Environmental Air Pollution

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Lecture No. 24

Vertical Temperature Profile of Atmosphere

If you recall, we were discussing about the change in the density with respect to change in the temperature. I want to go back to the basic model that we started with in trying to understand the system.

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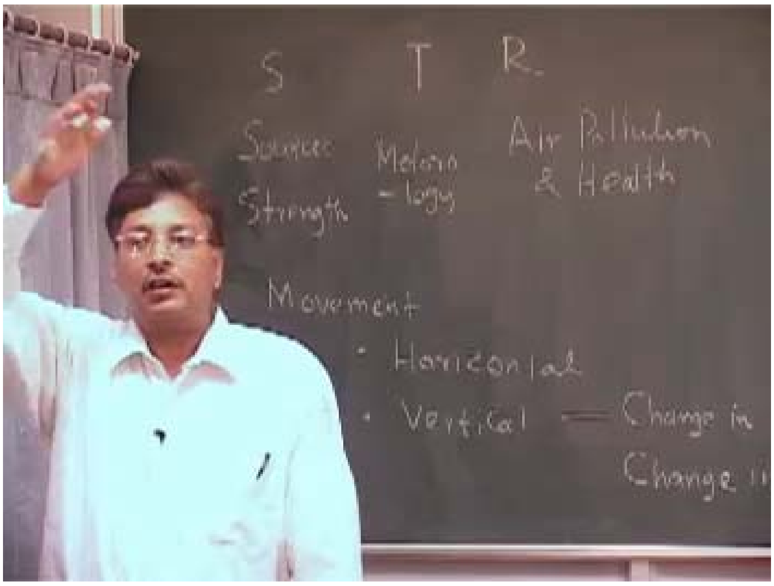

So far, we talked about the different kinds of sources: line sources, point sources, industrial sources, domestic cooking – we have talked about all kinds of sources. We have even talked about how to find out how big is the source and we did that through emission inventory. We have done not only the source types, but also the power of the source or strength of the source – we have done that so far. Now, you have a very good idea. Suppose I ask you to find out what are the sources in Kanpur, you can do the exercise. If I also tell you to find out which are the largest sources, like power plants or industry or a fertilizer plant, you can do that also. If I ask you to go and find out what are the sources of vehicular pollution, you can do that also. Not only can you identify them but you can also quantify them as to how much is the emission – that is very important when we talk about this system. You recall we also talked about the receptors, especially the health point of view, how people are affected – air pollution and health. To connect these two, we need to understand the transport of the pollutants. If you recall, we said that the study of the transport of pollutants in air is called meteorology.

Our focus in the coming lectures will be on the transport that is governed by meteorology. In meteorology, we talk about two things. The movement of the pollutants can be through two means – one is vertical movement and another is horizontal movement. We talk about the horizontal movement of pollutants and then vertical. In horizontal, we have talked briefly about wind roses, wind speed and wind direction but the focus now in this lecture and in the coming lectures is on how the vertical movement of the pollutants will be decided, how high they will go, how much they will disperse vertically – that is also very very important to us. Now if we are focused on the vertical movement of the air pollutants and if we say the vertical movement is important, then what causes the vertical movement?

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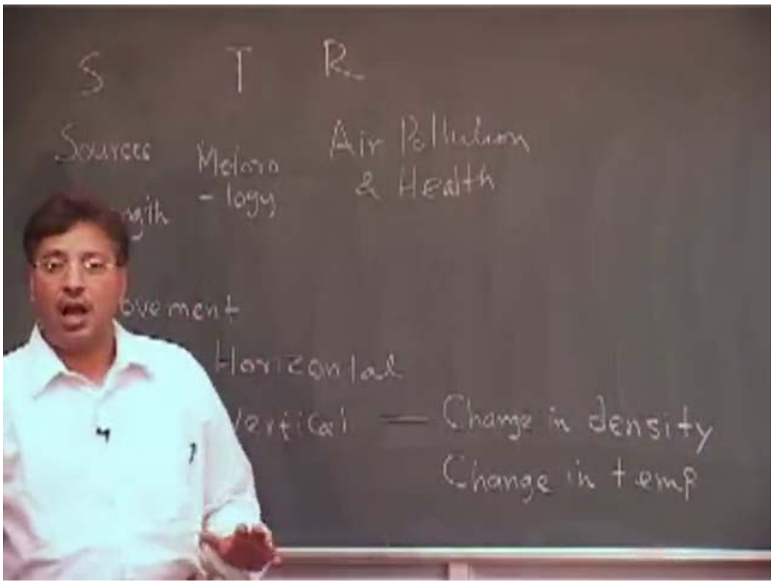

Vertical movement is largely because as we go up, there is a change in the density and the change in the density comes about because of change in temperature. We want to see how the temperature changes as we go up vertically, because that is largely going to decide the vertical movement of the pollutants that just go out from the chimney. You have seen pollutants. Sometimes, you see the chimney pollutants just continue to go vertically high;

sometimes, they just come down and sometimes, they are dancing like a… we call it dancing plume; sometimes, you see very thin plume travelling kilometers and kilometers. Vertical movement is decided by change in the density and change in the temperature. Our focus will be to see how the temperature changes as we go on. Generally, we all know that temperature decreases as we go up – Simla is always cooler than Delhi, Mount Everest is cooler than here. We understand that there is a change in the temperature and the temperature decreases as we go up, especially in the troposphere. We want to look at the physics of things and how they change.

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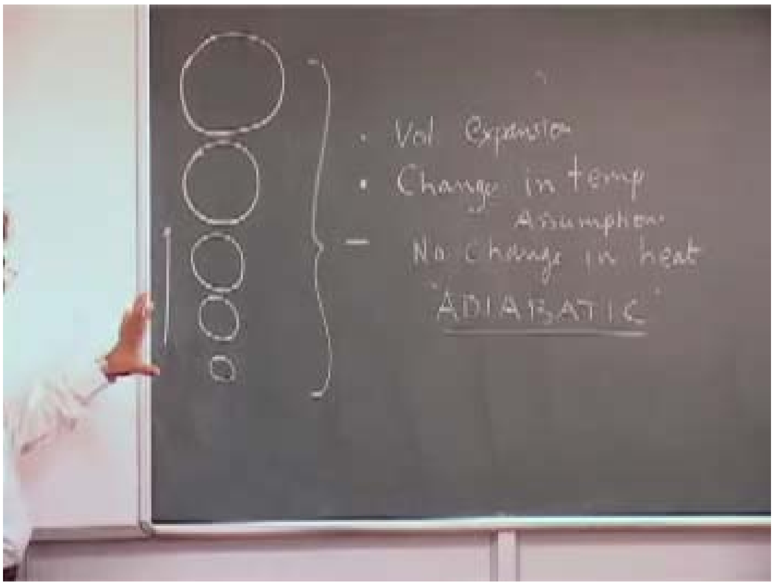

We will try to see this but for doing that, let us take an example. I take a small parcel of air that is here and suppose I have given it a vertical push and the temperature is higher. As you see, as it goes up, the particle or parcel of air becomes bigger and bigger – something like this. You see here the vertical movement is changing because the density decreases, the pressure is decreasing and as a result, there is an expansion in the size – same parcel, same mass but you see that as we go up, it changes. That is one thing we have to understand – the pollutants can change like this. What is happening? I can say that there are two things happening here – volume expansion. What else? The volume is expanding and change in the temperature of the air parcel; whatever is the surrounding temperature, that is not being affected because of this. So you say volume expansion and change in temperature.

Suppose we make an assumption here that because of the change in the pressure as things as moving up, expansion is taking place but there is no transfer of heat between the parcel of air that I am considering to its surrounding, which is a reasonable assumption. Things are happening so fast that the temperature transfer or heat transfer between the particles of the air parcel that I am considering with the air surrounding… If you agree that there is no transfer of heat between the parcel of air as it is moving up with the surrounding air, what is such a process called? Adiabatic. Adiabatic process.

I am trying to remember the assumption. We are trying to address how the vertical movement of the pollutants will take place and that will be decided by the change in the temperature as it moves up. Here, the assumption (which you all will agree with and is a reasonable assumption) may have some implications but I can define this process as an adiabatic process and so we say no change in heat input or output. The process that we will consider and use to address issues – we assume this as adiabatic.

These are the two things that will happen and we want to define these two with respect to considering the process to be adiabatic. If you like, I will write here that this is our assumption. For the same thing, I want to give you a different example so that you have a little feel of what really happens. You must have seen hot air balloons – it is starting from here and it goes up. Do you know the record that has been made by an Indian for flying the highest? Who was the person? Vijay Mallya. Vijay Preeti Singhania. He made the record of flying very high with the hot air balloon. I will try to give you a little more clarity about hot air balloons. Let us draw the picture anyway.

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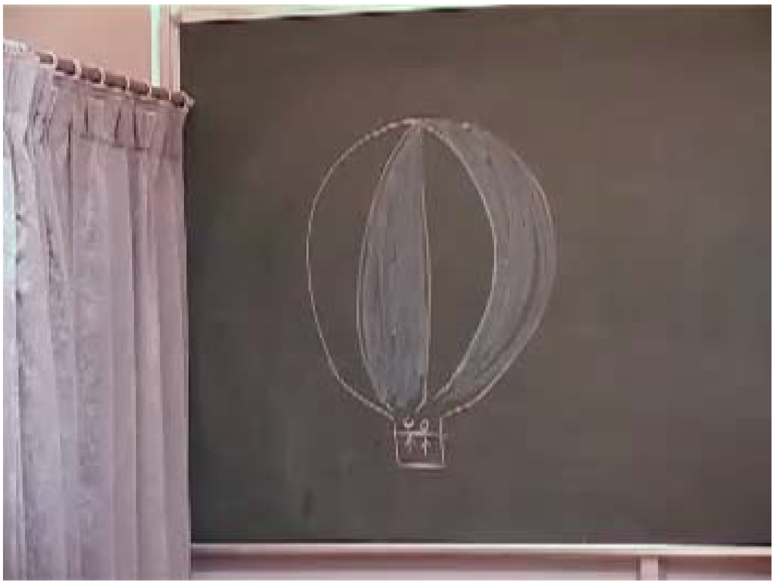

Generally, it is very colorful. You generally have two persons sitting here blowing the hot air through this and it goes up. Suppose you are travelling with your friend and it moves up, what you will notice is that as you move up (these are the strings), this portion (Refer Slide Time: 11:03), which is part of the balloon, tends to bulge out – it becomes bigger and bigger, bigger and bigger. You have to be… [11:09] strong. Then you will see that after some time, these things are fixed but this portion, which is a kind of balloon, bulges out.

Same thing – as it is going up, it comes out bigger and bigger and bigger. Maybe you do not notice it because it is going high up in the air. The same thing, the very same phenomenon is happening. Here, you are moving continuously up – we had the same parcel, same mass and the volume is going up. What we will do is we will try to… with the help of physics, a lot of thermodynamics, I will go a little fast because you have done all this in your high school.

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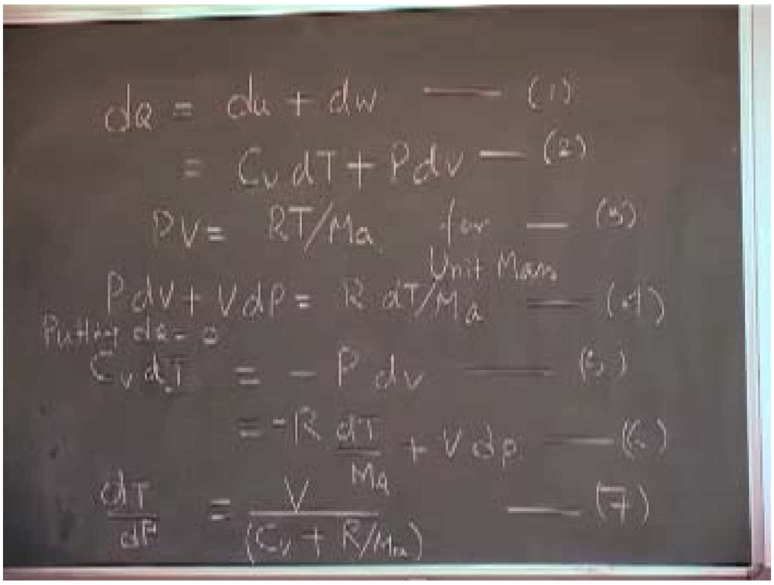

What can say I here is this: the change in internal energy and work done we want to represent as du plus dw. Let us say this is equation number (1). I am not writing but you can write this from the laws of thermodynamics – this is a basic equation we have been doing over the years. You can write this as C_v dT plus P dv – this is your equation number (2). I can also write for the unit mass of the air or gases that I am talking about – for the unit mass. Let us say that is my equation number (3).

If I differentiate this equation, I can write this as P dv plus V dP, R and M_a are the constants, so R dT by M_a, let us put small a – that is my equation number (4). I want to go back to the equation (2) and I can very coolly put dq is equal to… Adiabatic process, what is dq? 0. 0, fine, I can put dq = 0. Therefore, putting dq = 0, C_v dT will be equal to minus P dv. If I take up the minus P dv, C_v will be equal to minus P dv. I can pick up minus P dv from here and what will that be? C_v dT and then I can… My C_v dT is equal to minus P dv, let us go one step at a time.

In the place of P dv, I can write like this. This will be equal to R dT by M_a. Minus. Should I put minus here? Okay. Plus…? V dP. V dP. Now, with this expression, I will save some time and I can write an expression for the change in the temperature with dP. Can you write that quickly? You have the dT term here (Refer Slide Time: 15:46). Bring this here, take the dT out and you can write the expression for dT by dP. That expression comes out to be…. If you want, you can quickly write the expression and see if it matches.

[Conversation between student and professor - Not Audible (16:03 min)]

Go ahead. V upon…?

[Conversation between student and professor - Not Audible (16:19 min)]

Whatever it is that that you come up with. Let us do this. V upon C_v …. Plus R by M_a. Plus R by M_a. Anything else? All agree with this? Let me put this. I again use my same relationship here and I can still place the value of V from here. Let us give numbers, if you like. This is (5), this is (6), this is (7). We can put the value of V in (7) from (3).

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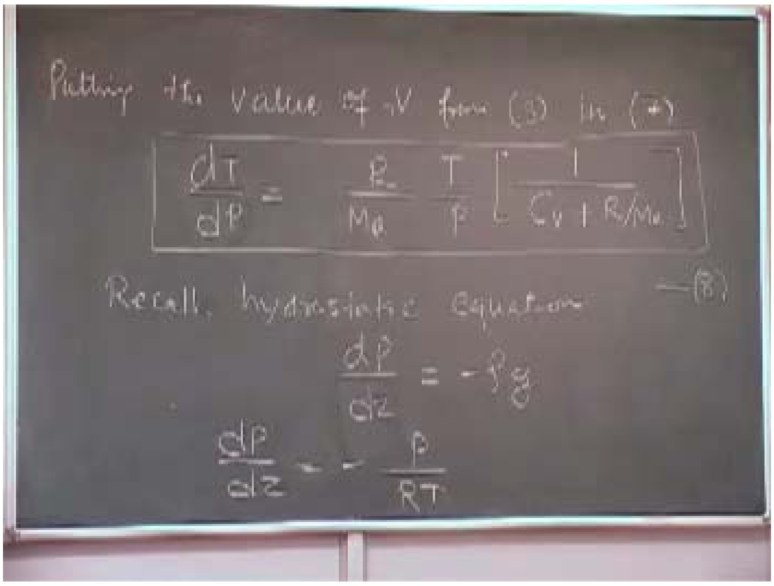

Putting the value of V from which equation? Basic equation (3). Where do I want to put it? In (7). Then, I will get some expression that is of interest to me and that expression is dT by dP. I would like to you give me that expression again and see if that matches. R by M_a whole upon …?

[Conversation between student and professor - Not Audible (18:13 min)]

This into…?

[Conversation between student and professor - Not Audible (18:16 min)]

Finally, we will write it in a little different way but whatever you are getting, let us write it. T by…? P and whole thing into 1 by C_v plus…? R. R. R by what? M_a. M_a, great. You get the same expression as I get. We will remember this equation – do not forget this equation because this tells me how the temperature will change with respect to pressure. Let us write this equation as (8). No problem? You have derived that out.

Suppose I now want to invoke the hydrostatic equation. We say recall the hydrostatic equation. I am writing for the atmosphere. What I can say is Z is my vertical direction. Do you agree or do I need to do something else? Minus. Minus sign. For this rho, again, I can invoke the universal gas law, which you see in equation (3), and I can put the value of rho in this. Right? Do that. We say dP by dZ and again, you give me the expression. Take rho in the form of mass by volume from your equation number (3) and give me the final answer that you get. I can put the negative sign very conveniently.

[Conversation between student and professor - Not Audible (20:37 min)]

What are you getting?

[Conversation between student and professor - Not Audible (20:42 min)]

P, g is there anyway by…? RT. RT. M term should also be there – do not forget there is M_a here. That comes in the…?

[Conversation between student and professor - Not Audible (21:00 min)]

Unit mass is here. This M here (Refer Slide Time: 21:09), M do not forget, what is this? This is not [21:41], this is the molecular weight of the gas that we are talking about, so this is not unit. Because this has to be mole fraction, we took this M as 1. We can even write it a little bigger – does not matter. What else will come here?

[Conversation between student and professor - Not Audible (21:32 min)]

M_a, up?

Does everyone get that? g. The g of course. Let us write this equation as (9). Now, life is simple – I have two equations that I derived and they are equation number (8) and equation number (9). Recall that we are doing all this to find out how the temperature changes as we go up. We know qualitatively that it changes and it reduces as we go up. What I can do is I can get the expression if I multiply equation (8) with equation (9). So I am multiplying (8) and (9).

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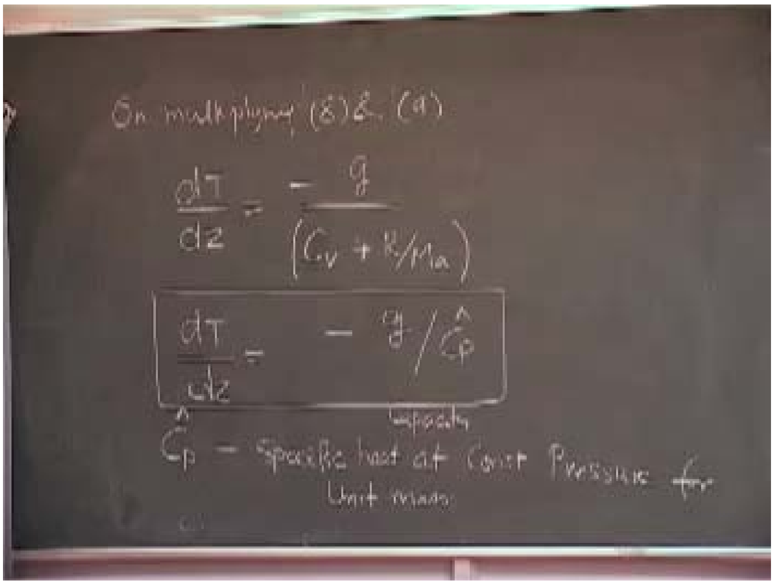

You should get some expression that should look like dT by dZ. Please give me that expression, whatever that comes out to be. There will be some cancellation here and there and let us see what you get. g upon C_v. g upon C_v plus…? R by M_a. R by M_a. I can put this in the bracket if you like and negative sign. If that is the case, if you agree with this, this can also be written as… where C_P hat is the specific heat at constant temperature for unit mass or specific heat capacity – or should we say specific heat capacity at constant pressure? Complete the sentence: constant pressure for…? Unit mass. Unit mass, excellent. Great relationship and we are going to use it consistently many times in the coming lectures and this is a very important thing we came up with. For this, let us use the other side.

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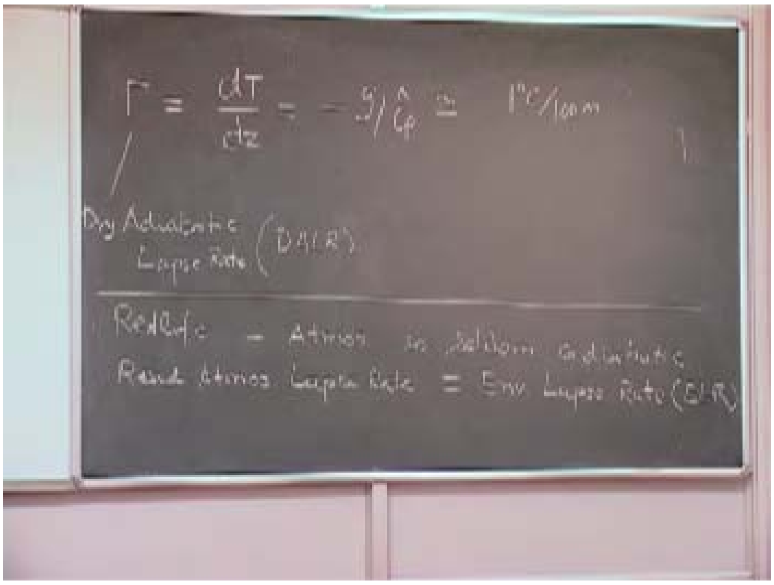

For the constants g and C_P hat, I am not putting the numbers as such but finally giving you the answers. It is better to make this as approximately and it is approximately this. The terminology we use in air pollution for this is lapse rate, because there is a lapse in the temperature or exactly we call it adiabatic because we invoke the concept of adiabatic lapse rate. Generally, the value of C_P that we have taken in here if you see the moisture content is very much variable in the atmosphere.

What we have done here is while putting the value of C_P, I have taken the mass of the air and all air as dry. If you do not mind, I will put the word dry there and call it dry adiabatic lapse rate. That is equal to minus g over C_P and that is equal to 1 degree Centigrade per [26:39]. Never ever make a mistake of calling this as the big sigma or what do you call that? gamma. Yes, big gamma. What do you see here is big gamma equals to…. It already accounts for the negative sign. Never write big gamma is equal to —1 degree Celsius [27:05] – you will make mistakes. I want to make that point clear again to you that this minus sign is already taken in when you are talking about lapse rate, because you are using the word lapse rate. The lapse rate is this and that is a very very important thing that we came up with.

Let me also tell you that for this derivation that we have done, we have simply used the laws of science and physics and this will also be valid whether you are on Mars or Venus – there also, you have the atmosphere. What will be different is that g will be different and C_P will be different. C_P will be determined by the composition of the atmosphere because in C_P, you have heat capacity, which will depend on the various gases that are present, and so, the molecular weight also will change. The derivation that we have done so far holds good whether you are on earth or you are on Mars or on Venus, but the things will change.

This is what we have got as a very very important thing and that is what we will be using the next time. Now, in a way, this answers not only why but how much Simla will be cooler, what will be the temperature in Mount Everest. But again, having said all these, in real life…. This situation is a little bit hypothetical, adiabatic condition. Moreover, more problematic than adiabatic is that we have considered it to be dry – the atmosphere is never dry. In real life, the atmosphere is seldom adiabatic, especially the range that interests us – from here to 2000 meters or so. In that case, the atmospheric lapse rate…. Here, let us write this as DALR. In real life, the atmosphere is seldom adiabatic and so the atmospheric lapse rate will be a little different than what we have derived. We call this atmospheric lapse rate as the environmental lapse rate – the real atmospheric lapse rate (real means actual at the time you are considering) and we call this as ELR.

Why are we using the word ELR? It is simply to avoid confusing with the word adiabatic because I could also use the word atmosphere here. Never be confused again because in books, they will use the word ALR – ALR is not atmospheric lapse rate, A stands for adiabatic. Confusion comes easily and so to avoid confusion, we will use this word when we want to define the real environment as the environmental lapse rate and ALR will not refer to atmospheric lapse rate but adiabatic lapse rate in the atmosphere.

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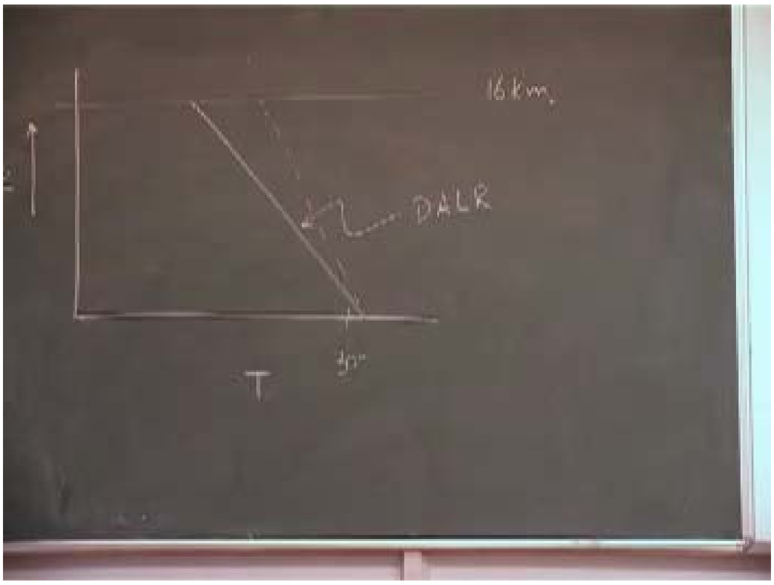

I just want to show and plot this. We will have many graphs in this lecture and many lectures. We will put the standard thing here, height above the surface level and we will talk about the temperature here, because that is what is of great interest to us – the relation between T and Z. We are talking about the troposphere. How much is the troposphere? How far can I go?

[Conversation between student and professor - Not Audible (31:58 min)]

How much? 16 kilometers. 16 kilometers. Of course, at the poles, it will be different and it will be different at the equator. At the poles, it will be less but let us say it generally goes up to 16 kilometers. You can start with a normal temperature – 28 or 30 degrees, it does not matter. It may reduce a lot, I will not be able to give you the exact number here but then you see that it will reduce to this. This is your adiabatic lapse rate. What do you expect? I can call this as DALR.

Suppose some percent of moisture is there, then what will happen? I will still have the lapse rate. Will the temperature decrease be on this side or this side? This side or this side? The left side? The change in the temperature will be like the heat capacity of that thing will be more. So C_P will be smaller and you may get something like this – depending on the moisture. Now if I want to draw or talk about.… We will remember these things – lapse rate business and we will use it several times.

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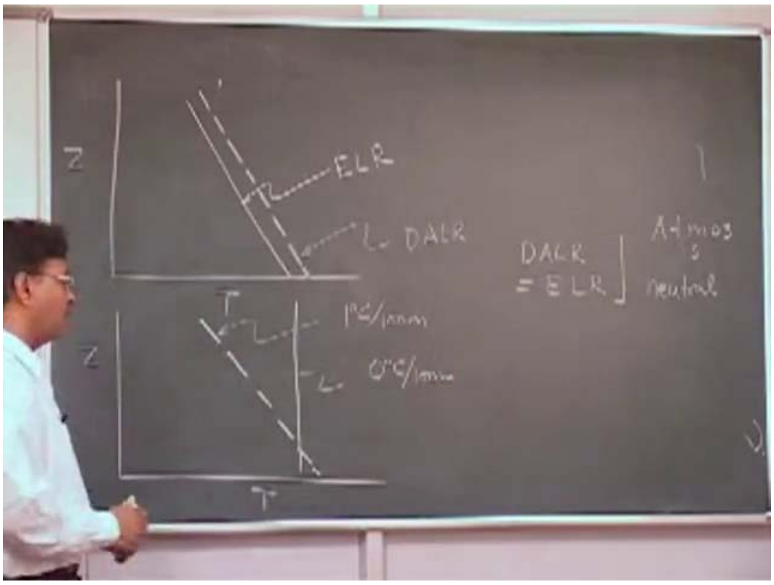

Since we have time, what we will do is plot a few things. Same Z here and T here. As a matter of convention, I will always draw DALR as a dotted line or dashed line. The moment you see I am making this, whenever you see a dashed line, it means we are talking about DALR – always. This is the situation. Suppose I went and really measured the temperature with respect to height in the atmosphere and I got a temperature profile. What you see here, the solid line is the actual thing. No confusion between DALR and ELR. ELR is my actual and I like to call it as the environmental lapse rate. What you see here in this picture is a situation that we call as neutral atmosphere, because the atmosphere is behaving the way the adiabatic lapse rate will behave.

[Conversation between student and professor - Not Audible (35:35 min)]

This thing is hypothetical in the sense that I can plot here or here or here – whatever temperature I started with [35:51] the temperature will decrease. This is the standard line and I can draw this here or draw here – it does not matter. Or does it matter? It matters if you want to find out the temperature but this is our reference – where we are with respect to the reference thing. This is just a reference, but of course, you do not want to plot it somewhere here or there. This is my reference and I want to see with respect to the reference how my atmosphere is behaving, what my atmosphere is doing – that is the idea. So one situation can be this. It is behaving exactly the way the adiabatic lapse rate is and such atmosphere – I will explain what is the meaning of this – we call as neutral.

Situation number two, this is Z and T and this situation can also come. The standard conditions or the reference standard conditions are there and then you see here that the temperature, in fact, increases instead of decreasing. What can you say here? Here, what was the DLR? It was equal to 1 degree per 100 meters – change in the temperature. For this, there is no change of course.

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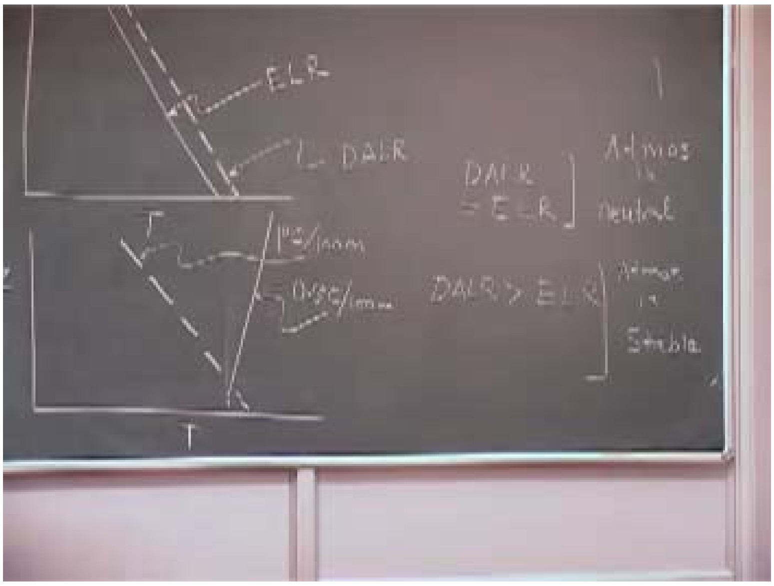

Or to can make the things little more interesting, I can even increase this, which is not uncommon – I can increase it. Suppose after increasing, I am calling that…. This was my this thing, this is my this and I am calling this as 0.5. Do I need to put some sign here? What sign do I put? Negative. Negative, because this temperature is…? Increasing. Increasing. It was decreasing and I have taken that for this. What you see here is that DALR is greater than ELR. Do you agree or not? You agree because there is a negative sign there. That is the situation and we call the atmosphere to be… stable or unstable? Stable or unstable? Atmosphere is called stable. I will explain why it is stable.

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This is the third situation that can be there – the temperature is decreasing rather…. This is my DALR and this is ELR. What I can say? Correct? The atmosphere is unstable.

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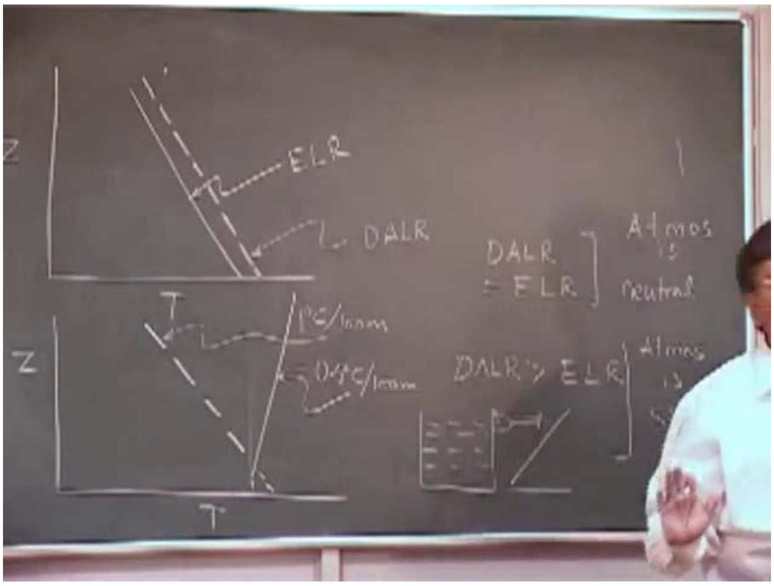

Here, why are we calling it stable? Suppose I have a beaker full of water. What is the situation? This is my height of the beaker. What is happening here? At higher height, I have a higher temperature and the temperature is lower here in the beaker. Suppose I take a big beaker and then I am drawing the profile of the temperature with respect to the height of the beaker, let us say it is like this – it means that as I am going up, the temperature is increasing. In a way, what I am doing is that I am heating the beaker as if I have put a burner here and I am heating it. Do you agree with me? Then only I can have the high temperature here and low temperature here. If this is the situation – you are heating the water from the top to get a temperature profile that looks like this, what will the water be doing – will it be boiling or jumping or will it be quiet?

It will be quiet because there is no convection – nothing going up and down and there is no turbulence. The water will be sitting more or less quietly as stable water. Same thing in the atmosphere. I gave you this example but if you look at the atmosphere, in a way, the atmosphere in some sense (how it is done is a different thing) is being heated up from the top and the temperature is lower at the bottom. As a result, there will be no convections, there will no current, there will no turbulence, there will be no mixing and as a result, we will call that as stable water – the water is stable. The atmosphere is also stable and so it means the pollutants will not travel or will not jump or will not do the things what they do.

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But here, if you look at the same thing here, what I am doing here is that…. Let us take the beaker business again. I am heating from the bottom – this is my burner. Obviously, the temperature will be higher here, the temperature will be lower here and I will get a profile like this. Then, you will see there will be convections, there will be turbulence and things going up and down and that is why we call this atmosphere as unstable – things will be unstable. Probably when I am not heating it all together, then you can call that atmosphere as neutral atmosphere. All these three conditions are common in the atmosphere – the atmosphere can behave like this (Refer Slide Time: 44:02), the atmosphere can behave like this and the atmosphere can behave like this.

If you can imagine with respect to what is happening in the beaker, exactly the same thing happens in the atmosphere. Suppose I tell you that the plume is dancing going up and down and there is huge turbulence, what is the situation? The situation there. When I say that the plume is just not moving – it is just like a trickle, small thing that is travelling, it is this situation and it means that there is no turbulence at all, things just tend to move – there is no vertical movement. Our lecture is especially focused on vertical movement of the pollutants. Then, you see here that there will be a reasonable movement. With respect to these, we can define the behavior of the atmosphere. I think I will stop here unless there are questions. We can take some questions and then we will get into a little more specification within these things – if it is here or here or here. We have done the broad picture and we will get into a little finer details of this in the next lecture.