Introduction to Atmospheric Science
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Lecture-13
Basic Thermodynamics

Okay. So, today we will see something first we look at the evaluation of geo potential thickness from Sonde data that means Radio Sonde Data. What is the radio sonde data? That means a balloon you send some instrument, ok. Then, it will go up, go up into the atmosphere, then it will record the temperature.

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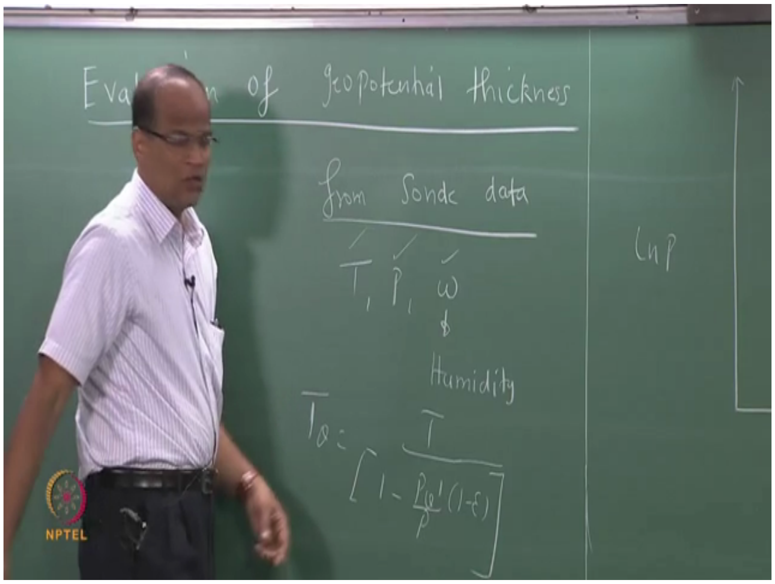

What will it record temperature? It will also record the humidity. Of course, it may go horizontally for some distance. But we do not worry. We say that within limits it represents the same station, ok. How do we calculate the geo-potential thickness because once you have the geo-potential thickness, you can process and do other things. How will you calculate the geo-potential thickness? From Sonde data, but now we have very powerful satellites available, ok. So, they can find out what is the radiation emerging at the top of the satellite in various channels, whether it is an infrared or microwave or visible.

From that they can calculate and actually you can work out the geo-potential thickness directly, before satellites were there, before satellites came into existence this Sonde data is the only thing which is available. So, let us look at the typical it will be like this.

So, it is like this Tv and the lawn P, ok. What is the formula for the geo-potential thickness Z2 - Z1 Rd Tv bar by Z naught lawn, ok. Now, what we are saying is you sent the balloon into the atmosphere radio sonde a instrument, balloon with instruments. So, you are measuring the temperature with height or temperature pressure and Omega, right. So, with that Omega you are calculating, you can get the straight away get the partial pressure of water vapor.

So, Tv = T by correct? So, whenever you are recording the temperature and the humidity, you are able to get the T V also. So, you will be able to plot so, across the atmosphere, you will be able to generate this plot of virtual temperature versus what is that lawn of pressure? What do we want Z2 – Z1 is what we want. Rd is no problem, g naught is no problem, P1 P2 measured. But you cannot solve this equation unless you get Tv bar, okay. Tv bar is not just Tv1 + Tv2 by 2 or something ok.

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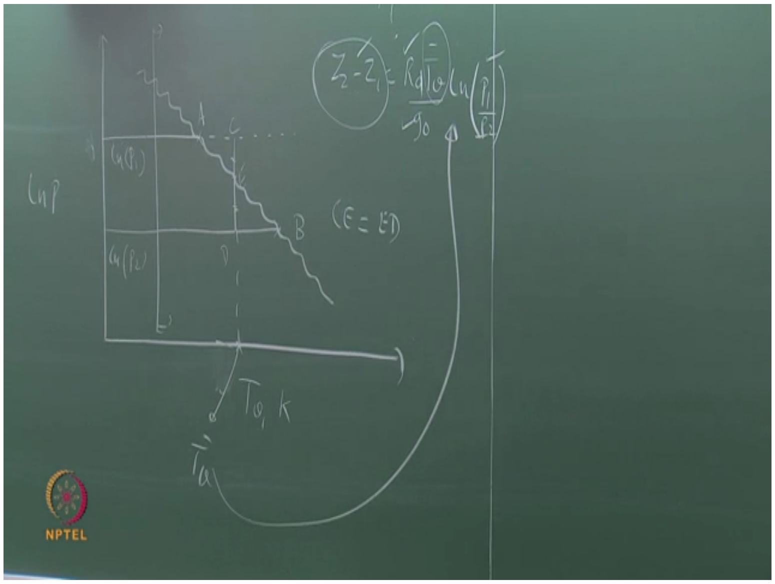

So, what we normally do is, let us take one particular station A, so this is a lawn P1, okay. So, let us say this is A. So, this is B, so, this is lawn p2 okay. So, you take a scale like this. You keep moving like this till you hit a point where this is equal to this buddy okay that is Pv bar dT understand is a very crude way of getting Tv bar. Now with calculator and this thing and all that is not required. But if you just add the sounding data, this is what you would have done.

I come again. So, you will get this raw data from your from your radio sonde, how do you get this from the Sonde data, you get temperature, you get pressure and relative humidity, relative humidity can be converted to partial pressure of water vapor. You know, this equation for virtual temperature, you can calculate virtual temperature with every pressure level, okay. Plot this let us take, so I can make this as C, D, E.

So, let us consider two levels P1 and P2 or lawn P1 and lawn P2. So, this point is A, this point is B. So, I know these two levels. I am interested in calculating the average temperature, average virtual temperature because my original intent or idea is to calculate the geo-potential thickness. So this is what I want. The Z2 - Z1 okay, so, this is 287 that is known to us. This g naught I know, lawn P1 P2 I know, so, I need to get Tv bar.

So, I plot this. Then, as I told you so, I will take a scale and move this horizontally sill till such time I get CE = ED, when it cuts the vertical. Draw it down fully down and what you get is now Tv bar. Now, this Tv bar you substitute into this equation, you can calculate the geo-potential thickness. Now, it appears very easy. Now, with the remote sensing and directly do it, ok, all right.

So it is possible for me to give you some sounding data in the exam. Ask you to plot give a graph sheet semi log or log or something, okay. You plot it and I may ask you to find the geo-potential thickness. Otherwise, there is a way of calculating your average virtual temperature; you have to get the integral, okay. So, instead of getting the integral we are doing a graphical or visual method of getting the geo-potential thickness. Is that okay?

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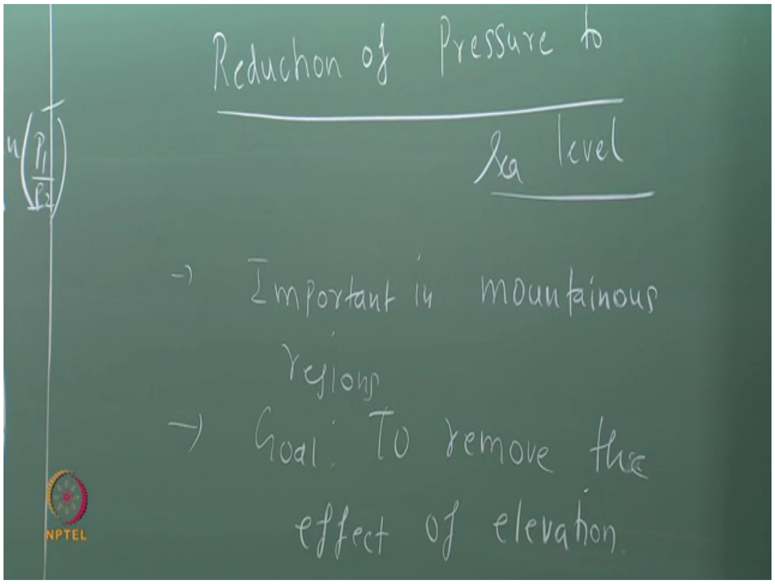

Reduction of Pressure to sea level

→ Important in mountainous regions

→ Goal: To remove the effect of elevation

Now, before we get on to the first law of thermodynamics, we need to study a concept on reduction of pressure to sea level. Now, tell me why is this required? Sir, we always we reduce it to sea level pressure. Sir, what is the, what is the big deal, what are we talking about? So, I will give you a clue, we are talking about something some regions which are special, which regions? When can the surface pressure itself change? Which kind of region?

In mountainous regions somewhere you will have 0 meter, somewhere in 100 meter, somewhere 500 meters, somewhere 400 meters, in hilly region, in modernist regions, the surface pressure alone will surface pressure itself will change. Then, if you are doing all your thermodynamic calculations and attribute your weather or changes to some other thing, you will make a mistake because you 0, itself is not correct, okay.

So, this is something important in mountainous regions, spelling is character mountainous, you can check it at Google. Now, what is the goal? The goal is to remove the effect of elevation. So, now, we need to know how the pressure decreases with height, for the first few hundred meters. Let us do, let us go back. For all this, you have to go back to the hypsometric equation. So, what we are doing is we are just playing with the hypsometric equation in various forms, how it can be used and so on, okay.

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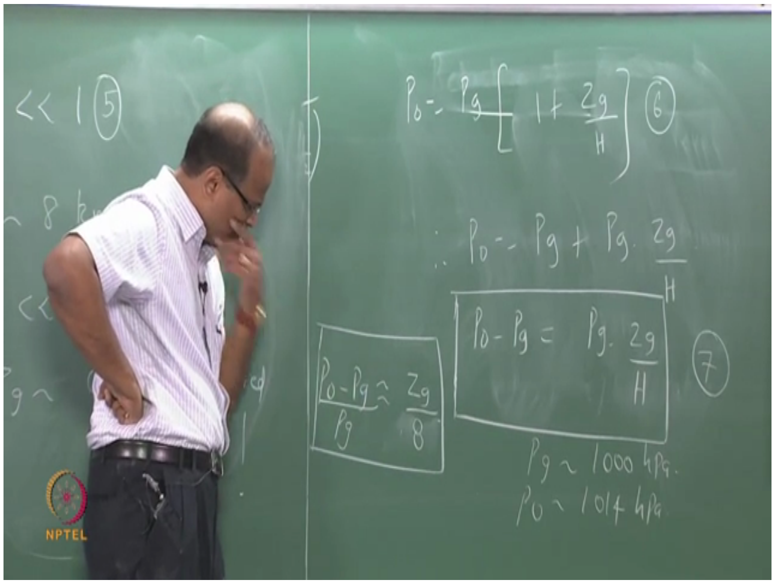

Before we get on to the first law of thermodynamics, So, Zg, Zg is ground and Z naught is sea level. You know what is that naught value but Zg is Zg is not, it is a simple matter, the Zg is not 0, okay. Now, so we can put P naught e to the power of please check whether it is +, is it okay, alright. Now, P naught is more than Pg, right. 1, we will start with 1 in today's class, all right. So, P naught = Pg in the 4, okay, I will erase this.

Now if Zg by H is much less than 1, when will this happen, what is value H? 8 kilometers, okay. H is about so when we will, when we will a Zg by hit be much, much smaller than 1, okay. So Zg a few 100 meters 0 to a few 100 meters, okay. Then, so, this is 5.P naught, how do you expand e to the power of Zg by H? When for small expansion? That is it correct. 1 + you can see, you can, you can check it if you want e to the power of 0.1 or something, ok. So, therefore hmm fix that so this 6, okay. Did we do it right? Now, just get an estimate of that. So, let us say Pg is about 1000 hpa.

P naught, so P naught - Pg is by 8? So, what is that okay so P naught - Pg by Pg if Zg is 100 meters, this will be 12.5, okay. If Pg is 1000 so, it will be so, many hectopascal and all that so you will get an idea of, so can we make a statement that in other words for altitudes up to a few 100 meters above or below sea level pressure decreases by 1 hPa for every 8 meters. The pressure decreases by 1hPa for every 8 meters. This is a rule of thumb, all right okay.

So, enough of the hypsometric equation; what is the hypsometric equation all about? The hypsometric equation is also known as the thickness of the equation which relates the geo-potential thickness to the gas constants, the average virtual temperature and the natural law of the ratio of the pressures. So, it is very important relationship where you can seamlessly go from ideal gas equation to hydrostatic equation, to geo-potential thickness, all these are combined, okay. Now, let us get on the interesting part, maybe the first law of thermodynamics. Any doubt so far?

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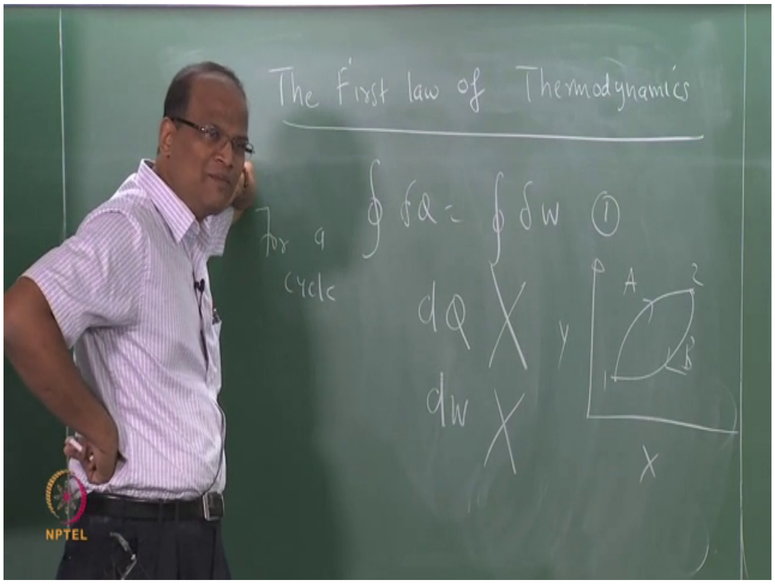

The first law of thermodynamics is one of the cornerstones of thermodynamics it gave the relationship between heat and work, okay, gave the previously the relationship between heat and work was not known largely because heat was not used to produce work. So, the first law of thermodynamics was necessary became was necessitated or it became necessary because people wanted mechanical power. For what, people wanted mechanical power for removing water. Why remove water, because they want, they wanted to go after coal?

Why did they want to go after coal? So, they wanted to burn, okay. They wanted to get, they were they wanted a source of heat. What were they doing before they were using wood, okay. They were using wood and trying to get charcoal from more than that, they were using charcoal, okay. Why not continue to use the wood, now? What is the first law of thermodynamics say? For a cycle, the cyclic integral of heat is equal to the cyclic integral of work. Both heat and work are path functions.

Therefore you have to put this Delta I cannot they cannot be represented by never okay. If you have learnt it please take an eraser and erase it from your brain, okay. As an IIT students if you put the DQ DW immediately, the professor's blood pressure will shoot up, okay all right, del Q and del W, okay. Cycle, what is the cycle?

You take something from 1 to 2 you bring it back from 2 to 1, ok; this is A this is B. So, a cycle will consist of at least two processes. Many people would be tempted to say 3 processes, but 2 processors is enough, ok? You take it from 1 to 2 and bring it back from 2 to 1. The total heat, the algebraic sum of all the heat interactions which can be very honorably replaced by an integral; so, if there are so many infinite number of interactions the summation can be replaced by an integral.

So the algebraic sum or the integral of the heat interactions will be equal to the integral of the working parts. But life is not always about the cycle. What about for a non cyclic process?

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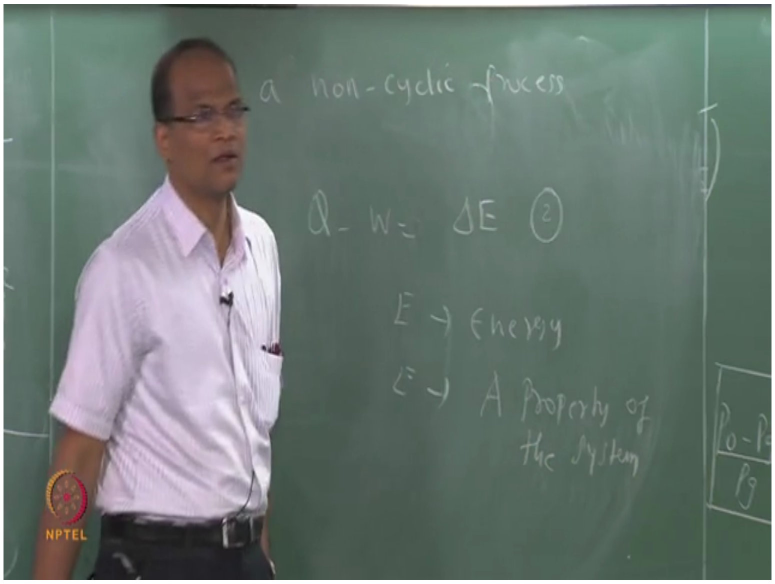

Q - W = Delta E, where Q is a algebraic sum of all the heat interactions. W is the algebraic sum of all the work interactions and Delta E is the change in energy. So, E is a property of the system.

A system is a given mass of something consideration, it can be steam, air or whatever which can have work and heat interactions, but there cannot be any exchanges of mass. If you want to have exchanges of mass also then, you call it as a control volume, okay.

So, the first law for a non cyclic process relates the Q and W and it says that Q - W must be = Delta E. It never says that Q - U = E. So, it is only the changes in the energy level which are very important. So, you can decide the datum as you please. The datum is not very important; we are looking at only changes in the E, okay. What is this change in energy?

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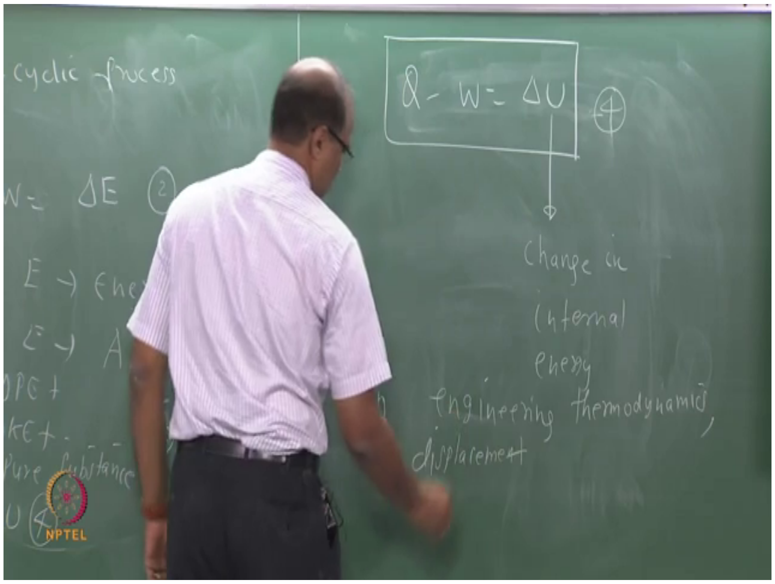

This change in energy can be change of many things: change in internal energy + change in potential energy + change in kinetic energy + capillarities, surface tension, electrical all those things +, +, +, okay. For a pure substance, where only there is only one displacement work and all the other things are negligible Delta E can be approximated to be Delta U. I am not saying E = U but Delta it can be approximated to be Delta U, okay.

So, this is the story Q - W. So, this is change in internal energy internal energy. Internal energy is that mode of energy which can be directly influenced by heat transfer. It is usually accompanied by a temperature change. But internal energy can also take place internal energy change can also take place without a temperature change, as in the case of phase change process melting or solidification or evaporation, okay. All this is not new to you. All this is known to you will teach it in ME1110 in thermodynamics. In engineering thermodynamics, displacement work is very important. What is the displacement work?

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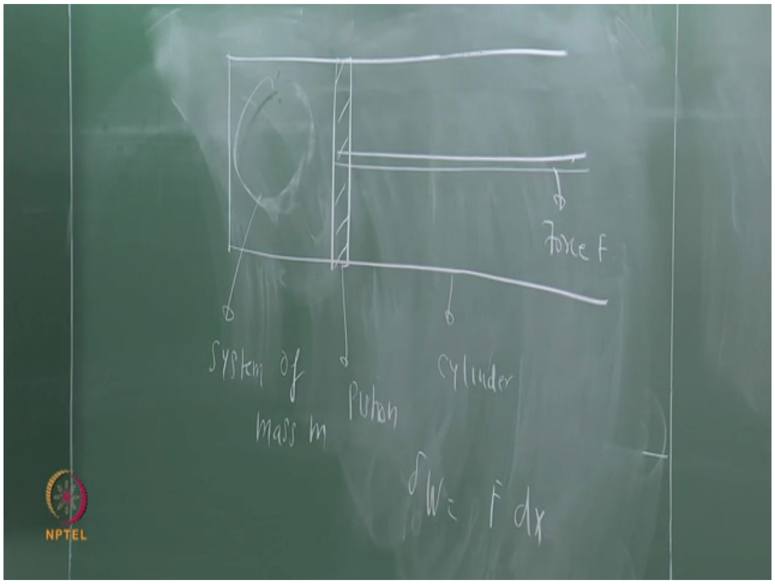

So, consider a cylinder and piston arrangement. System of mass M, okay so, you have got a air combustion, gases whatever you want, okay. This is your piston. So, the piston is moving either you are compressing or it has got high pressure it is moving in the other direction, okay. So, when force moves by a distance that is work, okay. dW is f dX.

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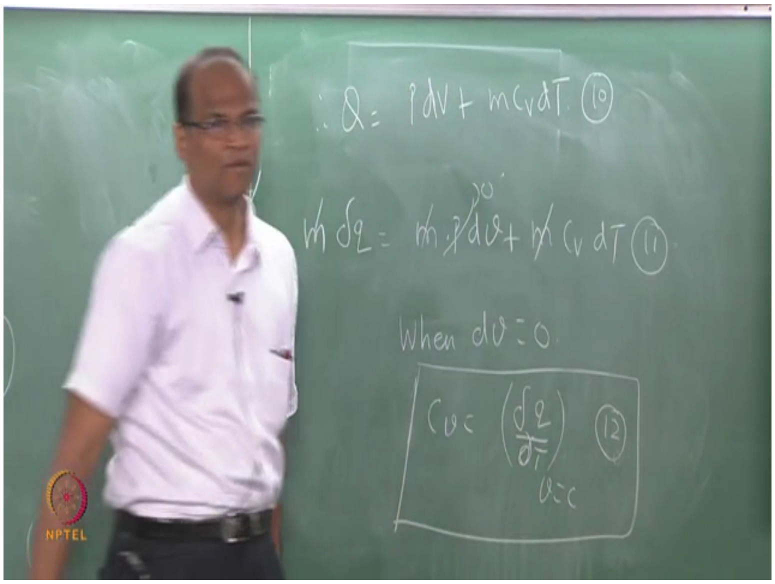

You want to keep it as dW or W okay. What is the force here? Pressure into area, so, it is a Pdv work Pd, okay. Let us stick to the numbers now 5, okay. So, Q = for a pure substance, you can define what is called a specific heat at constant volume, which is nothing but, okay. Pdv + if you want, you can, you can put it in various forms, okay. Then, when dv = 0, that is your heating or cooling something by holding on to the volume, this will become 0. Then Cv we will become, This is stupid High school definition of specific heat.

The amount of heat required to raise the temperature of 1 kg of water from 14 degree centigrade to 15 degree centigrade. Why is it a stupid definition because heat is a heat is a path function. Heat is not a property of the system it takes place only when interaction, it happens only during an interaction. But specific heat is a property of the system. Temperature is a property of the system it is conceptually incorrect to define a specific heat based on heat.

Therefore, in thermodynamics we are very clear that we do not use this physics definition which has been endlessly repeated by physics professors, all by your physics teachers. The Cv is the partial derivative of the internal energy with respect to the temperature when V is constant. This is a more acceptable definition because all the quantities on the left-hand side and the right-hand side both numerated, remember what have you, they are all properties of the system, okay. Shall we proceed, okay?

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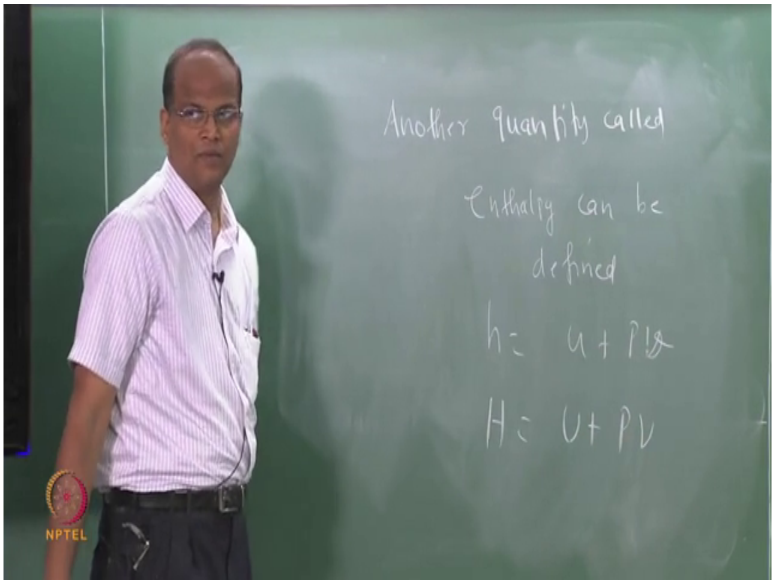

Now, we can define a new, another new quantity called enthalpy can be defined. Please note that when I put small h I put small I put small v specific volume. Otherwise I had to put current, 13 and 14. So, let us work on this. So, the d, you can also define a specific heat. So, this is specific heat at constant volume, okay.

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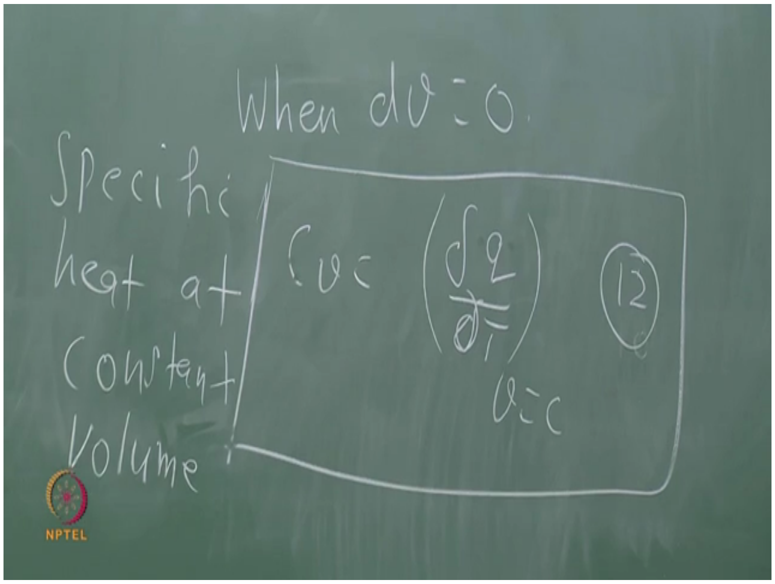

When $dv = 0$.

Specific heat at Constant Volume:

$$\boxed{C_v = \left(\frac{\delta q}{\partial T}\right)_{v=c} \quad (12)}$$

You can also define a specific heat at constant pressure Cp =, okay. Now, please do a small exercise establish the relationship between Cp and Cv for an ideal gas, okay. I repeat please do a small exercise, establish the relationship between Cp and Cv for an ideal gas. Please do it I will give you some time. And then, I will, I will start doing it on the board.

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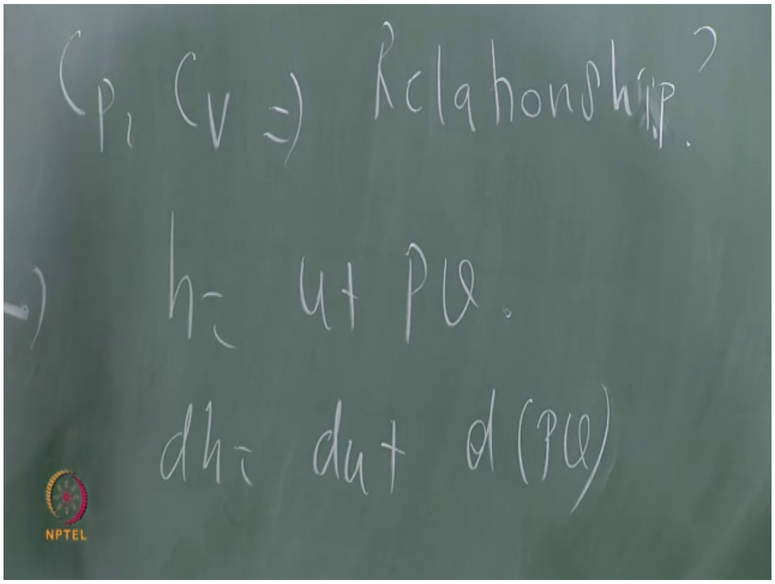

$C_p, C_v \Rightarrow$ Relationship?

$h = u + Pv$.

$dh = du + d(Pv)$

To just expand DHS, I hope you know where to start now from. Then, at constant pressure what happens? At constant pressure, now please help me. P = very good. Now for an ideal gas you so we are an equation 23. What you get from that P dv = when it is valid? Constant pressure, very good. It is called the mayor's relation. For air, it is 287 CP is 1005. Therefore, please calculate the value of CV. 700 or something, correct.

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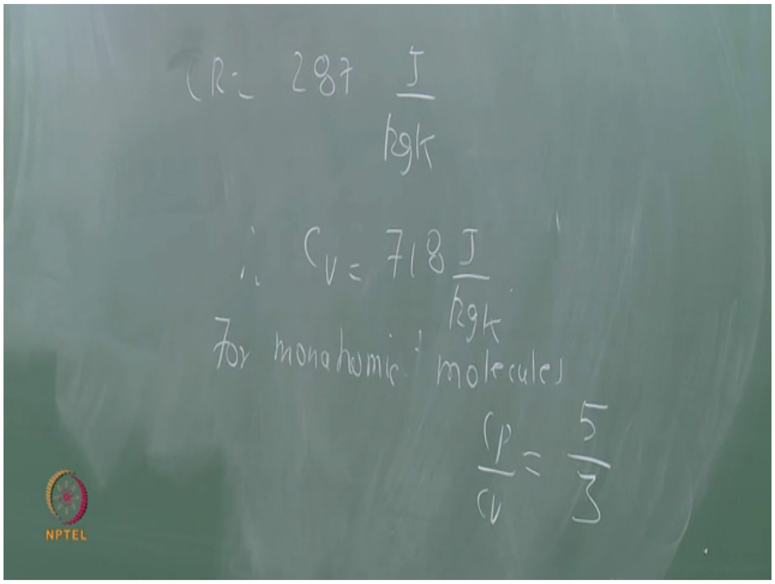

71 sometimes it is 71, 718, it is okay. For monatomic molecules, Cp by Cp is 5, 5 3rd, is it not correct. Let me check, Cp by Cv is 5 3rd. For diatomic, 7 5th correct, 7 by 5. Air is predominantly diatomic, is it not? So, we will check that.

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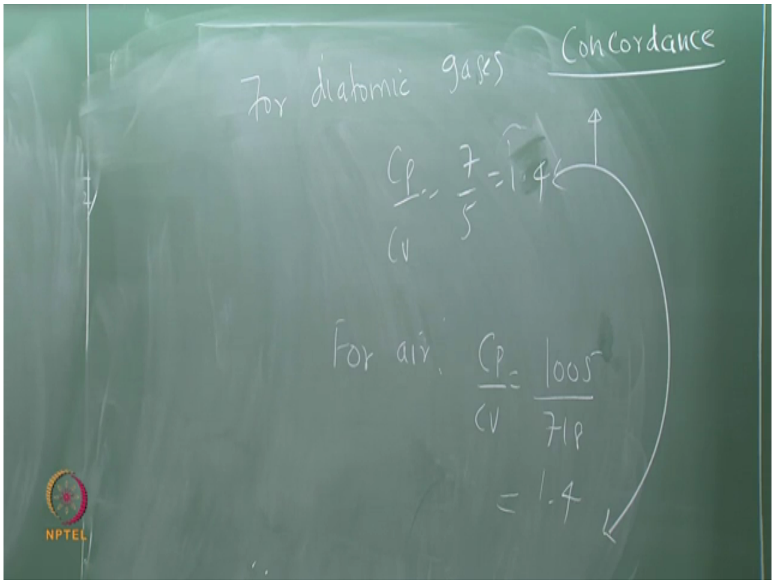

One point what you are recalling from memory, we are able to see the concordance, okay. This can be theoretically derived that 5 by 3 and from kinetic theory of gases. You must have done somewhere, all right. So, this moisture we have not considered; mostly ideal gas, dry air and all that, ok. Now, we look at some interesting, we have come, we have to now look at some adiabatic processes. Adiabatic processes are very important the atmosphere, okay. So, let us look at the adiabatic process. So, we covered a lot of ground today. That is good.

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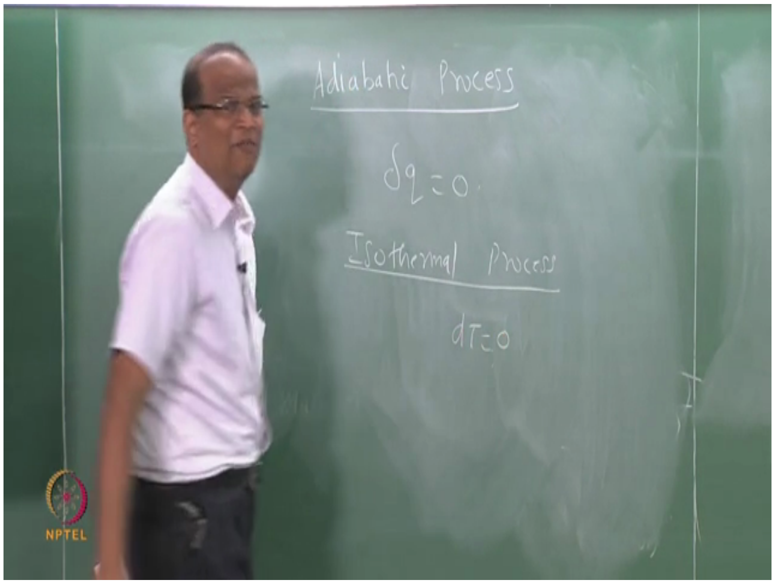

An adiabatic process in one in which is one in which dq = 0 an isothermal process, dT = 0 temperature is the same is a very low level, you say dT = 0, okay. Now, I am going to ask you a question.

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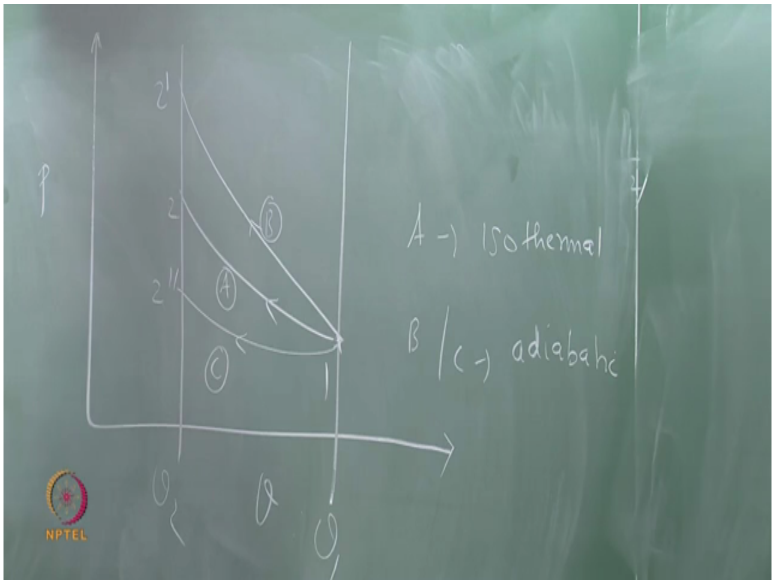

I draw a pressure volume diagram, you go to state diagram thermodynamics, okay. v1 v2 I have an isothermal process, 1 to 2. I want to use an adiabatic process, okay. Please give me a scientific answer as to this a okay. I will mark the options. So, if the isothermal is from 1 to 2 for reaching the same volume, will an adiabatic process follow 1, 2 double dash or 1, 2 dash, in simple English is the adiabat steeper than the isotherm, or the isotherm is steeper than the adiabate?

Please prove it mathematically. Please prove it from first principles. It is not you cannot do it in one step. Please prove it from first principles I want a long proof. So, which we will use repeatedly? The first law of thermodynamics; so, first law of thermodynamics is given to you and the definitions of isothermal and adiabatic process are given to you. The concept of ideal gas is also given to you, ok. So, please go ahead okay. I write it on the board. It is the adiabatic steeper than the isotherm is the question clear, okay. Let me start.

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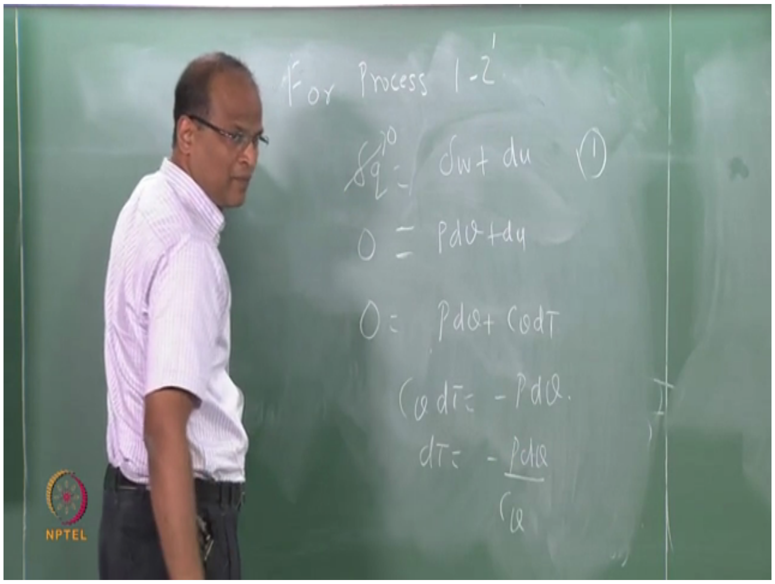

So, for process 1,2. You want to do process, okay. Process let us say 1, 2 dash, for the process all right so dq is 0. Let us start with 1, how to proceed from here. Sorry, Pdv + du I messed it up dw + du = P dv + du. Some of you may already understand what is the route I am taking.

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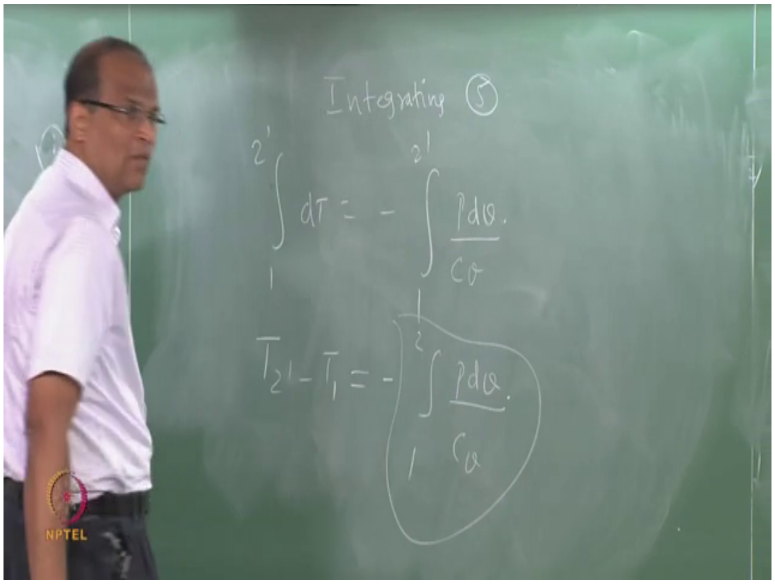

So, what integrate, integrate 5 1 to 2 dash, 1, 2 dash, what is this? Right side it is comprised or what is the value of this integral, sign of the integral? Negative? Why? We are compressing from v1 to v2, okay. So, this is negative. If this is multiplied by negative t2 dash - t1 is positive, okay. Therefore, however, for 1-2, t1 equal to t2 because 1, 2 is a isothermal process. Therefore,

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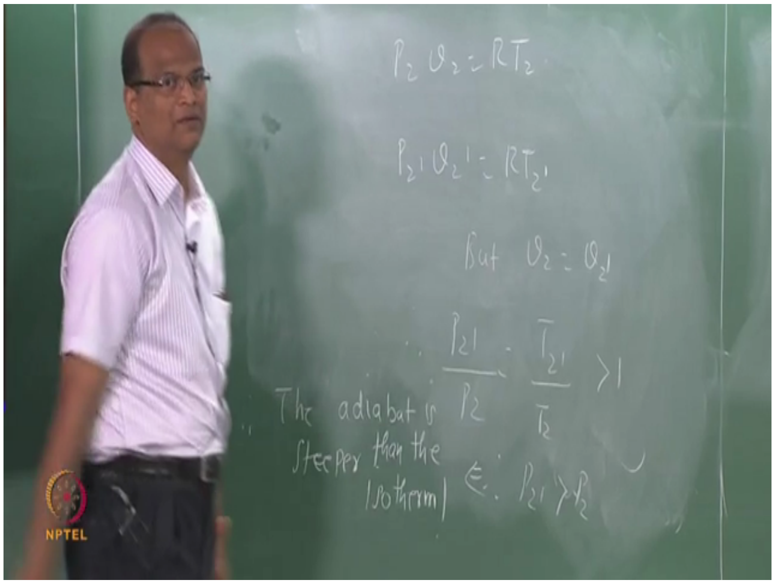

Okay, but, because we are compressing it to the same level; in simple English, the adiabat is steeper than the isotherm. Proved? Is it okay, therefore, okay. So, we will stop here. Any doubts? So, we will continue. Is the proof clear, logical? Okay.