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Course
On
Laws of Thermodynamics

by
Prof. Suman Chakraborty
Department of Mechanical Engineering
Indian Institute of Technology Kharagpur

Lecture 21: Review of Learning Concepts

So today we are going to have a review session where we will essentially try to divide certain concepts on entropy by asking some short questions.

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STATE TRUE OF FALSE

1. All isothermal processes must be reversible.
2. $\oint \delta Q$ may $\rightarrow 0$ for irreversible heat engines.
3. A process with no net change in the system entropy must necessarily be reversible and adiabatic.
4. All slow processes must necessarily be reversible.
5. Throttling of an ideal gas is approximately an isothermal process.
6. Area of a closed loop representing a thermodynamic cycle in a T-s diagram signifies the net work done in a cyclic process.
7. A process with zero net change in entropy must necessarily be isentropic.
8. A piston/cylinder arrangement contains water at 40 °C. Heat is transferred into the cylinder from a heat source at 100 °C, and the water expands in a quasi equilibrium process. The process is reversible.
9. A system undergoes change in state from (1) to (2) by
   (a) reversible
   (b) irreversible process.

Change in entropy of the system is greater in case (b).

10. The entropy of a fixed mass of ideal gas decreases in every isothermal compression.
11. The specific internal energy, enthalpy and entropy of an ideal gas are each functions of T alone.
12. A process that violates the 2^{nd} law, violates the 1^{st} law too.
13. One corollary of the 2^{nd} law state that change in entropy of a closed system must be greater than or equal to zero.
14. A closed system can experience an increase in entropy only when there is energy transfer by heat to the system during the process.
15. Constant pressure lines in h-s diagram have negative slopes.
16. Entropy of a system can decrease or increase during heat rejection process.

So I have projected the questions on the screen, but I will read these questions out and we will discuss these questions one by one. So these questions are relating to state whether the following statements are true or false. So certain statements are given you have to say whether these are true or false and in case you are able to give the correct answer you also have to justify it okay. So the first question is all isothermal processes must be reversible, this is the first statement, so true or false. So let us try to analyze this.

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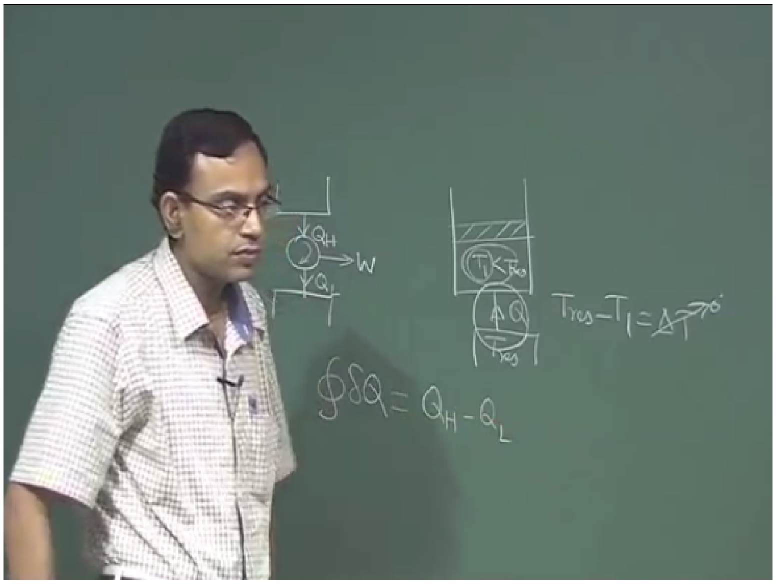

Let us say there is a piston cylinder arrangement and there is a heat transfer from a thermal reservoir. Let us say the temperature within the system is T1 which is less than T reservoir. So that there is a heat transfer, so if this temperature T1 of the system remains the same there is an isothermal process for the system and if it is isothermal it is suppose to be a very slow process, so that it is a reversible isothermal process.

However, the reversible isothermal process by reversible we mean internally reversible, but if you look at this temperature difference between the thermal reservoir and the system boundary, there may be a finite temperature difference. So isothermal may assure internal reversibility, but it will never assure total reversibility. It will be totally reversible process if this T reservoir minus T1 is some ΔT very small tending to 0, then it is reversible, externally reversible.

Otherwise, it is not externally reversible and we can say that it is just an internally reversible process. So all isothermal processors must be reversible this statement is not correct. Let us consider the second statement, cyclic integral of δQ may tend to 0 for irreversible heat engines. So cyclic integral of δQ, so let us say that there is a heat engine which takes heat QH rejects heat QL and thus some work W in a cyclic process.

So cyclic integral of δQ is QH-QL, can it tend to 0 for an irreversible heat engine? Surely, because the difference of this is work done, and if the engine is highly reversible the work done will be less unless and therefore, in the limiting condition for a highly reversible situation this may tend to 0. The third question is a process with no net change in the system entropy must necessarily be reversible and adiabatic. So a process with no net change in entropy must necessarily be reversible and adiabatic.

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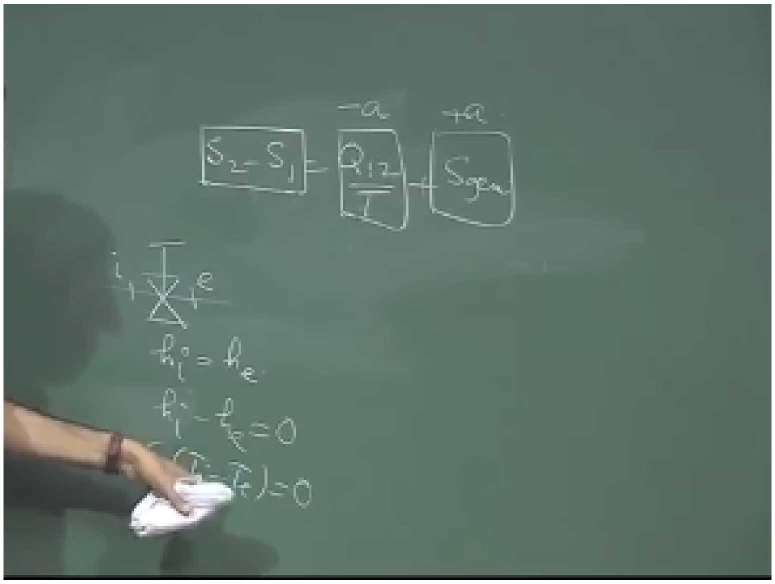

See let us write the expression for change in entropy of the system. S2-S1=Q12/T+Sgen, so what is saying is that this is 0, how can this be 0? There are some possibilities one is, it is a reversible adiabatic process, if it is reversible entropy generation is 0 if it is adiabatic Q12 is 0. However, there would be some other case also when this is 0, when this is 0, for example, this is some minus positive number a when this is negative when heat is transferred from the system to the surroundings.

And let us say this is +a so then the total is 0, but it is not a reversible and adiabatic process. So net change in entropy is 0 does not mean it is an isentropic process, isentropic means the entropy remains same throughout the process not just the final entropy minus initial entropy is 0. So this is the case when the change in entropy at the end of the process is 0, but it is not reversible and adiabatic.

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So a process with no net change in system entropy need not necessarily be revisable and adiabatic let us consider the 4th question all slow process must necessarily be revisable so this is also not true because all slow process must necessarily be internally reversible but they may be externally revisable so if they are externally revisable that means that net process becomes irreversible. The next question is throttling of an ideal gas is approximately an isothermal process.

So throttling the process of throttling something like this so you have a throttle volve and across the volve the fluid is flowing in such a way that there is no scope of any heat transfer or work done and if you neglected changes in kinetic energy and potential energy the first law for a steady flow process will tell that $h_i = h_e$ remember that this does mean that it is an isentropic process.

The enthalpy does not remain same it is just the enthalpy before immediately before throttling same as enthalpy immediately after throttling but we are talking about an ideal gas so now this means that dh so $h_i - h_e = 0$ so if it is a constant specific heat even if it is a constant specific heat it means Cp (Ti – Te) = 0 not for all ideal gas only for ideal gas with constant specific heat but even then you cannot say that it is an isothermal process.

Why because it is for an ideal gas with constant Cp Cv this means that the temperature before throttling is same as temperature after throttling but this does not mean that temperature remains same throughout the process, so it is an isothermal process.

Next question area under the close loop representing a thermodynamic cycle in Ts diagram signifies the net work done in a cycle process so if you have a Ts diagram and you have a area enclosed in the Ts diagram.

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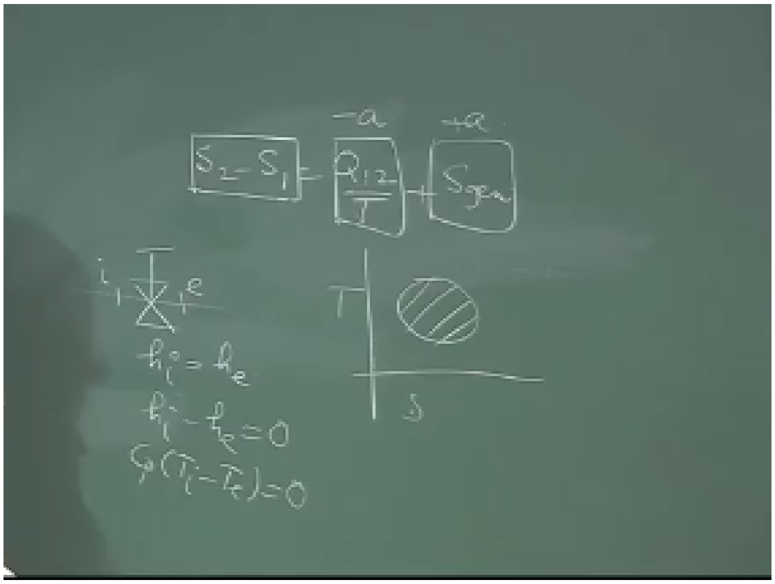

So the area enclosed in the Tds in the Ts diagram in a cyclic process, so that is integral of Tds that will be ∂Q provided it is a revisable process, so if it is a revisable process the of course this area also represents the work done because cyclic integral heat = cyclic integral of work from the 1st law of thermodynamics but if the process is such that it is not totally a revisable process then you cannot write ∂ Q = Tds and then this equivalence will not be there.

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Next question a process with 0 net change in entropy must necessarily be isentropic so this is the same question that we had here 0 net change in entropy means s2 – s1 = 0, so s2 – s1 is = 0 does not mean it is an isentropic process because it just indicates that the final entropy is same as the initial entropy but it does not assure that entropy remains constant throughout the process. Next question a piston cylinder arrangement contains water at 40^0C heat is transferred into the cylinder from a heat sources at 100^0C.

And water expands in a cross equilibrium process the process is revisable clearly the process the cylinder the water expands in a cross equilibrium process that means it is internally revisable however there is a temperature difference between the system and the heat source is 100^0C and system bounded is at 40^0C so because of this finite temperature difference cross which heat transfer is taking place it is an externally irreversible process.

Therefore the process is not irreversible it is only internally irreversible but not externally revisable next question a system undergoes change in state from state1 to state 2 by a revisable and irreversible process that change in entropy of the system is greater in the irreversible process this is not true. Because when the system goes from state 1 to state 2 that change in entropy s2-s1 does not depend on the path it depends only on the end state 1 and 2 because it is a point function the entropy is a point function the next question the entropy of a fixed mass of ideal gas decreases in every isothermal compression so entropy of a fixed mass of an ideal gas decreases in every isothermal compression, so let us try to address these question so let us try to use this.

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10. The entropy of a fixed mass of ideal gas decreases in every isothermal compression.
11. The specific internal energy, enthalpy and entropy of an ideal gas are each functions of T alone.
12. A process that violates the 2nd law, violates the 1st law too.
13. One corollary of the 2nd law state that change in entropy of a closed system must be greater than or equal to zero.
14. A closed system can experience an increase in entropy only when there is energy transfer by heat to the system during the process.
15. Constant pressure lines in h-s diagram have negative slopes.
16. Entropy of a system can decrease or increase during heat rejection process.

TdS relationship TdS = dh – Vdp for an ideal gas dh is Cpdt isothermal means dt is 0 so ds is – vdp / T compression means pressure increases right, so decrease positive specific volume is positive and this is absolute temperature it is always positive so dS is negative that means entropy of a fixed mass of an ideal gas decreases in every isothermal compression next question the specific internal energy enthalpy and entropy of an ideal gas are each functions of temperature alone.

So internal energy and enthalpy of an ideal gas are functions of temperature alone but entropy is not right, we call the formula for change in entropies if an ideal gas with constant CP CV so S_2 – S_1 is C_p and T_2 – T_1 – R_{ln} P_2 / P_1 so you can see that entropy of an ideal gas will depend on temperature, so entropy of an ideal gas is not is a function of temperature as well as pressure whereas internal energy and enthalpy of functions of temperature only, but entropy is a function of temperature and pressure or temperature and specific volume right.

So this statement is not correct again I am repeating the specific internal energy and enthalpy are functions of temperature only for an ideal gas but entropy is the function of the temperature as well as pressure next question are process that highlights second law highlights the first law to this is not correct because second law talks about the directionality of available process, so according to first law if energy balance is satisfied you can still have heat transfer from a lower temperature body to a higher temperature.

Body without any work input however according to second law such a process will not be visible until that analyze will give a work input, so even though you satisfy energy balance which is the essence of first law and second law may not be satisfy so a process that while a second law violates the first law to is not correct, in a sense that a process that violated second law may not violate first law energy balance is satisfied but second law is not satisfied. Next question one correlated.

Of the second law states that the change is entropy of a close system must be greater than or equal to 0, so the change in entropy of a close system if you see this is the change in entropy of a close system can we guarantee whether this is positive negative or 0, we do not give a guarantee see where it many times we loosely say that entropy always increases but we do not mention that it is entropy of the universe system + surrounding together that increases, entropy of a system or surrounding separately.

Those might either increase or decrease or remain the same sum total of entropy of the system and surrounding if you consider that will always increase so for example entropy of system can decrease how it can decrease like if you have heat rejection then this negative for this is always positive for all cases so some total may be positive negative or 0 so entropy of a close system just change in entropy of a close system must be greater than or equal to 0 this is not a correct statement.

Next question a close system can experience and increase in entropy only when there is energy transfer by heat to the system during the process, so a close system that experience and increase in entropy only when there is energy transfer by heat to the system during the process that is not correct even this heat transfer is not there or there is heat transfer from the system a close system can in experience that an increase in entropy because of generation right.

So this statement is not correct next question number 15 constant pressure lines in ages diagrams have negative slope ages diagrams are very important and for steam this particular diagram is also known molecular diagram moldier chart which is used commonly in industry so why this diagram is important is because for working out various changes in thermodynamic properties for analyzing devices in power plants you may often may required the enthalpy and entropy data.

So if you have enthalpy what it is entropy diagram, by looking into the diagram you can immediately read out the data, so the question is constant pressure lines in the ages diagram have negative slopes so let us write this.

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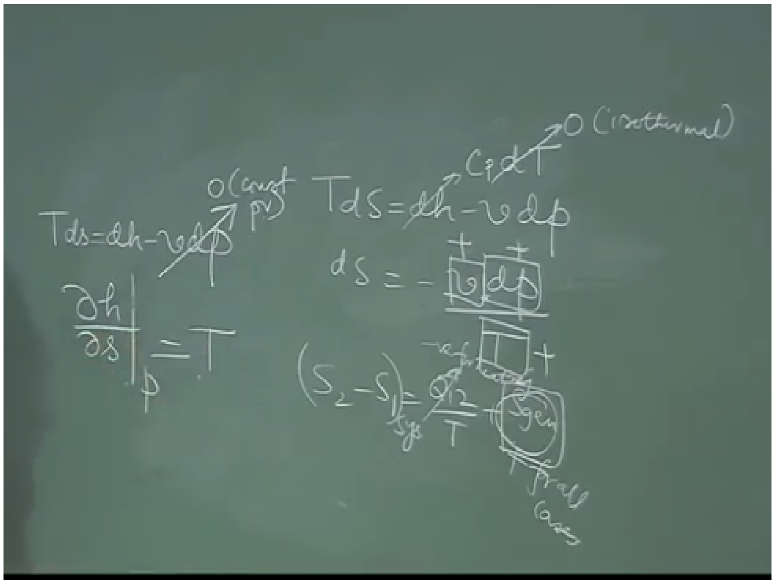

Tds = dh vDP constant pressure line means Dp is 0. So you can write in the HS diagram the slope of the constant pressure line is the absolute temperature and the absolute temperature is always positive, so constant pressure lines in the HS diagram will have positive slope because this is absolute temperature this is always positive. The next question entropy of a system can decrease or increase during heat rejection process? So during heat rejection process this us negative entropy generation is always positive some total may be positive negative or 0 so during heat rejection entropy of a system may decrease it may increase or it may, may not change.

All these three possibilities are there during a heat rejection process so entropy of a system can decrease or increase during heat rejection process this is possible even it may remain same, okay. Now I will come to a difference set of short questions.

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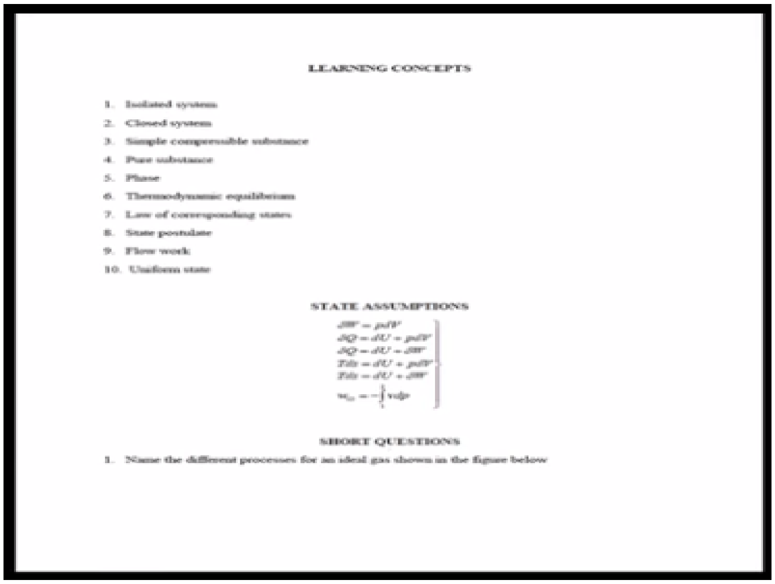

LEARNING CONCEPTS

1. Isolated system
2. Closed system
3. Simple compressible substance
4. Pure substance
5. Phase
6. Thermodynamic equilibrium
7. Law of corresponding states
8. State postulate
9. Flow work
10. Uniform state

STATE ASSUMPTIONS

$$\left.\begin{array}{l} \delta W = pdV \\ \delta Q = dU + pdV \\ \delta Q = dU + \delta W \\ Tds = dU + pdV \\ Tds = dU + \delta W \\ w_{12} = -\int_1^2 vdp \end{array}\right\}$$

SHORT QUESTIONS

1. Name the different processes for an ideal gas shown in the figure below

So this set of short questions so because this is a review section I want you to review this following concepts and I do not want to give you the answers to these learning concept because we have already discussed in great details but just consider this isolated system so a system that does not interact with the surrounding close system simple compressible substance pure substance phase thermodynamic equilibrium law of corresponding state, state postulate flow work, uniform state.

So please try to revise these learning concepts so these concepts are important because I mean based on these concepts you can basically develop a foundation on the basic laws of thermodynamics, these are not exactly the laws of thermodynamics but these are concepts which act as preludes to the practical application and realization of the various intricacies of the laws of thermodynamics.

Next the next questions we will discuss state the assumptions behind the equations that are given, first equation δw = Pdv so what are the assumptions for δw = pdv? The assumptions are very straight forward simple compressible substance and quasi equilibrium process these are just the two Important assumptions there is no other assumption that goes behind this, next δQ = du + pdv. So basically it is a first law where you have neglected first law for a close system where you have neglected the changes in kinetic energy and potential energy. That is why du and not d and in place of δw you have written pdv that means you have assume it is a quasi equilibrium process.

So it is a first law for a closed system with negligible changes in kinetic energy and potential energy and quasi equilibrium process δQ = du + δw so δQ = d u + δw is the first law for any process for a close system then next tds = so this s will be capital S, TDS = du + pdv so TDS = du + pdv this is the TDS relationship that is valid for any process now I want to discuss a little bit of this because there are confusions on this in almost all students. That why th3e TDS relationship is valid for all process.

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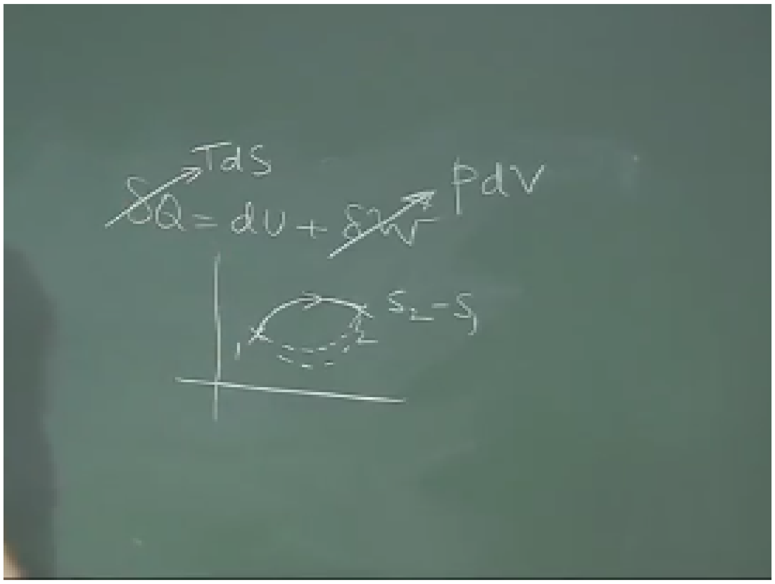

So if you write ∂ q = du + ∂ w for a reversible process for a simple compressible substance you write pdv, reversible process for simple compressive is substance you write TDS so that means this you are considering a reversible process of a simple compressible substance but then how do you claim that is true for any process is true for any process in a sense that if you use this to calculate the change in entropy between two states one and two you just construct a reversible hypothetical reversible process and calculate s2 – s1 using this formula by integrating this.

Once you have evaluated this that s2 – s1 will remained valid even if you have any other arbitrary process which is not reversible because it is point function, and all the parameters here in this formulas are point functions. Therefore it is valid for any process, so the integration of this formula has to be carried over a reversible path but once the integration has been carried out that result can be applied for any process that is the spirit of calling that or mentioning that this is valid for any process provided it is a simple compressible substance.

Next one TDS = du + ∂w again here ds will be D capital S TDS = du + ∂w, so what are the assumptions? See this is first law where you have substitute a ∂q = TDS that means this must be a reversible process you may argue that if it must be a reversible process why you have not written ∂w as pdv the reason is that it might not be a simple compressible substance it could be another case where other forms of worker also there so you are actually not committing what is ∂w.

But as you have committed that ∂ q = TDS that means you have committed it is a reversible process. The last one state the assumptions w = - integral of vdp so this is any reversible steady state steady flow process with single inlet and single outlet with negligible changes in kinetic energy and potential energy. The derivation of this formula we have done in the in one of the lecture, so you already know but the assumptions we can summarize that steady state steady flow process with single inlet and single outlet and negligible changes in kinetic energy and potential energy, okay next question.

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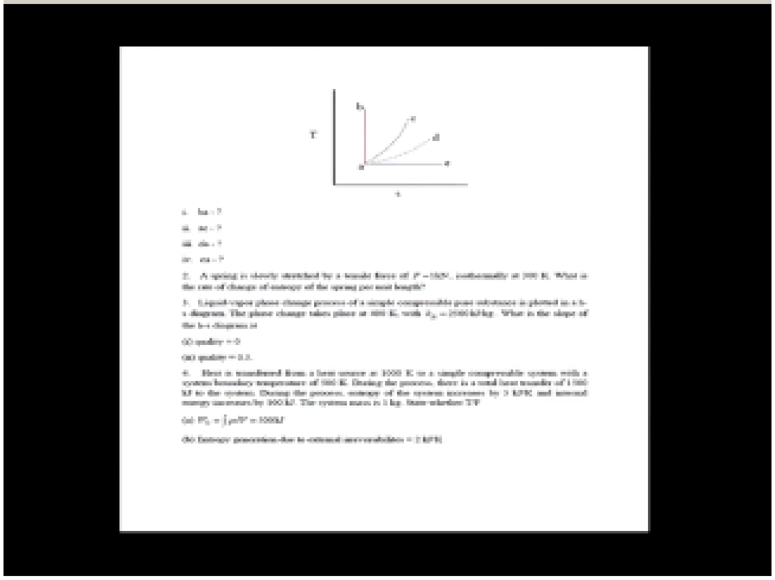

There is a Ts diagram given here you can see where there are sudden lines which are drawn for an ideal gas and the may be ideal gas as a special case you may consider ideal gas with constant cpc. So what do these lines represent so V_A, V_A is what so this you can tell very clearly? So it is an isentropic process no doubt about it but expansionary compression so let us see, let us use the TDS relationship here, so TDS = D_h – vdp. So reversible adiabatic process means ds = 0.

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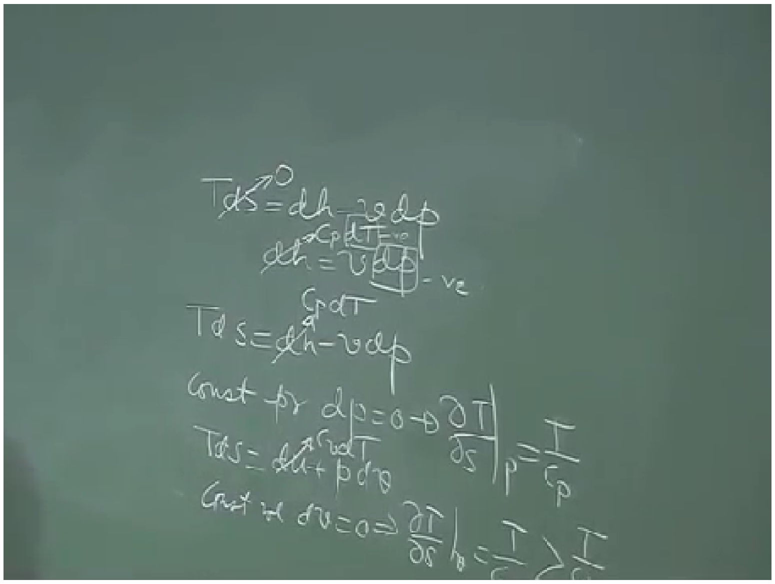

So D_h = vdp dh is for an ideal gas is cp D_t, so as you go from b to a if you look in to the diagram here if you go from b to a the temperature is decreasing that means D_t is negative, that means itself expansion so it as an isotropy expansion.

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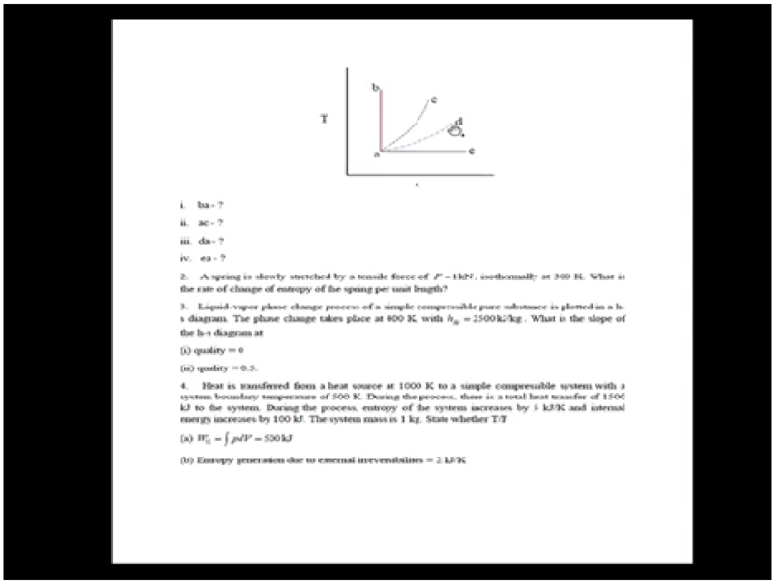

i. ba - ?

ii. ac - ?

iii. da - ?

iv. ea - ?

2. A spring is slowly stretched by a tensile force of $F = kx$, isothermally at 300 K. What is the rate of change of entropy of the spring per unit length?

3. Liquid-vapor phase change process of a simple compressible pure substance is plotted in a h-s diagram. The phase change takes place at 400 K with $h_{fg} = 2500$ kJ/kg . What is the slope of the h-s diagram at

(i) quality = 0

(ii) quality = 0.5.

4. Heat is transferred from a heat source at 1000 K to a simple compressible system with a system boundary temperature of 500 K. During the process, there is a total heat transfer of 1500 kJ to the system. During the process, entropy of the system increases by 5 kJ/K and internal energy increases by 100 kJ. The system mass is 1 kg. State whether T/F

(a) $W_{12} = \int pdV = 500$ kJ

(b) Entropy generation due to external irreversibilities = 2 kJ/K

Next AC and DA so we are trying to consider whether out of this two I give a choice one is a constant volume and another is constant pressure so out of this two which one is constant volume line which one is constant pressure line so you have Tds=dh-bdp so for constant pressure now dh is Cp dT so constant pressure means dp is equal to 0.

So ∂T/∂S at constant pressure is equal to T/Cp similarly if you see Tds is du/pdQ and for ideal gas is du is Cv dT for constant volume dv is 0 that means ∂T/∂S is T/ Cv so out of this two which one is because Cv is less than Cp so T/ Cv is better than T/Cp so constant volume line in a Ts diagram must be cheaper than the constant pressure line.

So if you look into the diagram here AC must be constant volume and AT must be constant pressure so out of this two one is heat addition and the heat rejection so if you have entropy increases that will be necessary in heat addition but if you have entropy decrease that one also must be heat rejection so AC is constant volume heat addition and DA is constant pressure heat rejection.

If you have an option between constant volume and constant pressure EA is what is EA, EA the temperature is constant so it is isothermal process from E to A if you are going it is heat rejection so it is an isothermal heat rejection process okay now we will work out a couple of short questions and this questions are short problems this questions are typically very short problems.

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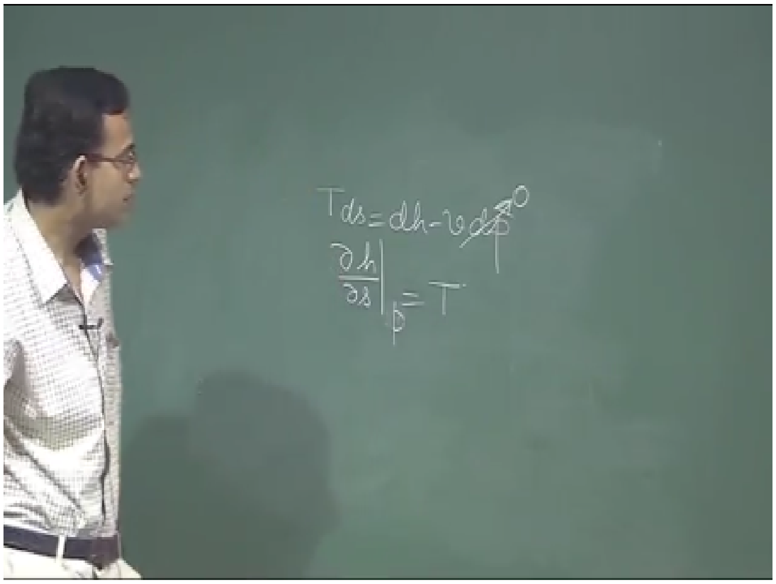

So the question is this is question number two given in the screenshot but I am repeating this question a spring is slowly stretched by a tensile force of one kilo neutron isothermally at 300 Kelvin what is rate of change of entropy of the spring per unit length so this is the case where you have to use Tds =du instead of pdv now it is a spring stretching watt minus fdx why this minus this is minus because when the pdv work is done work leaves the system and when does spring is stretched.

So when the displacement of the spring with the force this is watt come by the force and when you come to the pdv that is watt done against the registers so it is just a different watt of looking into so you can write so du is cdT under isothermal condition this is 0 so ∂S/∂x constant temperature is minus F/T so the spring force is given as 1 kilo neutron and the absolute temperature is 300 Kelvin. So you can calculate this one so the entropy decreases because this is negative.

So on stretching of spring the entropy decreases why? Because if the spring is coiled there are large number of possible micro state for the given micro scope state, if the spring is stretched, then the number of micro states for given micro state that decreases, if it is stretched, so less number of probably micro state for given micro states, next question, question number 3.

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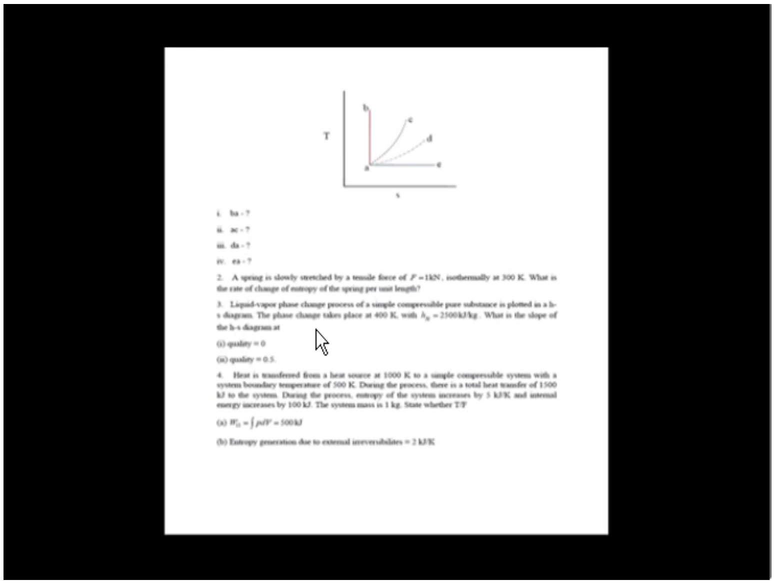

i. ba - ?

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2. A spring is slowly stretched by a tensile force of $F = 1kN$, isothermally at 300 K. What is the rate of change of entropy of the spring per unit length?

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(a) $W_{12} = \int pdV = 500 kJ$

(b) Entropy generation due to external irreversibilites = 2 kJ/K

Liquid vapor phase change process of the single compressible pure substance is plotted in the di9agram. The phase change takes place at 400kv with hfg value given. What is the scope of the hs diagram for quality = 0 and quality = 0.5. so basically we are talking about the hs diagram for the phase change process.

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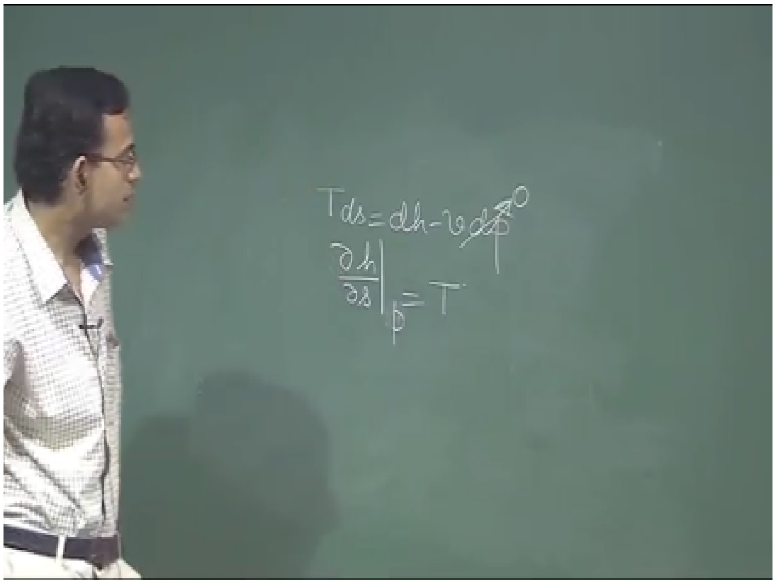

$$Tds = dh - v\cancel{dp}^{0}$$

$$\left.\frac{\partial h}{\partial s}\right|_{p} = T$$

So we will use Tds = dh – vdp for change process of the single compressible pure substance this is 0, so phase change of pure substance takes place at constant pressure , so ∂h /∂s at constant temperature or constant pressure rather constant pressure here means constant temperature also, that is T. So this does not depend on the fraction on quality, it depends only on absolute temperature, so because the absolute temperature same during the phase change process this slope means constant during the phase change process, so it is a essential a straight line. Now the final question of this particular session, heat is transfer from a heat source at 100kv to a simple compressible system.

With the system already temperature of 500kv, during this process there is heat transfer of 1500kj to the system entropy of the system increases by 5kj/kv and internal energy increases by 100kj, the system mass is 1 kg. State whether the following is true or false, the work done = ∫pdv x 500kj and the entropy generation due to external is 2kj/kg. So let us see whatever these statements are correct or not. So let me try to draw a schematic of this.

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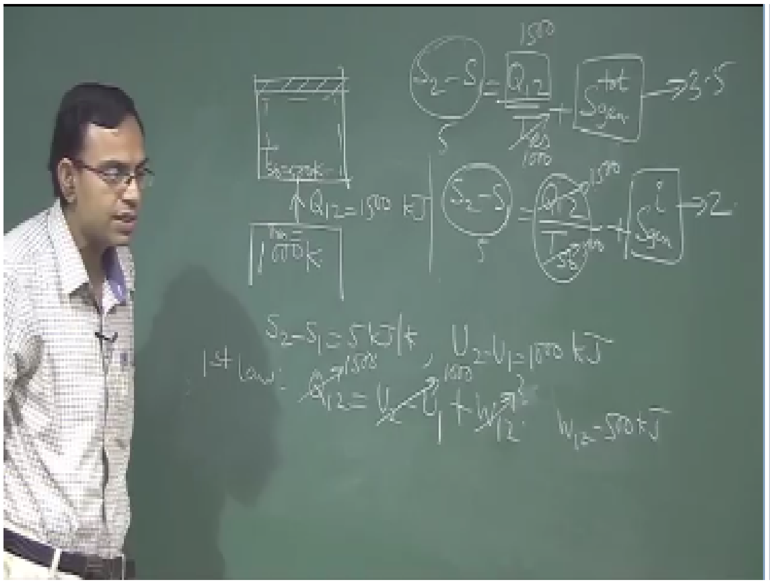

Heat is transferred from the heat source and 100k to a system with the boundary temperature 500k, so this T system boundary this is T reservoir, there is a total heat transfer of 1500kj during the process entropy of the system increases by 5kj/k and internal energy of the system increases by 100kj sorry, 1000kj. So first law if you apply $Q_{12} = U_2 – U_1$ for the system this is the system let us say, + W_{12}. It may be a piston cylinder, so the heat transfer is 1500 and work is 1000, sorry change in internal energy is 1000 so what is the work? That is 1500 -1000 that is 500kj.

Now let us do the 2nd law analysis and take the entropy generation, so we can write $S_2 – S_1 = Q_{12}/T$ + entropy generation $S_2 – S_1$ IS given as 5 the question is what T you will substitute her it depends on as I told are you interested only calculate the internal reversibility and the reality generation and the total entropy generation and we can calculate the to6tal entropy generation then this should be the temperature of reservoir.

And you are interest to calculate only the entropy generation due to the internal reversibility then this is the temperature of the system boundary and this is due to the internal reversibility. So this is what the Q 1` is 15 and the reservoir temperature is one thousand write so this is fifteen hundred / one thousands and it is 1.5 5- 1.5 is 3.5 I am not writing the units.

For this is 5 this is fifteen hundred and the temperature of the system boundary is 500 so this is 3 5-3 this is 2 so what are the heat transfer and what is the entropy generation and due to the external reversible is and this is the total entropy generation and this is the total entropy generation due to revisable, so the remaining entropy generation is due to the external revisable and the 3.5 – 3 and that is 1.5 kilo joule per Kelvin.

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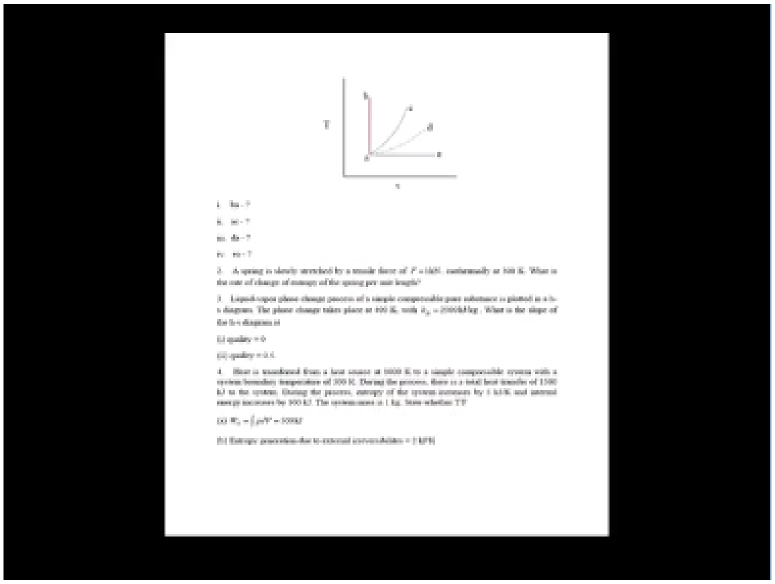

so the part v of the answer is given and the entropy generation due to the externals reversibility is 2 kilojoules perceiving that is wrong it should be 1.5 kilojoules per Kelvin and the first question w1 2 integral P D = to 500 and this is very typical question and the W 1 and 2 and this 500 kilojoules and this incorrect but this not equal and the integral P D V because it is not a quadrillion process and this is not equal to the quadrillion process and this is the equilibrium process see there is entropy generation due to the internal revisable.

What is there posses equilibrium it6 is such as three process bust be internally reversible if it is internally reversible the entropy generation due to the internally reversibility must be 0 so it has been 0 that means I could be have the formula and this P V formula but because it is not 0 you cannot use the pv formula so although the watt is = to 500 kilo joule but it is not equal to the integral p d v so the first transfer is also not correct okay so we have come to the end .

And this is the course we have to summarize we have discussed various law of the thermo dynamics to begin with we have discussed the some of the basis consideration like the system control volume and the concept of macroscopic and microscopic approach then in the properties posses states then pure substances space and the concept of the quadratic equilibrium and it is the compressible substance which is the equilibrium posses all these concept we have developed using these concept.

We have to the specify the and the properties and the fix the pure substance using the property data or the equation of the states and then using the bend law we have learned various law of thermodynamic so the primary law that is understood to the covert of the thermal equilibrium of the zeroth law of thermodynamic and mix then we have studied the first law of thermodynamics then we have studied second law of thermo dynamic mix the eventually the third law of thermodynamic.

And we have watch out the various problem stats these law of thermodynamic and these are very critical because no matter what ever the Brach of the science of the engineering I am talking about the very biological science and these are the chemical science and the mechanically sciences whatever the met logical and the material sciences and the basic building blocks are the thermodynamics remain to the basic law of the thermodynamic so that was the abject of this course I believe it was enjoyable for all you go through this cause it was pleasure on my personal to deliver lecture is close I wish all of you a great time ahead thank you very much.