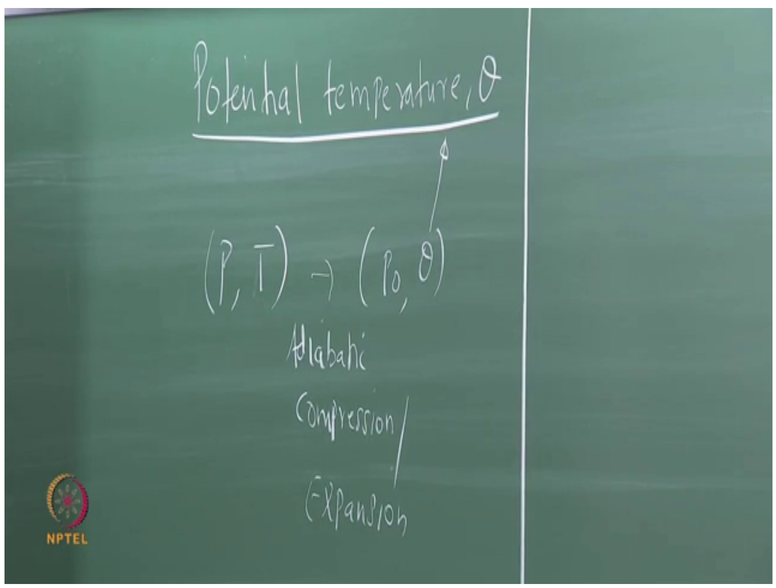
Introduction to Atmospheric Science
Prof. C. Balaji
Department of Mechanical Engineering
Indian Institute of Technology-Madras

Lecture-15
Potential temperature

Okay. So, welcome back. So, in the last class we started, I started introducing this concept of potential temperature theta, which is a very important concept in atmospheric thermodynamics, okay. So, let us revisit the invitation sorry definition, okay. The potential temperature theta of an air parcel is defined as the temperature that the parcel of air would have if it were expanded or compressed adiabatically from its existing pressure and temperature to a standard pressure, okay which is P naught, generally taken to be 1000 hPa.

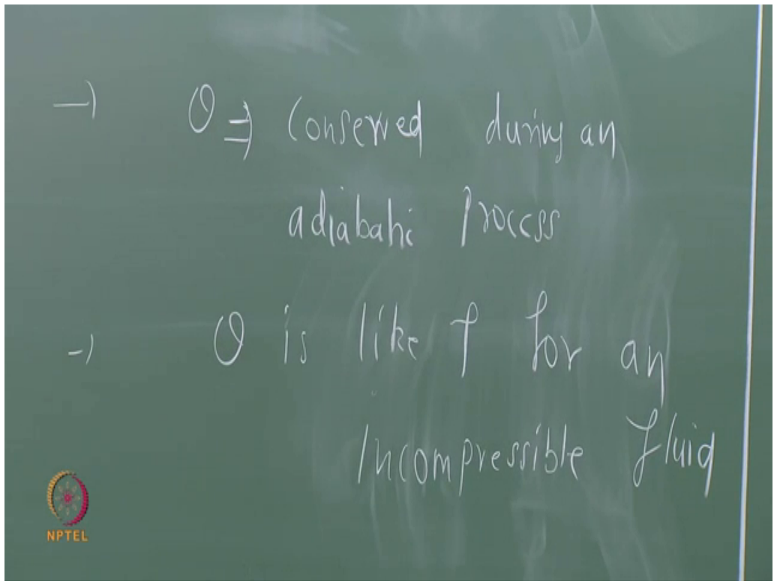
(Refer Slide Time: 00:51)



So, it is under pressure of P and temperature of T it is taken to a pressure of P naught, it will reach a temperature there, if this is adiabatic, okay. If it is adiabatic, this could be adiabatic compression or expansion. This theta is called the potential temperature, okay. So, the challenge is to be able to calculate, the potential temperature for any set of P and T, correct. So, it is like a reference point. So, we should be able to calculate the reference point.

And so, with this, we can do we this will aid us or help us in solving problems, involving adiabatic transformations, alright. So, first let us figure out what is the relationship between Pd and P naught theta, all right.

(Refer Slide Time: 02:35)



So, for dQ from the first law, okay correct. I am going to expand d of PV as Pdv + Vdp, one of these things will get canceled. I will write d h and CP into d. So, you need not wait for me, you can go ahead and it is adiabatic. We can set the left hand side to 0 and you can start, you can integrate. So, the limits are P to P naught and T2 theta. So, you can straight away get an expression for theta in terms of the two pressures and the temperature, alright.

And I will just give you two minutes so, please do it, then I will do it on the board. So, please expand from this. You can substitute the value for Cp substrate, the value for our take R = Rd you will get some constant power, some .286, correct. You are getting that, okay. So, adiabatic, but what is Rho? P by RT correct, now, please integrate substitute the limits. Is it okay up to this stage? I will just give you two more minutes to integrate. Done? Then okay. This is okay to the power of; okay.

So, R let us put some equation numbers. R is approximately Rd. What is this fellow, value of this fellow? Very good 287, therefore, for 1005, whatever, fine. 285, you are getting nothing 0.286 does not matter 0.285, all right. Therefore, an important equation, we derived in today's class, okay. For any given set of conditions P and D, for any state of the atmosphere, you can find the corresponding potential, potential temperature, okay. So, this is the equation for potential temperature, some 15, okay.

Why is this concept very useful? Can you tell me some reason, why is this concept very useful? Let us start with the first thing is many processes in the atmosphere of adiabatic, ok. We just proved in a little while, the theta is conserved during an adiabatic process. So, when adiabatic transformations take place, the theta is a constant with which you can simplify some calculations.

So, theta is a very useful construct, okay. So, theta is like Rho for an incompressible fluid which does not change, whenever the velocity is increasing, area is decreasing, increasing, pressure is increasing, water means 1000 kilogram per meter cube. Air is a problem that is a, air is compressible; water is incompressible. So, it is like a Rho for an incompressible fluid.

Suppose, you say, sir, how are you, how do you know that Thetas considering adiabatic process. First you know, believe me, we proved it in a few minutes, okay. So, theta is like a Rho for an, what did I say, sorry, incompressible. So, the potential temperature is an important concept. You can construct charts with potential temperature as one of the coordinates. They will be called adiabatic charts, pseudo adiabatic charts and all that.

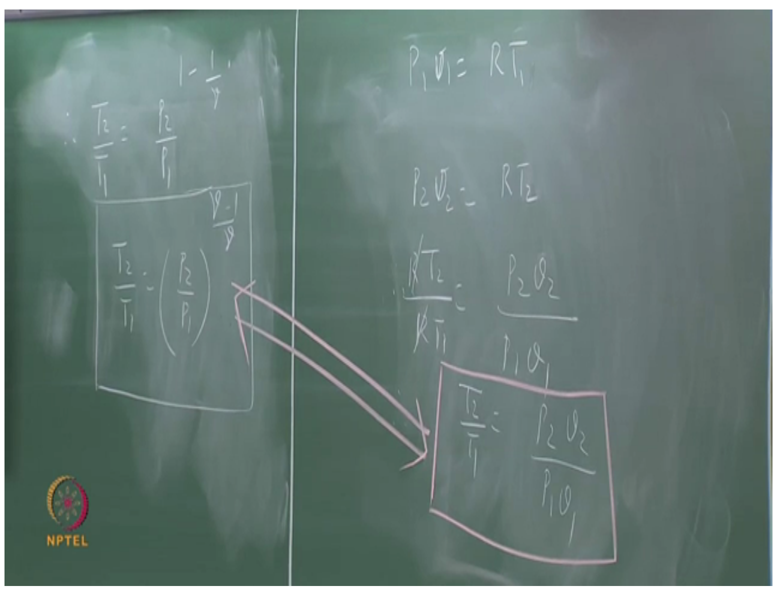
So, with this contraption, we use it tomorrow, it will come up and I will start drawing the various lines I will take the chart we are setting it up. So, constant temperature constant pressure constant theta all these lines will draw. And then, we will stop which we will start solving atmospheric science problems, with some charts, okay. I will distribute the charts to you. So, you can do it there. I will do it on the board. And then at the end of the class, we can save it and I can actually take a printout also every problem we solve.

So, we will switch to tablet in due course, alright so, so far, so good. Problem number: 20. Very good. This is lecture number 15, I think, ok it does not matter. Please decide problem number 20. Problem 20: Prove that for an adiabatic process undergone by an ideal gas, prove that for an, for an adiabatic for a reversible adiabatic process undergone by an ideal gas, Pv to the power of gamma is a constant.

The isentropic issue we don't have to introduce entropy in this course. Later on I will introduce reversibility betting is also called isentropic, entropy remains constant, okay. So, I lost the flow, what did I say? Prove that for an for a reversible adiabatic process for an ideal gas, a reversible adiabatic process of an air parcel which can be considered to be an ideal gas Pv to the power of gamma is = constant all that you do not have question.

Simply can read Pv to the power of, prove Pv to the power of gamma is constant. Then, using Pv to the power of gamma is constant and the concept of potential temperature, we will say that potential temperature is preserved or conserved during adiabatic process. So, we are actually confirming this statement which we made a couple of minutes ago, okay. Please do it. Problem number: 20. So I erase this.

(Refer Slide Time: 16:20)



So, already it is adiabatic, right so, where do you start? First law. You start with the first law, okay. So, what is that? Yes, please tell me, CV where did you start? No, no, no CPDT. Let us hang on. dP by V Rho you want to do this or no? You are keeping this. ah now, it is substituting for P here. You can substitute for P here isn't it? You are already having dt here, fine. How do you do that? PV by R, you are complicating things. There are many ways of doing it. Tell it in the simpler way. Can you substitute for V here, will it come? P by; PV = RT, RT by P. So, CP what is this?

So, T2 by T1 is, I lost track of the equation numbers. You can start if you want you can start 1,2,3,4 yeah. I am writing it too fast just focus on this for two minutes. Let this build I think it is too fast. Just please assimilate the steps you already you have finished? Shall we continue, okay? Okay, an important result in mechanical engineering. You are talking about the Brayton cycle.

The Brayton cycle is used in used to power gas turbines is the thermodynamic cycle used for powering gas turbines which are used for the aircrafts. So, if you take the gas from the pressure P1 and temperature T1 and compress it to P2 + T2, at the end of the compression stroke, when the compression ratio is T2 by T1, what will be the temperature at the end of the compression is obtained by this.

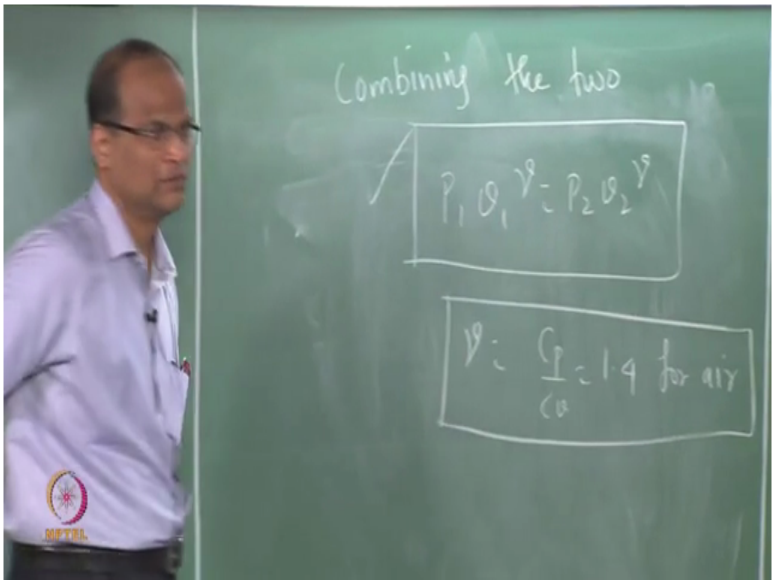
After it reaches a temperature of T2 combustion takes place, it will reach a temperature of T3 which will be much higher compared to T2. Then, it will expand if you go to T4. Then, from T4 it is an open cycle gas turbine, you just come out; if it is a closed cycle gas turbine, it will be recycle it will come back to T1 and the cycle is completed, ok. So, that is the gas turbine cycle. In air standard, air standard cycle is the one in which the properties can be assumed with that of air which is not strictly correct because it is somewhere the combustion products are getting mixed up.

But since the air fuel ratio is so high, we can assume that everything is consisting of just air, dry out dry air. Then, we can do the calculation. That is called a air standard cycle analysis, okay. There is a two minute course, course on gas turbine cycles. You can have advanced guests have been cycling with intercooler and this thing and all that, okay. Let us get back to this.

Now, please combine the two and you, you get the result, usage, is it okay? There are many ways of doing it. But you cannot deny that, this is a method, this is a way of doing it, okay. And during the process I also taught you about gas estimate, okay. So, let us combine these two. The problem is stem from the fact that your, you have taught shortcuts in GE. Profs will never use shortcuts. We will explain step by step, what is that hurry? There is no time rule for the example.

This is not an example, clarity is very important, correct. Usually I do not miss steps in derivations alright. Now, combining these two:

(Refer Slide Time: 27:15)

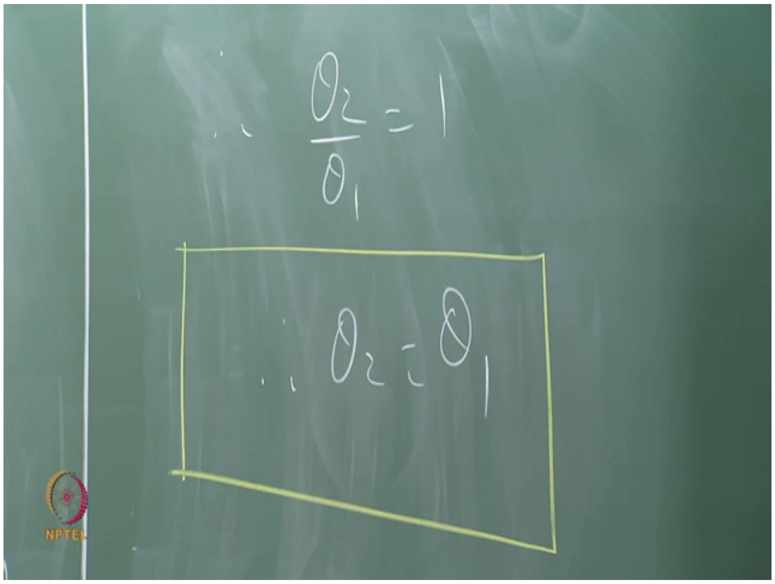


Shall I straight away write ok. Prove, it is good problem, problem number 21 prove that problem number 21 through that the potential temperature of an air parcel, does not change, when the parcel undergoes through sorry when the parcel moves around prove that the potential temperature of an air parcel does not change when the parcel moves around under adiabatic and reversible conditions, under adiabatic and reversible conditions in the atmosphere.

Let me come again problem number 21 prove that the potential temperature if you want true that the potential temperature theta of an air parcel does not change when the parcel moves around under reversible and adiabatic conditions in the atmosphere. Please solve I just wait for two minutes. Please start, yes are you able to prove it, without using P to the power of gamma also you can do.

I can prove there are many ways of proving this. Let me teach you a way of, what did they do, okay? So, I just use the concept of potential temperature itself okay. So, this is interesting way of doing if use the P1 V1 to the power of gamma also you can get it. Shall I erase the whole thing?

(Refer Slide Time: 30:30)



The 21, to prove, okay, so, the fellow is going from this adiabatic process taking place in the atmosphere he is going, he means the parcel, he is going from P1 V1 to P2 V2 but the link is that P will PV to the power of gamma is constant. But what I am saying is for the P1 V1, there is one T1 correct. There is also T2 which can be got straight away from the ideal gas equation PV = RT.

Now what is P1 and T1 that is theta 1 know? This is a potential temperature theta 1 is = T1 to the power of gamma by gamma - 1. For this fellow R by CP no it should be fine, now P naught by P1 gamma -1 by gamma, correct; now it is correct right fine good. Now P2 T2 now theta 2 I find that theta 1 = different from theta 2 I do not know as yet okay. So, I get, I get a new theta 2, which is T2 of P naught by; okay.

Now therefore, theta 2 by theta 1 is nothing but T2 by T1 to the power of then what I am getting is P1 by P2 agreed. But T2 by T1 is P2 by P1 to the power of gamma - 1 by gamma already proved. Just I will give you two minutes to assimilate this. So, theta 2 by theta 1 = what? The same, if theta 2 is the same as theta 1.

Therefore, the potential temperature theta is conserved during an adiabatic transformation. Yes class, please tell me, what are the other ways of proving? If somebody is putting his hand up, we will show the camera. Any volunteer okay Akil, somebody same. Is there any way better, everybody did this you assume that separately theta 1 theta 2 1 oh Sajith, okay. So, you believe now my earlier statement that theta is conserved.

So, theta is very important something like your red bulb temperature and all that know in psychometric everything you calculate. I would not say it is red bulb temperature, it is some quantity okay. So, this potential temperature is a useful quantity. Now, we will solve a simple problem involving numerical values and then stop for the stop for the day. So, tomorrow we will see how to put this theta into a chart involving pressure and temperature that is called the pseudo adiabatic chart.

Then you have a skewed, skewed temperature and lawn of pressure. That is a very important chart in atmospheric thermodynamics. So, that will be that will be do or die for you because second quiz, the problems will be based on that chart. So, we will hang around with that chart for many, many classes. I am trying to explain most of the atmospherics thermodynamic concepts like lifting condensation level.

How much heat and air parcel will raise before it condenses and this thing and after that, if it raises and it falls off as precipitation and very, very interesting problems involving moisture thermodynamics. We use instead of using equations; we will try to solve it using charts. So, I will switch to this hopefully they will fix it tomorrow. I will sit whenever we discuss a problem so I take some it is possible to change the color also there. So, I will practice also. So, we will there will be a lot of fun with tablet problem number 20.

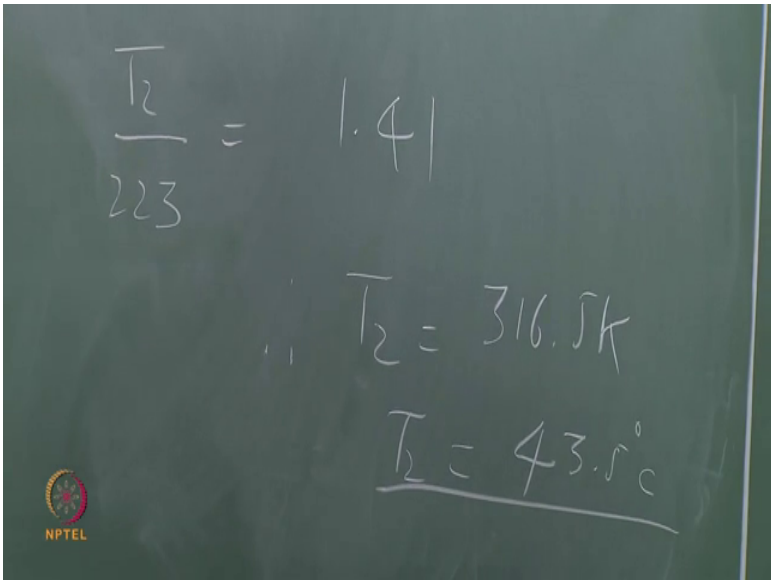
Let us do problem number 22. A parcel of air has a temperature of - 50 degree Celsius, 50 at the 250 hPa level. What is its potential temperature? That is part a. You missed it, Wait, a parcel of air as a temperature of - 50 degree Celsius at the 250 hPa level, what is - 50 and 250 hPa a level. That is a level at which commercial airline will fly; 250 hPa will be about 12 kilometres - 50 degrees will be the temperature outside.

If you open you know people have gone. Not only because of the temperature, is oxygen not enough, few seconds close. So, this is the condition corresponding to outside, we will know. So, the first part is what is the potential temperature? Second part what temperature will the parcel have, what temperature will the parcel have if it is brought into the cabin of a passenger jet?

what temperature will the parcel have if it is brought into the cabin of a passenger jet and compressed adiabatically and compressed adiabatically to a cabin pressure of 850 hPa, okay I come again problem number 22 a parcel of air has a temperature of - 50 degree Celsius the pressure is 250 hpa hecto pascal. First question what is Theta, potential temperature?

Second question, what temperature will the parcel have, if it is brought into the cabin of a passenger jet and is compressed adiabatically to the cabin pressure of 850 hPa and it is compressed adiabatically to a cabin pressure of 850 hPa okay.

(Refer Slide Time: 40:33)



Done, very good, so, you are considering the condition as P1 and T1, right okay. So, P1 T1 is; for part a, theta = T into; so, please put in the values 3 ok 1000. What is this value, this value just for the sake of its being recorded, so, for the sake of clarity 1.486 okay. We will try to solve it using the chart also. I will try to bring the chart tomorrow. Part b: Compress adiabatically to which one this fellow, okay, gamma - 1 by gamma, please put in the values.

Please tell me that value so that I write it and then we will simplify. Problem is solved, problem is not solved. The mathematical problem is solved but the actual problem is not solved. Do you understand my question? I come again the mathematical part of the problem is solved; but the actual problem is not solved; what do I mean? If you bring it to the cabin and you all the people are sitting and what will be the temperature 43.5, okay.

People used to Vijayawada it is alright. But you cannot have a long distance rate with 43.5 is continuously maintained. What is the funda? It has to be, after compression it has to be cooled. So, you require an air-conditioner in the aircraft not only, not only can you not use these outside air straight away first you have to compress it to 850, where 850 the oxygen level is sufficient for the people. So, the air conditioning system it has to work properly, okay.

So, from 250 hPa, this -, a pilot will always announce, temperature outside is - 50 -, it has significance. It is - 50 and 250 hPa that air cannot be let inside. It has to be compressed. So that power will come from the engine power, okay. So, after compression, it is 43.5. So, when an outsider at - 50 is brought in, is compressed adiabatically and brought into the cabin it would have had it would have had a temperature of 43.5, therefore a further cooling by 20 degree centigrade is required.

You can write down a further cooling by approximately 20 degree centigrade is required to maintain the cabin at 24 or 25 degree centigrade which is comfortable for most people. Of course, humidity is also that is another okay so this adiabatically compressed air has to be cooled by about 20 degree centigrade. That is the inference you get from this, okay. So, he maintains it that okay.

Sir, why are you asking; why are you; why did you ask for the potential temperature initially? When we are walking now, when you go to the classroom, when you are walking in IIT what is the pressure atmospheric pressure so if the 250hPa is I adiabatically compressed to the atmospheric pressure what will be the temperature 61. How much will the pilot have to cool that? It is why the pressure is not 1000 hPa plane travel for long journeys uncomfortable. Not only is a pressure 1000 hPa temperature might be uncomfortable, humidity is also problem.

They will keep it very low whether they will condense in the wrong places and give trouble cleaning and this thing in. The humidity is we maintain at 5 to 10 percent in extremely dry. People, some people get nosebleed and long, long-haul flights, transatlantic flights and transpolar flight. So, these aircraft air conditioning is very much related to atmospheric thermodynamics. Shall we stop here? So, tomorrow's class we will discuss how to do this using a chart. Then we will get on with the charts. Thank you very much.