Introduction to Atmospheric Science
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Lecture-14
Concept of air parcel and dry adiabatic lapse rate

Okay. So, we will continue with our discussion adiabatic processes and I will introduce the concept of air parcel to you. The concept of air parcel is very important. Using an air parcel and adiabatic process will it lead us to an important concept called the potential temperature theta. It is equivalent of density in incompressible fluid where density remains constant. So, in today's class, we first introduced this construct or a quantity called the potential temperature called theta.

Then, we will see that it is conserved during adiabatic processes and then in subsequent classes, we will use this framework of the potential temperature to solve many problems of interest to atmospheric thermodynamics and atmospheric science in general, okay. So, to have a quick recap of what we did yesterday:

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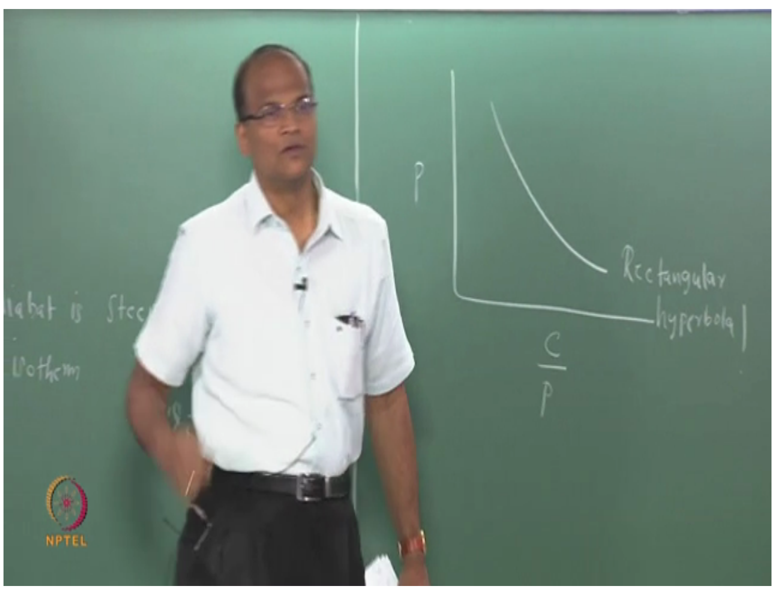

An adiabatic process is one with dq is 0, as you know, the heat transfer could take place either by conduction, convection, radiation or one or more of this. So, when you say dq is 0, all of these are suppressed with some way or the other, okay. And we saw case where, we saw a case where if you go from 1 to 2 also go from 1 to 2 dash. And this was the A that are B and we wanted to figure out when we declared A as isothermal, right okay. I posed the question to you P2 dash is P2 dash greater than P2 or finally we concluded that P2 dash is indeed.

So, the adiabate is, recall that we are treating atmospheric air to be an ideal gas, right. And then, Pv = RT to be specific volume. So, this is another way of writing P = Rho RT. Now, isothermal process, T is a constant, therefore Pv is a constant, okay. So, the isothermal process is rectangular hyperbola, correct. So, already we know that PV to the power of gamma is constant.

But let us pretend that we do not know that Pv to the power of gamma is a constant, so, we will turn around and prove that Pv is = gamma is = constant maybe after a half an hour. And the time is opportune for us or it is required for us to prove that. And then, we get on to the concept of potential temperature. Is it fine? So, we have discussed this it is steeper than this but still let us pain or pretend that we do not know the relationship.

How so, if for the general polytropic process PE to the power of n is constant what is this n in the case of an adiabatic process, let us figure it out after some time. But now we have to introduce the concept of air parcel.

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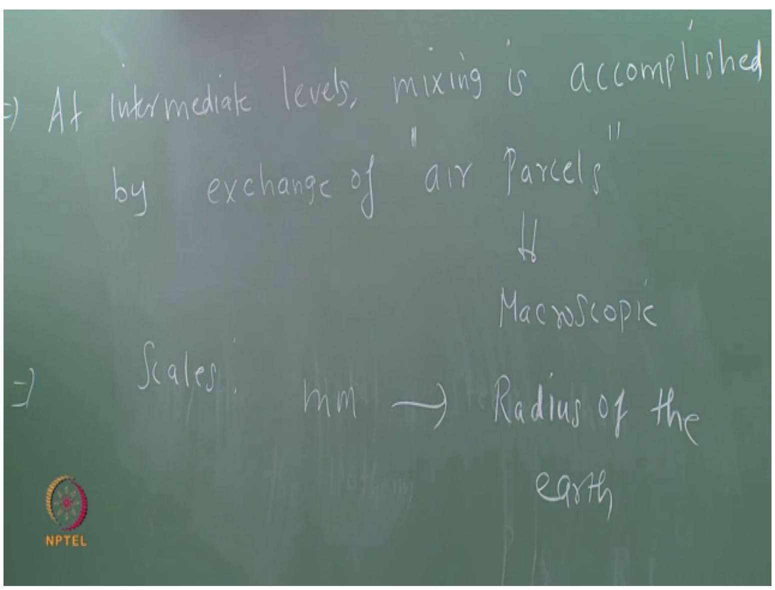

So, we have to look at the concept of air parcel. In conventional fluid mechanics, the mixing is viewed as what? Mixing in fluid mechanics, for mixing is a result of random motions of individual molecules, right. Over in the atmosphere, mixing is important only in the first few centimeters above the Earth's surface and beyond the turbo pause that is beyond 105 kilometers. So, more or less from 0 to 205 kilometers mixing is this microscopic mixing is not a big deal.

We, if you use this microscopic mixing it will it will not lead you to; you will not make substantial progress in your theory of atmospheric thermodynamics and your ability to solve equations and so on, is it ok, so, because we have, because this will involve solving of very complex equations and all that lead to the CFD equation, Navier-stokes and all that, okay. So, in the atmosphere mixing is even in atmosphere we will still do it.

But they for the concept of for solving problems in thermodynamics this is too small a scale for us, ok. Mixing is important and beyond turpopause. So, what do you do? At intermediate levels, I stand corrected in the atmosphere, molecular mixing, okay so, at intermediate levels, mixing is accomplished by exchange of macroscopic air parcel, okay. So, it is a framework with which we can analyze problems just like we introduce a system or a control volume, in normal engineering thermodynamics, in order for us to study the first law for a closed system.

For a system, we introduce what is the system. Then, if you want to look at devices where some mass comes in and comes out and some as in the case of a pump or turbine compressor, the system concept is no good. We saw that it you have seen in your first year courses that it is very difficult to solve problems where some mass is coming in some mass is going out; using the concept of using the construct of system.

So, we introduced something called control volume where you put some dashed box and you find out what are the masses entering, what are the masses leaving, what is the enthalpy which is coming in, what is the enthalpy which is going out. So, the net change in enthalpy must be = the difference between the heat and work done. And this work when this work will be WX, we call it as the external work; work which could be negative in the case of a pump and compressor and it will be positive, in the case of a windmill or a steam turbine or a gas turbine.

This is how we solve problems in thermodynamics. So, when you have a control volume, we look at what is called SFEE Steady Flow Energy Equation. Then, you also solve unsteady problems. Unsteady problem classic example is deflation deflating a balloon, inflating a balloon and all this. These are some special cases. Otherwise generally we will solve steady state problems. As far as atmosphere is concerned just like we introduced this concept of system and control volume we have to introduce concept called air parcel, okay. So, this air parcel we do not worry about individual molecules, they are too small for us, okay.

So, what should be the scale of this, what are the scales, I mean, length scales? So, it can vary from millimeters all the way up to the radius of the earth, all are included. So, everything is an air parcel. So, it makes the analysis a lot easier okay. You understand? Now, we have established the conceptual framework for the concept of an air parcel. What are the assumptions in involved in an air parcel. We list them 1,2,3,4. Based on these assumptions and based on the concept of an air parcel, what could we do further?

We can actually after this air parcel concept is introduced, we can first figure out how temperature changes with height in the atmosphere. That is called the lapse rate. This is called the theoretical lapse rate the actual lapse rate will be measured by a balloon or you can infer it from a satellite it will be a little bit different because some of the assumptions will be violated or there will be other mixing, there will be winds and all this, okay. So, that is what we are going to see.

Then, we will see using this idea air parcel and adiabatic concept, we will also introduce the potential temperature, all right.

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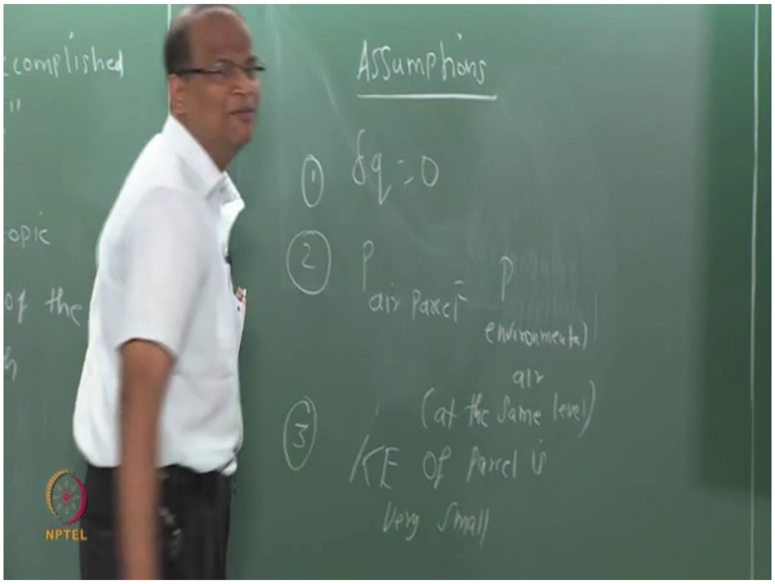

So, assumptions, shall dictate the assumptions? Yes, that would be better. So, assumptions number 1: Please take it down.The air parcel is thermally insulated from the surroundings. The air parcel is thermally insulated from the surroundings. So, I am reading, the mathematical equal mathematical statement of that on the blackboard. The air parcel is thermally insulated from the surroundings. The air parcel is always at the, it is same pressure, as the environmental air at the same level.

The kinetic energy of the parcel, the kinetic energy of the parcel is a negligible fraction of its total energy. What does it imply? The parcel moves the parcel it means that the parcel moves very slowly, okay. So, these are the three main assumptions in our theoretical development. So, it is adiabatic, the pressure of the air, the pressure of the air parcel is the same as the pressure of the environmental air; otherwise it will not stay in that level, know? It will do something. Then, the kinetic energy of the parcel is very small compared its total energy.

In reality one or more of these assumptions will be violated. Be that as it may we assume that none of this is violated so that you get a theoretical handle on the problem so that we are able to make progress in an atmospheric composition. What net? Is it for a stationary air parcel? Yes, for a stationary air parcel it is. Even if it is moving at the uniform velocity, net force is 0. So, you have to be careful. Next concept is the dry adiabatic lapse rate, ok. Is it clear up to this stage?

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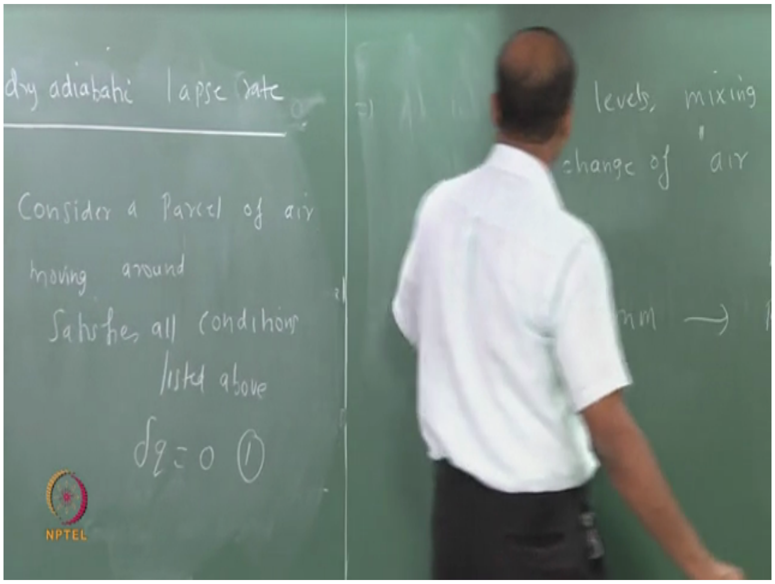

Consider a parcel of air moving around in the Earth's atmosphere, it satisfies all the conditions, satisfies all conditions, okay. Now please apply the first law to the parcel.

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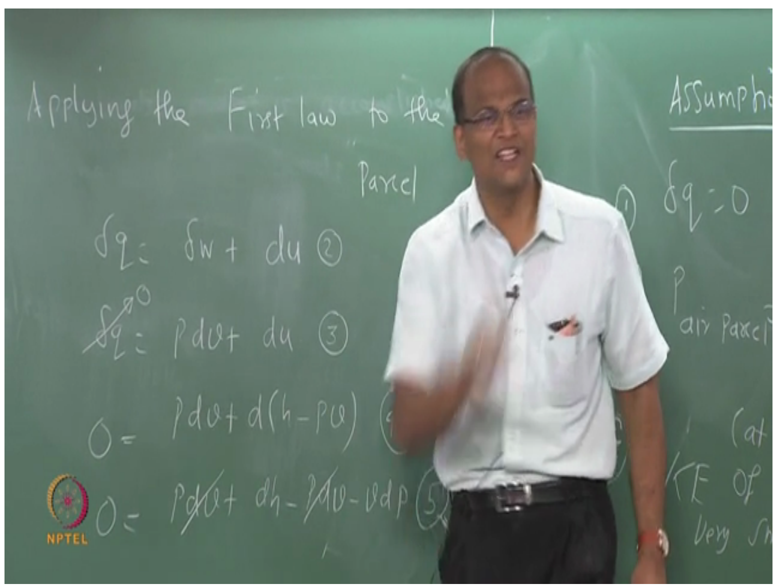

You apply the first law to the parcel. dq is = dw + Pdv. I am always making this mistake ah, from yesterday onwards, + du. So, I would stay with du, for the time being because I have a reason. So, dq is okay. Please expand that. It seems you are so doing the same thing again and again from yesterday; some people you get that feeling what is again and again we are going round and round.

But now there is a clear there is a departure which I am going to make. I am going to talk about, we are going to what is the idea of this exercise? We want to get the lapse rate. dT by dZ this dh, is already CP into T so dT is inherent there so please bring this Z into the equation. So, where will that Z come, what is that equation so? What is that? It is coming from; it is coming from the hydrostatic equation.

Hypsometric equation is a thickness equation, Z2 - Z1 is R dv by d naught, law of P1 by P2. So, you have to get, so we are linking up the first law of thermodynamics, air parcel, adiabatic process and the hydrostatic equation. That is why temperature and Z. Otherwise temperature and Z it is very difficult to link the two, all right.

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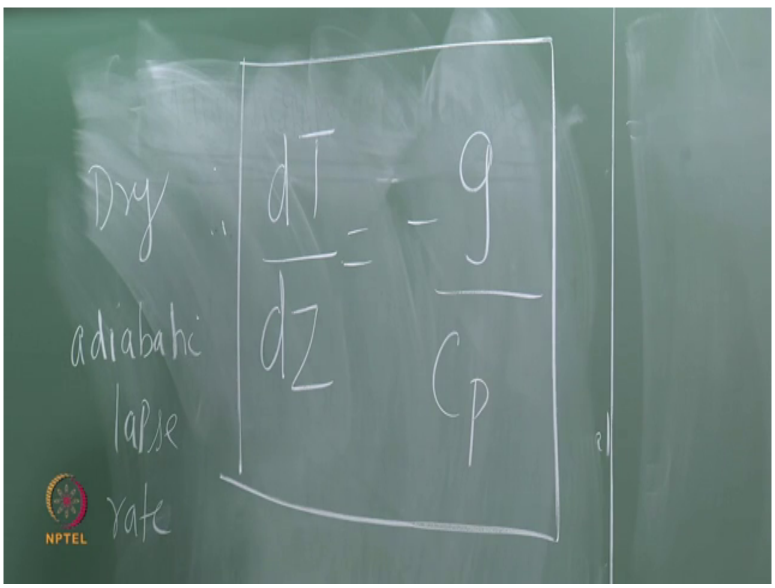

Let us do that okay. So, the dhs + vdp, is it okay? -, so, let us; so, this is the expression for the dry adiabatic lapse rate. How temperature decreases with height in the atmosphere. But it is a theoretical lapse rate and dry lapse rate. The actual lapse rate will be different because moisture has not been considered there are many assumptions you have made in the air parcel and all that, okay. So, it is a dry adiabatic lapse rate. Please substitute the values of CP for air and g and get the value.

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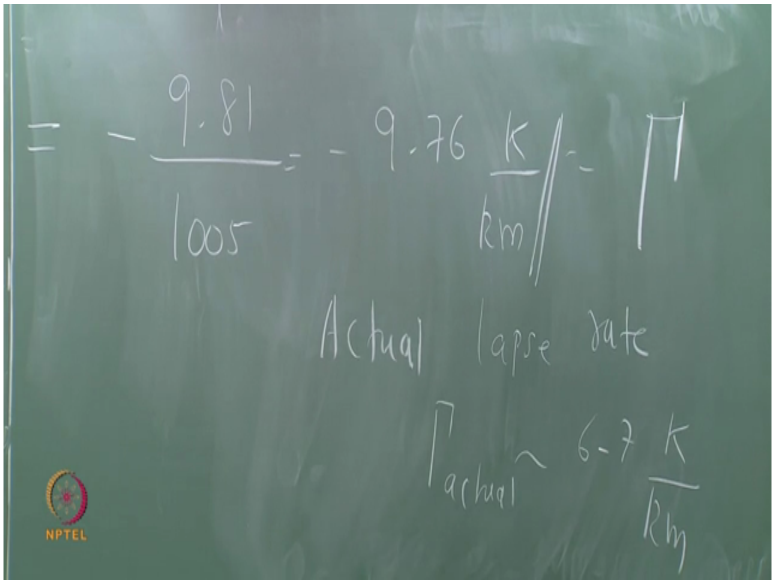

If you want you can have that - also. But please note that it is not applicable beyond tropopause, this thing and troposphere. Please remember, the general nature of shape, general nature of the shape of the temperature is Z profile, okay. Interview question, a temperature decreases so it will keep on decreasing until we go to the Sun. That question is it a stupid question asked by many people in the interview. At least after going through this course you know that this happens in the troposphere, okay.

So, actual lapse rate so this is called gamma. This is one form of gamma okay actual lapse rate actual lapse rate gamma is usually between 6 to 7 okay. Let us do a simple, now, let us consider now 10.25 in the morning. Okay. Let us say Coimbatore.

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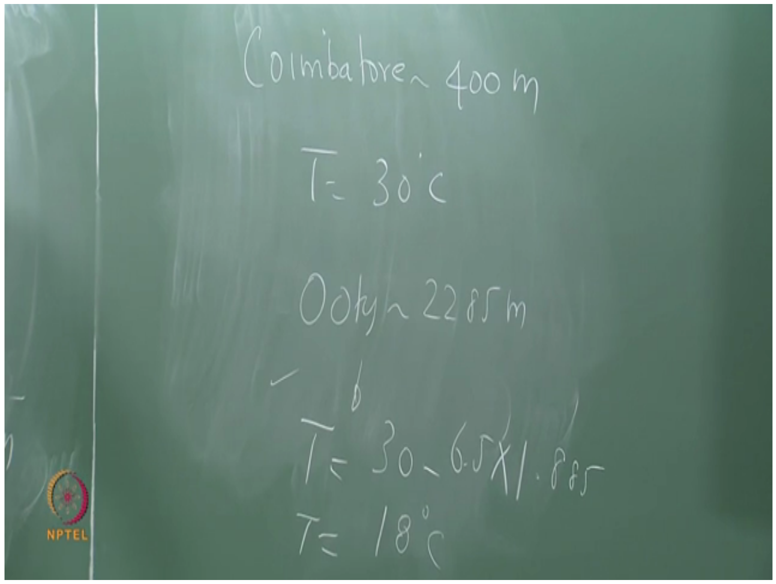

I do not know Coimbatore's elevation. Let us say some 400 meters. So, Ooty is at some 2,285 meters. Can you find out what will be the temperature in Ooty now? Ooty is a hill resort. You have been there, is it before coming to classes itself. So, what? Ooty will be cool, correct how much by how much? So, assume some 6.5 okay of course, because of vegetation, lakes and winds and all that it may be slightly + or - 1 or 2 degrees. But is it correct? So, how much is it? 18 degrees;

20 degree centigrade and 50% related humidity is considered as the best considered as human comfort. So, all the air conditioners are set for some Ashrae is called the Ashrae standard. So, 25 degrees and 50. But this is I do not know why they have set it for all the countries, okay. It is not; need not be applicable for a tropical country like India where generally it is very hot. So, for example Japan where I had been to recently, the trains everywhere they have set at 27.

Instead of 25 if you set it at 27 some enormous savings you can do. Particularly, in a country like that power, there is no need for it. But actually here because it is very hot, they would set it to 23 so there will be lot of difference, when you go into an AC room and come out of it. It should not be the case, right. So, but they are not able to agree because then if we there should be some national or regional standards which you say that everybody need not subscribe to.

Different people can feel comfortable at different temperatures within a range, right. Everybody's temperature now will not be 98.4. So, now this Ooty temperature we have found out. So this is, so this is the concept of lapse rate.

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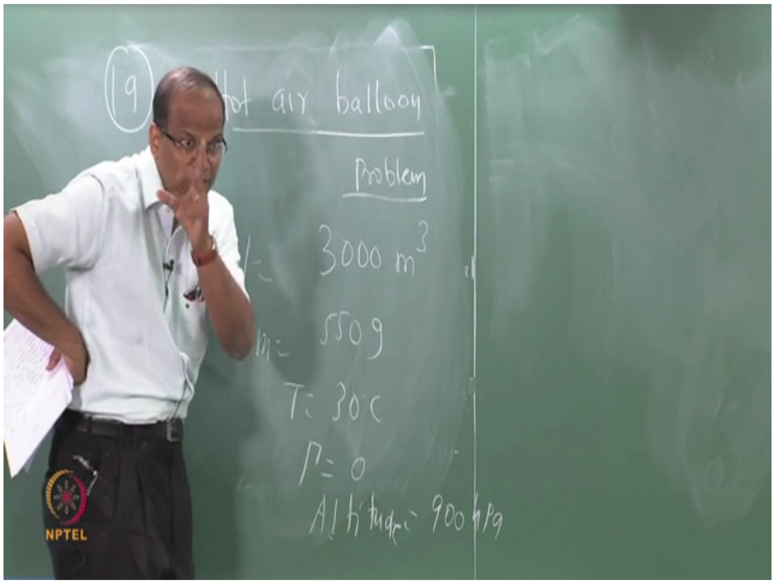

Now, shall we solve the problem? Now, yes, we will solve the problem. Problem number: It is an interesting problem on hot air balloon okay problem number 19, okay. So, you call this as a hot air balloon problem. I ask such questions frequently in the interviews for MS and PhD students. I have a helium balloon, it is of some volume and I tie it inflated and leave it. How far will it rise? It will go to the moon how far, how far will it rise?

Well, surprisingly not many people are able to answer this simple question. It is a buoyancy know the difference in density still we will such time because the density of air will keep on decreasing at one point it will become = the; so right, We will do something like this. But this is a hot air balloon. This hot air balloon people are also using it for fun. It is also using for a leisure tourism and all that, okay.

Please take down this problem. Hot air balloons on sightseeing flights attain volumes of 3000 meter cube, huge okay. Consider a balloon whose total weight including the basket, fuel and passengers but not the air in the balloon, on one such flight, it is 550 kilogram if the ground temperature is 30 degree Celsius if the ground temperature is, lapse rate is 0 to make it simple, if the ground temperature is 30 degree centigrade lapse rate is 0.

Do not worry too much about the lapse rate know now. And the balloon is in hydrostatic equilibrium at a cruising altitude of 900 hPa. Some people have been surprised. Sir, does not know the difference between pressure and height. The basic idea of this course is pressure and height are the same, okay? So, I would say altitude is = 900 hPa then, you do that - that one whatever Z = and all that. We will do hydrostatic equilibrium cruising altitude - at 900 hPa, what do you want to find?

Determine the temperature of the hot air inside the balloon. So, your question is very valid. Force balance and so here a net force = the pressure is balanced by; the buoyancy is balanced by the weight. Please do it so, please solve it. So, the temperature and the pressure of the outside air are given. So, the ideal gas equation is applicable to the environmental air as well as air in the balloon. Therefore Rho infinity that is the density of the environmental air has to be found at first. Keep it okay.

Then, you write the force balance the only thing will which will be unknown is again the density of the hot air. The density of the hot air you replace everything and keep temperature of the hot air inside the balloon as the unknown so that force balance equation can be converted to an equation in which the only unknown is a temperature of the hot air. Or you determine the density first and then P = Rho RT for the air inside the balloon get the temperature.

If it is less than 30 degrees you are in serious trouble. Somewhere you not taking care of the - sign correct. So, who is the volunteer? Is anybody any luck yet, got it? Now, let us so, try to solve it systematically so, using a force balance.

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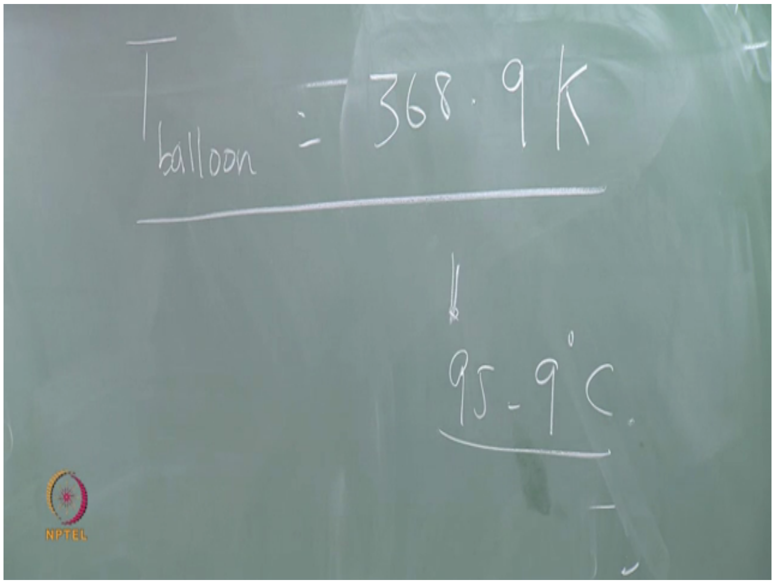

So Rho is more than Rho infinity or Rho infinity is more than Rho. What is this buoyancy force, very good? All that passenger, basket, all that, them, they have been neglected and some energy required and inflating the balloon deflating the elastic and all those things will work. Pack all that. Is =, this is down, what is this? Sorry, sure? This is down is 550 into; very good correct okay. So, what we will do is, is it okay?

So, Rho infinity, applying the ideal gas equation to the environmental air, hPa is almost 10 to the power of 3 or 2. What is the T infinity? 303. It shows you are frowning that lapse rate suppose I made it lapse rate then you will integrate and all that and such things are reserved for quizzes and exam. You have to struggle. You have to find the; but do not worry tomorrow will not be so difficult. Now, so Rho infinity is what is it? What is the value 1. okay.

Now 3,000, correct, what is Rho? 0.8, 0.7, 0.9, 0.8 for you I want just one more confirming 0.8 please decide, 85 so, the first confirmation is Rho is less than Rho infinity, that is why the balloon is all higher. So, it is good for us. So, we have reason to believe that we are proceeding in the right track, okay. Now, Rho = P by RT balloon 0.85. What is the pressure? The balloon is in equilibrium, hydrostatic equilibrium, R is the same? We can hey which is okay; we can take it as 287 into t balloon.

What is T balloon? 368 Kelvin, 0.9 since 90, so the hot-air balloon must be so the people cannot be inside, they will be in the basket outside. How in this hot air produced? By burning so fuel, this thing everything, the whole setup must be there. So, there should be fuel, there should be burning so this thing, you must have seen that, this basket and you must have seen in some movies and all that, ok. These are typical but then sometimes this also leads to freak accidents and so on.

Big plane itself is disappearing, so but for, is it ok? This is a good a good problem wherein you have learnt, lapse rate we have not used, other concepts we have learned we have used. So, if we put the lapse rate is going to make it difficult. But it can be still soluble. So now, I will just introduce the concept of potential temperature and I will stop. Any doubts? Ok. That is something we want to see potential temperature. Potential temperature theta: Let us do this.

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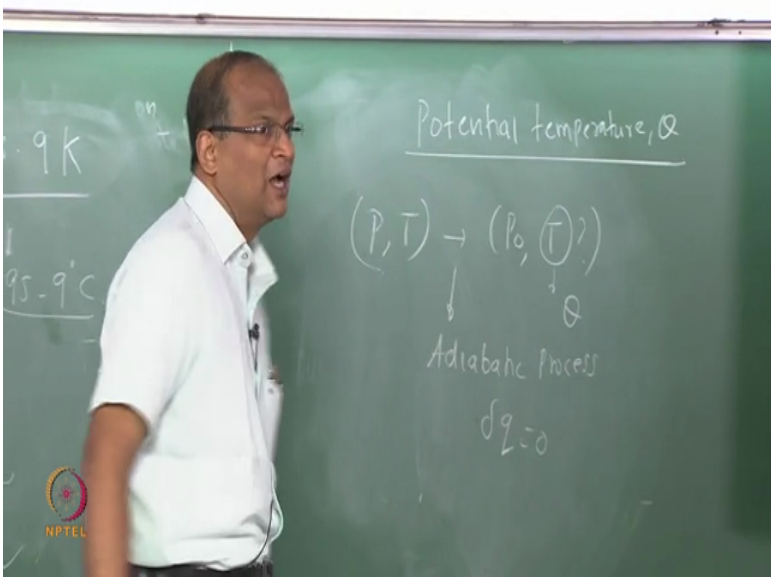

So, please take down this definition. The potential temperature theta of an air parcel is defined, as the temperature that the parcel of air, the potential temperature theta of an air parcel is defined as a temperature that the parcel of air would have is the temperature that the parcel of air would have, if it were expanded, parcel of air would have if it were expanded or compressed, through the potential temperature theta of an air parcel is defined as a temperature that the parcel of air would have if it were expanded or compressed adiabatically.

If it were compressed or expand expanded or compressed adiabatically, from its existing pressure and temperature, to a standard pressure P naught within brackets, generally taken as 1000 hPa which one standard pressure, standard pressure P not generally taken as 1000 hPa, okay. I need for the sake of completeness, I will go through this again. People who have missed certain things just listen to this carefully.

The potential temperature theta of an air parcel is defined as the temperature that the parcel of air would have if it were compressed or expanded adiabatically from its existing pressure and temperature to a standard pressure P naught generally taken as 1,000 hPa. So, the potential so there is a air parcel at P and T. You are taking it to P naught okay. What is the route? You are using an adiabatic process dq is = 0 the temperature of the air parcel will take if you use an adiabatic process to reach P naught from P that temperature is nothing but theta.

We can derive it mathematically but that we are going to do in the next class. What are the uses of this potential temperature? The potential temperature concept is extremely potent and powerful. It is very useful in atmospheric thermodynamics because most of the processes which are taking place in the atmosphere of adiabatic processes.

If most of the processes are adiabatic processes and we have a framework called potential temperature in the next class I am going to prove that the potential temperature remains constant during adiabatic transformation then we say that the potential temperature is conserved during many of the atmospheric processes. So, if something is conserved during atmospheric processes with the potential temperature, we can learn so many things.

We can work out problems; we can understand phenomena better. It is equivalent to density in incompressible fluid flow which will never change. The fluid may be actual rate at density pressure may increase degree whatever, the dense density of water 1000 kilogram per meter cube okay. Air is a different story, okay. So, just like density an incompressible fluid flow, the potential temperature remains conserved, with which then, we can define something like equivalent potential temperature and this thing and so we can keep going.

And then, we can construct charts and then instead of using equations to solve problems, if you are able to get adiabatic temperature, potential temperature, pseudo adiabatic, temperature red bulb potential, white bulb potential all that we are using charts, we can solve many problems when some air parcel is going up, going down, it goes up then, it sheds its moisture then it becomes rain.

All those kinds of problems can be immediately solved without taking recourse to very complicated maths, by just using the some of these concepts. So, this derivation of this potential temperature and proving that the potential temperature remains constant along with the simple thing that Pv to the power of gamma is a constant for adiabatic process all this we will see in next Tuesday's class.