_L$: amount of heat absorbed from the low T medium

$Q_H$: amount of the heat rejected to the high T medium

COP for reversible R, and HP

$$\boxed{COP_{R,rev} = \frac{1}{T_H/T_L - 1}}$$

$$COP_{HP,rev} = \frac{1}{1 - T_L/T_H}$$

$$COP_R \begin{cases} < COP_{R,rev} & \text{irreversible refrigerator} \\ = COP_{R,rev} & \text{reversible refrigerator} \\ > COP_{R,rev} & \text{impossible refrigerator} \end{cases}$$

Highest coefficient of performance

Okay, so let me now touch upon Carnot refrigerator, and heat pump which is based on the similar principle. Refrigerator or heat pump based on reversed Carnot cycle, particularly we have already discussed the Carnot cycle, now we are talking about reversed Carnot cycle. Particularly the refrigerator or heat pump if they are based on reversed Carnot cycle, that is called Carnot refrigerator or Carnot Heat Pump.

And we already know Coefficient of performance of Carnot refrigerator, and Carnot Heat Pump. So remember here this is nothing but Ql because you are going to extract this much heat in order to keep the temperature of the refrigerator. Certain temperature, maintain it at a certain temperature.

So this divided by whatever work you pump in, so W net in, okay which is of course Ql by Qh. And similarly you can write this because the desired output would be Qh. So this is the coefficient of performance for the refrigerator and heat pump. So Ql is already known, define here amount of heat absorbed from the low temperature medium. Qh is heat rejected to the high temperature medium, okay.

So, in the case of reverse Carnot Cycle what we are going to do is, we are going to just simply replace Ql by Qh by the ratio of the temperature. So this is what we have written here, and this is subscript reversible means we are making use of the Phi that this is based on reverse Carnot cycle, okay. So this is for the case of refrigerator, and this is for the case of heat pump. So this would be the highest coefficient of performance.

Okay, so similar to what we have done for Carnot heat engine, you can also do the exercise for the case of Carnot refrigerator. This is COPr which is equal to COPr reversible refrigerator. For the case of irreversible, so this would be lower, for the case of irreversible this would be greater than COPr, okay, of irreversible refrigerator.

And this would be the case for impossible refrigerator because you cannot have coefficient performance of refrigerator greater than reversible refrigerator for the case of reversible refrigerator. So this cannot occur, okay. So this is something simple understanding that for the case of reversible or any process based on any Carnot cycle would be having highest thermal efficiency for the case of heat engine, or highest coefficient performance of refrigerator and heat pump.

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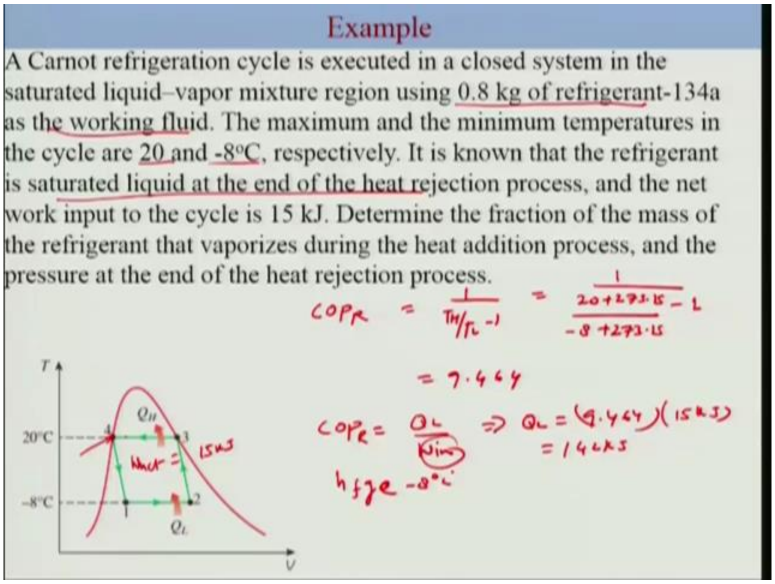

## Example

A Carnot refrigeration cycle is executed in a closed system in the saturated liquid–vapor mixture region using 0.8 kg of refrigerant-134a as the working fluid. The maximum and the minimum temperatures in the cycle are 20 and -8°C, respectively. It is known that the refrigerant is saturated liquid at the end of the heat rejection process, and the net work input to the cycle is 15 kJ. Determine the fraction of the mass of the refrigerant that vaporizes during the heat addition process, and the pressure at the end of the heat rejection process.

$$COP_R = \frac{1}{T_H/T_L - 1} = \frac{1}{\frac{20+273.15}{-8+273.15} - 1}$$

$$= 9.464$$

$$COP_R = \frac{Q_L}{W_{in}} \Rightarrow Q_L = (9.464)(15\,kJ)$$

$$= 142\,kJ$$

$h_{fg}$ @ -8°C

So, let me end this lecture by taking an example. So this is an example of Carnot refrigeration cycle which is executed in a closed system in the saturated liquid vapour mixture region using point 8 kg of refrigerant as the working fluid. The maximum temperature, and the minimum temperature in the cycle are 20 degree, and minus 8 degree Celsius, respectively.

It is known that refrigeration is saturated liquid at the end of the heat rejection, okay. So this is the start here, and started you’re your Carnot (())(19:55) region, okay. Heat is being pumped in, and this process where it evaporates, and here finally at the end of the cycle you have working fluid on the saturation liquid line, okay.

What is being said W net here is 15 kilo joules, determine the fraction of the mass of the refrigerant, and vaporise during the heat addition process, and the pressure at the end of the heat rejection process which is essentially this, okay.

So let us consider ideal Carnot Cycle, okay, this is considered ideal Carnot Cycle then we can simply divide coefficient of performance for refrigerator as Th by Tl minus 1 which if you put the Th is nothing but 20 plus 273 point 15 divided by your minus 8 plus 273 point 15 minus 1 and this turns out to be 9 point 46, okay.

Now COPr is also your Ql by Win, and Win we know that work, and this is essentially means Ql is 9 point 464 into 15 kilo joules, and this is 142 kilo joules, okay. So this is the heat supplied, and the refrigerant has evaporated from 1 to 2 state. So we can find out what is the hfg, heat vaporization at specific minus 8 degree Celsius, okay.

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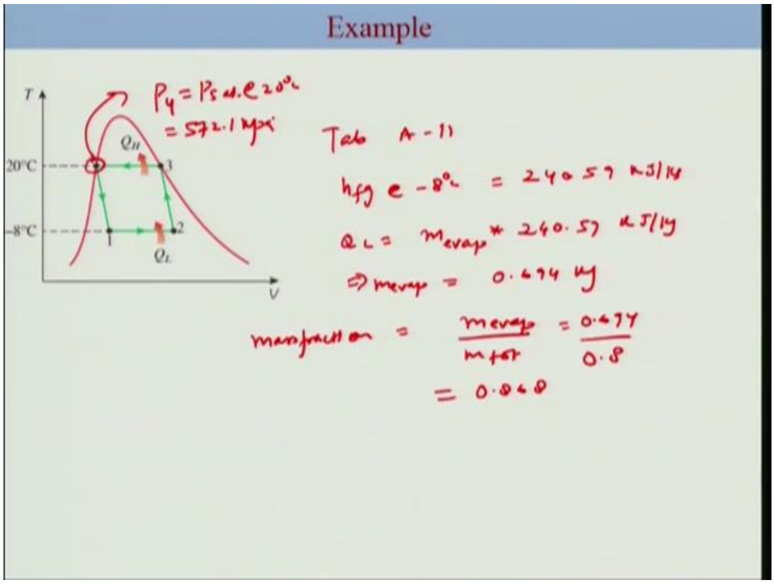

Example

$P_4 = P_{sat} @ 20°C$
$= 572.1$ kPa

Tab A-11

$h_{fg} @ -8°C = 240.59$ kJ/kg

$Q_L = m_{evap} * 240.59$ kJ/kg

$\Rightarrow m_{evap} = 0.494$ kg

mass fraction $= \frac{m_{evap}}{m_{tot}} = \frac{0.494}{0.8}$

$= 0.848$

So, let us look at the table. Table A 11 gives you hfg at minus 8 degree Celsius is 240 point 59 kilo joules per kg, okay. So, Ql is nothing but M, whatever amount have been evaporated multiplied by 240 point 59 kilo joules per kg, and thus you can find out M evaporation with the mass of refrigerant which has been evaporated, and this turns out point 694, okay.

So, mass fraction amount of mass which has been evaporated divided by the total mass initially present. So that is the mass fraction which has been evaporated. So this mass fraction is M evaporation divided by M total, okay, 0.694 divided by 0.8, and this turns out to be 0.868. Now pressure here at the end is P4 which is Ps at 20 degree Celsius, okay, which turns out to be 572 point 1 Kilopascal. Okay, so that will be the kind of exercise which we typically have to do, and this will be the end of the lecture. Let me just summarize what we have done in this particular module.

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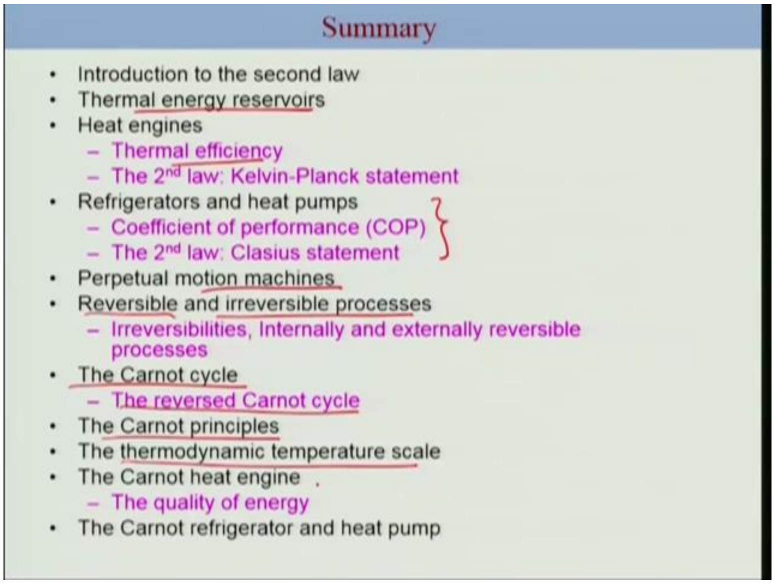

## Summary

- Introduction to the second law
- Thermal energy reservoirs
- Heat engines
  - Thermal efficiency
  - The 2nd law: Kelvin-Planck statement
- Refrigerators and heat pumps
  - Coefficient of performance (COP)
  - The 2nd law: Clasius statement
- Perpetual motion machines
- Reversible and irreversible processes
  - Irreversibilities, Internally and externally reversible processes
- The Carnot cycle
  - The reversed Carnot cycle
- The Carnot principles
- The thermodynamic temperature scale
- The Carnot heat engine
  - The quality of energy
- The Carnot refrigerator and heat pump

We have introduced the second law of Thermodynamic, okay. We talked about Thermal Energy Reservoirs, and essentially we define the Thermal Efficiency well through the statement of Kelvin Planck, and Clasius Statement, okay. We discussed Coefficient performance or refrigerators and Heat pumps. We also discussed Perpetual Motion machines violates first law as well as the second law, so of type one and type two. We defined reversible and irreversible processes, and finally we introduced the Carnot Cycle, and as well as Reversed Carnot Cycle.

So, in today’s part we concluded Carnot Principle, and defined Thermodynamic scale, the definition of Kelvin Scale, and then illustrated examples, and introduce this Carnot Heat Engine as well as Carnot refrigerator and heat pumps.

So, that would be the end of today’s lecture as well as this particular module. So next time we will start a new sub chapter, and I will see you in a next lecture.