Introduction to Atmospheric Science

Prof. C. Balaji
Department of Mechanical Engineering
Indian Institute of Technology-Madras

Lecture - 27
Conditional and Convective Instability

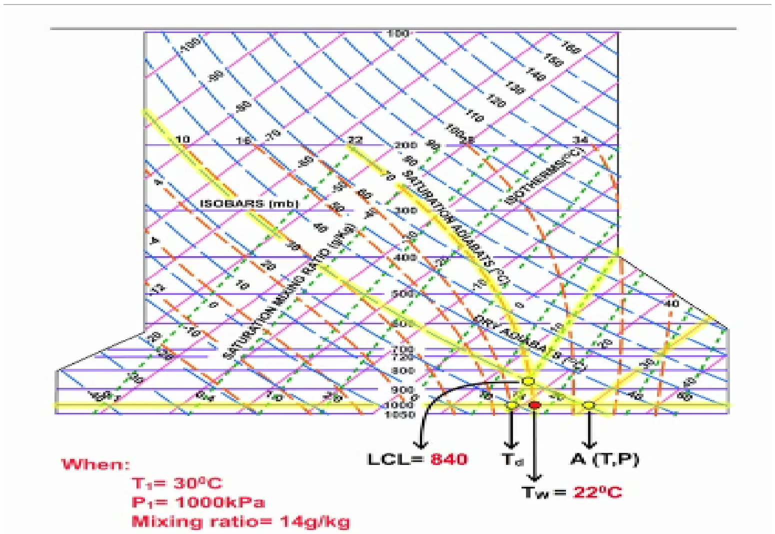
Okay, Good Morning. So we were looking at the stability of an air parcel correct. We were looking at the stability of an unsaturated air parcel and so on and we have to move on to stability of saturated air parcel okay. As you know the transition from unsaturation to saturation takes place basically by knowing the lifting condensation, sorry the lifting condensation level.

Beyond that there is something called the level of free convection LFC which we will see in today's class. But before that the first few minutes I thought that the problem number 38 which was involving a Chinook wind. As you know the Chinook wind is a snow is called a snow beater where cold winds are blowing from one side of the ocean, they hit the mountains, they climb. Once they cross the lifting condensation level they shed the moisture in the form of precipitation.

And because of the winds they cross the other side, the air parcel crosses the other side and then it follows a dry adiabat and then when it reaches the 1000 hPa we have seen that it becomes much more hotter than it originally started out with. So the leeward side of the mountain you got dry hot winds okay which can melt snow. So it is called a snow beater. So it is particularly prevalent in Canada and in the and US for example in Colorado and so on alright.

So this problem we have already solved using the Skew-T ln P chart. I thought that I will just show you an animation today okay. Then so you have already solved this. So let us go through this okay. The problem number 38.

(Refer Slide Time: 02:01)



Coordinate system of the Skew-t, Log-p Diagram

So these pink lines are the isotherms. Skew-T ln P. So this is Skew-T ln P chart. Now initially we have temperature T 1 is 30 degree C. Temperature T 1 is 30 degree C and the pressure is 1000 hPa. I am sorry it is 1000 hPa. So that is point A. So it is indicated by the blue lines sorry yellow lines. So the pressure is horizontal and the temperature is the skewed straight line. So the intersection gives you the point A. Superimpose the saturation mixing ratio on this.

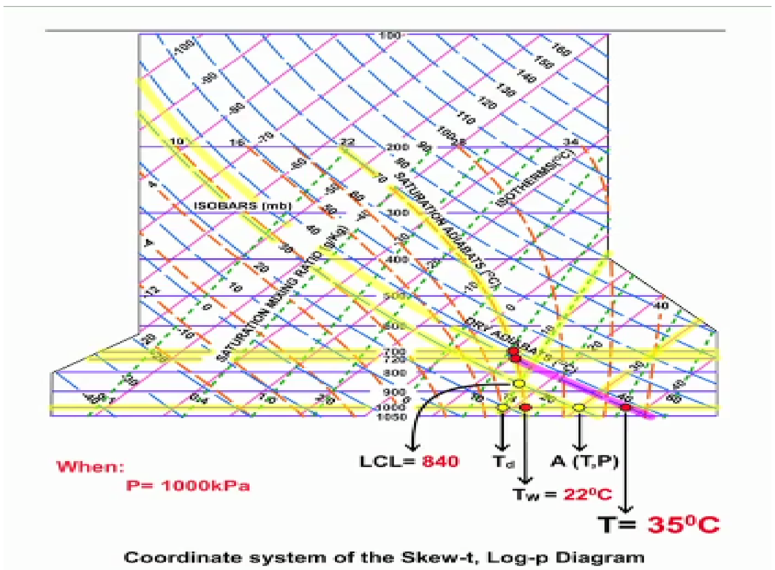
Now the mixing ratio has been given to be 14 g/kg. Now find out where for this omega is equal to omega s where it hits the 1000 hPa at the same pressure level. That will be the dew point. Then you draw a straight you draw a line which goes along the saturation mixing ratio 14. It is going up, that is yellow line right okay. Now, from the original point A take a dry adiabat that is going up.

So this saturation mixing ratio corresponding to omega equal to omega is equal to 14 g/kg will meet this curve of dry adiabat which is originating from the original point A and this intersection gives you the LCL, very good. So LCL is 840 hPa. Any doubt so far? It is fine okay. So it gives you so you find the lifting condensation level. Next, these are the saturation adiabats okay saturation adiabats.

So after a parcel crosses the LCL unit further climbs it has it cannot its dharma is it will follows the saturated adiabat okay. Now that is indicated by this line okay. Now, when you put that line back into the 1000 hPa you actually get the wet bulb temperature right and this wet bulb temperature is also the potential wet bulb temperature because it is 1000 hPa. Suppose when original condition were to be 950 hPa then you will pull this yellow line back to the 1000 hPa and that you will call it as theta w.

But when it crosses the original if it is 950 that will be the T w. So the original pressure is not equal to 1000 hPa. T w will not be equal to theta w. But in this case since the original pressure is 1000 hPa is a normal therefore the theta w equal to T w. Any doubt so far? So already we found so many quantities alright. Then we solved a problem like this in the quiz right.

(Refer Slide Time: 04:57)



Next, it goes you have drawn one more horizontal line which is the 700 hPa correct because it rises up to 700 hPa. That is the point. So that is the maximum height it has reached 700 hPa. We can take P by P not is e to the power of - z by H. Have a scale height of 7.5 km. You can actually find out the height. Did we find out? Oh we did not find out. Okay let us not. We did not. Let us not agonize it further. So it will be some height. Okay some kilometers it will have.

From there I am drawing another 720. What does, how do I get the 720 because it is coming back. When it is coming back from 700 it will follow the saturated adiabat and that is the point. Once it has come to 720, now it will follow a dry adiabat all the way up to 1000 hPa. So that will be the pink line. Can you follow the pink line? It will again cut the 1000 hPa. That will be the final temperature which is 35 degree C.

So we have solved the complete problem on the Skew-T ln P chart. So from the original condition we found all the things; dew point, wet bulb temperature, lifting condensation level, final height. Then from the based on this point when it reaches the final height you know what will be the mixing ratio. Then what is the original mixing ratio, that will be saturation mixing ratio. The remaining must be shared or it must be held as water; 80% is removed.

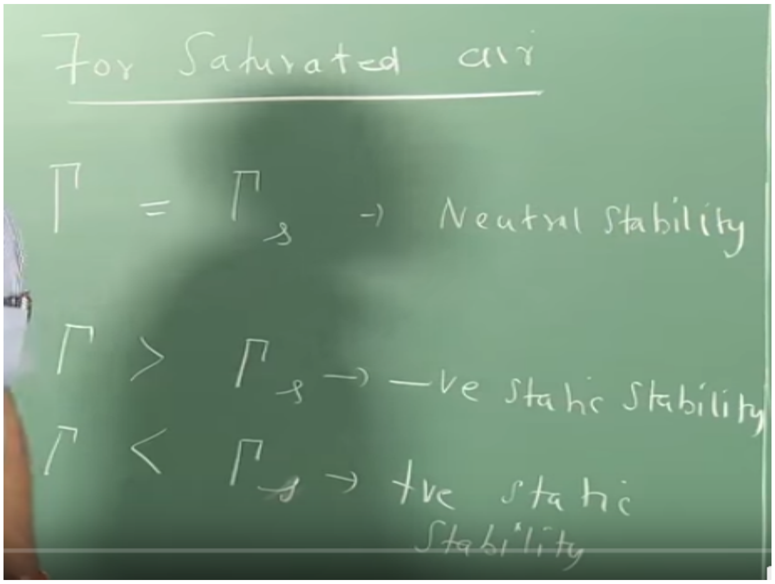
What is remaining will be 10.8, 14 minus 80% of 4. So 10.8 is remaining. With that 10.8 you are going all the way. Then you got the final temperature 35. You can still calculate the relative humidity. I think it is drier correct? The original relative humidity was 45 or 50%. Now it has become 25 or 20%. How much was it, 24%. So this is the way I expected you to have solved in the quiz paper. Anyway I will start looking at it over the weekend.

Hopefully, you are all now experts in using the Skew-T ln P chart alright. Now the Skew-T ln P chart, it can get really involved. Now you can see that if I give a sounding, if I give you a sounding data, various pressures and heights, then finding the stability of the air layer and all that it is more and more involved. This is what meteorologists routinely do everyday in their sitting in their offices okay.

I do not know how much deep we can go because we still have radiation, climate change all those things. But I want to finish this week or next week maximum first class thermodynamics and get on to radiative heat. So I think we got too deep into the okay. That is okay we will see. Did I tell you about the saturated air also, no. So the Brunt-Vaisala frequency which we derived in the last class is a measure of the stability of the air parcel.

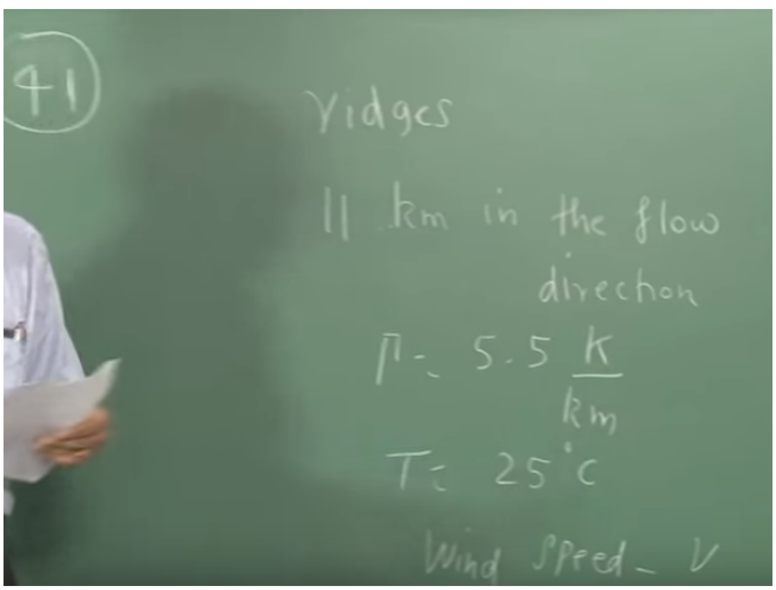
Greater the Brunt-Vaisala frequency better is the stability alright because that gives you an idea of the restoring force and all that. We actually derived it from first principles Brunt and Vaisala are the 2 meteorologists who worked on this problem. That is why it goes by the name Brunt-Vaisala frequency.

(Refer Slide Time: 08:13)



Now for saturated air, gamma < gamma s is, gamma < gamma d was stable or not for the unsaturated yes so it is positive static stability. This is negative static stability. What is this, it is neutral stability okay.

(Refer Slide Time: 09:38)

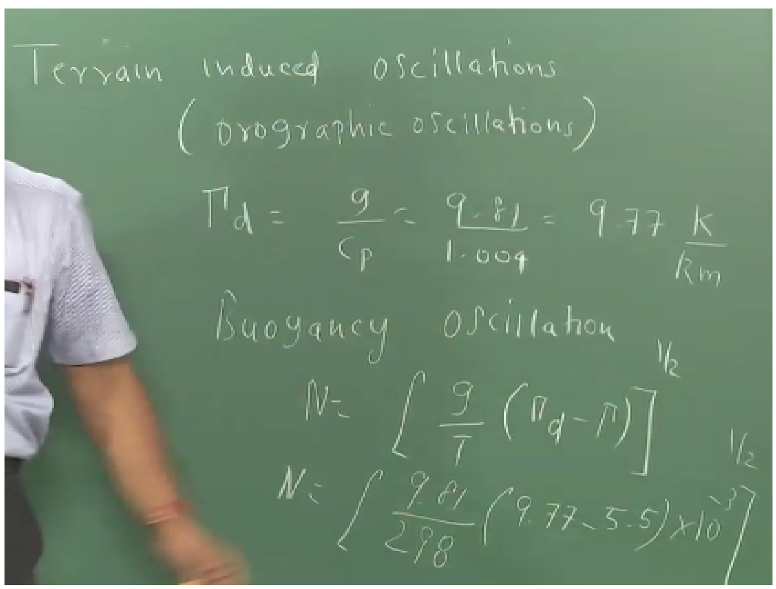


Let us solve a problem now, problem number 39; 41, okay. After that we solved 2 is it? Oh, we derived the Brunt-Vaisala okay. So problem number 41 okay. We will easily cross the half century. So if you have solved 50, 55 problems and then 6 to 8 problems in the quiz and some 10 problem in the end sem, you would have some 70 problems. That is actually the learning according to me, maximum learning. Theory you will forget.

So if you have solved 60 or 70 problems that means it is a good foundation. It does not mean that you know everything in atmospheric science but next time you take a book it is easy for you to follow and you can build on it okay. That is the whole idea. A layer of unsaturated air, a layer of unsaturated air flows over a mountain. A layer of unsaturated air flows over a mountain where the ridges, it is gaps, where the ridges are 11 km.

They are 11 km in the flow direction. Gamma and the lapse rate is 5.5 K/km and T is 25 degrees okay. For what value of wind speed V will the period of, for what value of the wind speed V will the period of terrain induced oscillations, because of the ridges some oscillations will be induced right.

(Refer Slide Time: 12:24)



For what value of the wind speed V will the terrain induced oscillation for what value of wind speed will the period sorry will the period of the terrain induced oscillation or the terrain induced forcing you can take oscillations through forcing match the period of the buoyancy oscillation. You are getting the question? For what value of the wind speed will the period of terrain induced oscillation or forcing match the period of the buoyancy oscillation. Just calculate.

It will take a couple of minutes. It is also called orographic oscillation. Orography is the effect of topography particularly in relation to mountains. If you have mountain gaps and all that that can also induce some oscillation. For example when we do high resolution monsoon calculations or you for example I am trying to track cyclone for example Hudhud which came yesterday, day before yesterday.

If you want to track the Hudhud so the possibility is whether in your model you will include the Western Ghats or not. Though it is on the Bay of Bengal we do not know. So you will have to look at the model with and without Western Ghats and see the difference. The Western Ghats can be 2, 3 kilometers. But generally I do not expect in that case. It will be severely affected by the Western Ghats.

But if you do a monsoon calculation over Bombay without the Western Ghats you will get all junked answers correct because Western Ghats are significant, 2.5 to 3 km height. So this is called the effect of orography. And the effect of orography the problem is the topography is not always updated and it is always changing. So we use some topography data which is 30 years old. In 30 years we do not know how much it has changed.

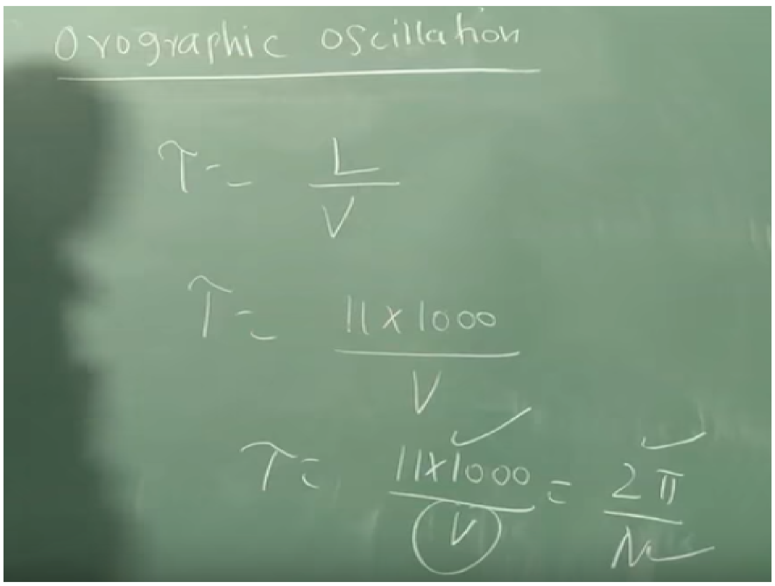
So we have to do survey so we have to depend on surveyors to find out what is the so you have to get the latest topography updates in order that. So atmospheric calculations will involve so many things. You need to know exactly the salinity of water because the emissivity of water is the function of salinity and the emissivity of the water will decide the radiation forcing which will decide the dynamics also. Because radiation will be a term in the energy equation.

So it is all very complicated. But let us stick to the story. So problem number 41. You will do the simple calculate the oscillation terrain in this oscillation and the buoyancy induced. So which means first calculate the Brunt-Vaisala frequency alright. I am circulating some paper. Where is it now? So today we have to finalize. If you have not decided anything just do inky pinky ponky decide on the topic, decide on the partner and then be done with it okay.

I will freeze and then in the next few days I will send an email. Nov 15, 9 o'clock. Somebody has an end sem at 2 o'clock whatever you have to come 9 o'clock you come and finish. If your end sem is 9 to 12 you come at 12:15. If your end sem is 2 o'clock come at 9 and all the present you have to divide if there are 3 people if it is 12 or 15 minutes 5 minutes all of you must present and you should not run away when the other do a presenting and you should not run away when other groups are also presenting alright.

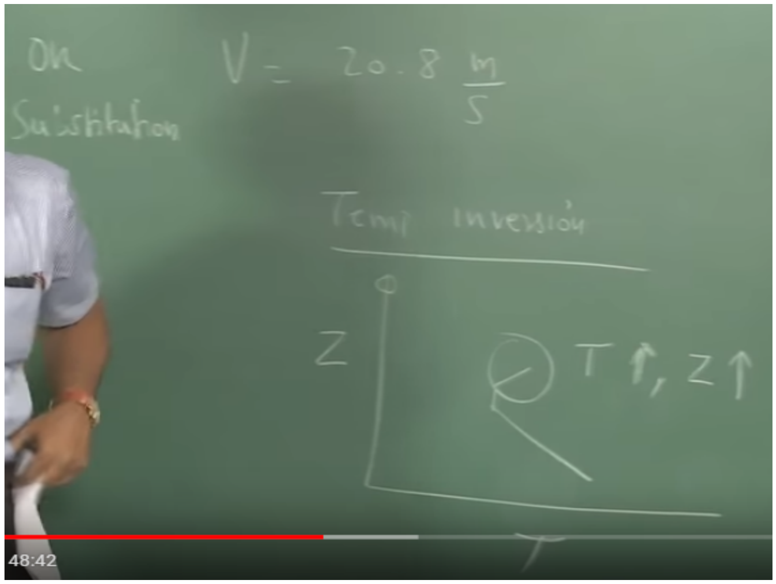
Okay. So what is this now solution? What is gamma d how much is it 9 point 9.8 9 point okay alright. Temperature is 298. So the Brunt-Vaisala frequency is real ya right what is that 5? What did I give? Watch out watch out it is K/km so into. Is it correct, - 3 or + 3? Here. Correct?

(Refer Slide Time: 18:51)



Orographic oscillation is, so the time period is L by V; 11 km 11 into 1000/V alright. Then 2 pi by N alright. Now 11 into 1000 is known. This is known you have to find it. Marius is it okay. So as simple as that. The N is coming from the buoyancy because we are going to match this buoyancy with the orography. So what is the value you are getting? Very good 20.8 that is what I am getting okay.

(Refer Slide Time: 20:16)



So if you are having a wind velocity of 20.8 m/s you may be in trouble, something will happen right. The air parcel and this thing and some resonance will take place and some other atmospheric phenomena may right. So there will be so the 20 m is a critical speed for this case. 20 m is a little high but it is not that high. It can happen sometimes okay.

Now, if you have high static stability with negative lapse rate okay let us talk about temperature inversion. What is the temperature inversion? A temperature inversion is that is generally not on. Where is it happening in the atmosphere from the original profile? They happen in the troposphere or stratosphere or, stratosphere. So lighter layers are above, if it is hotter at the top if you take a layer it is hotter at the top it is lighter okay. So if it is colder it will come down.

So it will be stratified. That is why it is stratosphere. If it is stratified it will stay there for a long time. So if in a jet you just pollute the atmosphere with the carbon dioxide, that carbon dioxide will stay there in the stratosphere for a long time. So this pollution and also lot of this cyclonic this cyclone may take place. Lot of this rain activity will not take place at that altitude because the rain activity is the first few kilometers in the troposphere.

So if to cut a long story short if you put something up in the stratosphere already the situation is that it is stratified. So the cleansing will not take place so easily in the stratosphere. Are you getting the point? That is why if you put something in the stratosphere it will take a long time okay right. But this are you getting the point no that it will not come back. The air parcel will be there no, how will it come back. It will not flush out that CO_2 because of its temperature profile.

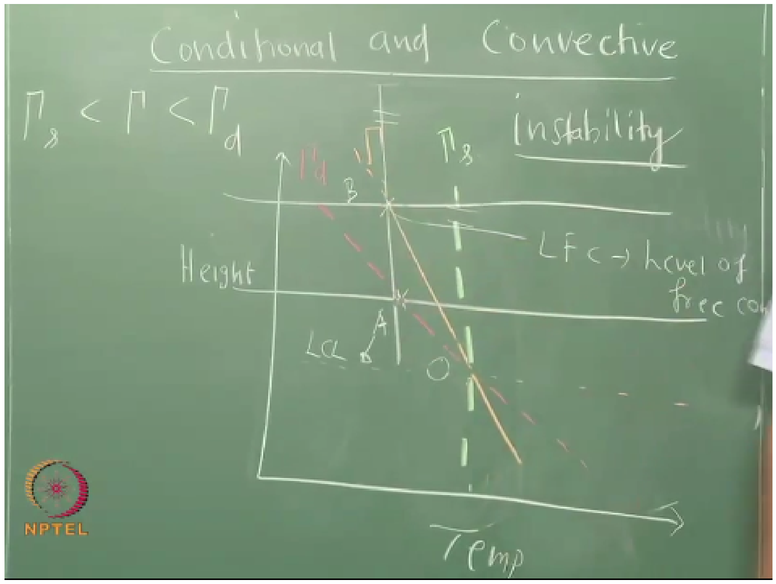
Because of its temperature profile, the hotter is above. The hotter is less dense. So it will stay like that. When will convection take place? When the denser is above the lighter. When the lighter is above the denser it is fine. So only if it comes back then it can be washed by the oceans, water it will go to the somewhere it will get mixed with carbonic acid nothing will happen. So it will stay like that.

That is why we gave the name we give the name stratosphere it is stably stratified, it is stratified. So we should be careful that we do not inject lot of pollutants in the stratosphere okay. Now, we have seen all this. The saturated air also we have seen the stability and all that. But what if this parcel keeps rising and it crosses the LCL. We have seen that. Problem number 38. From 840 it went all the way up to 700.

How do we handle the, how do we know whether it is stable or not. Once okay if lot of instability is there some convection will break out which is good for us. We are always looking for instabilities. If convection breaks out its rain. So as a meteorologist we want to know whether it will break out and this thing and but there are other factors but now based on the sounding, sounding means temperature versus height.

Can you say something about the conditional stability. So now we have to go deeper and look at what is called conditional and convective instability okay. That is the next one. So I will use the full board. Is this fine?

(Refer Slide Time: 26:17)



Let us consider the height versus temperature. So please pay attention. There is some involved, I am going to talk about some involved concepts now. Let us say that this is gamma. So the gamma is obtained from the sounding correct? Now, always our original point, the starting point is some O okay. Now, this is gamma s lapse rate for saturated air, saturated air parcel okay. Gamma s, gamma and then, are you able to distinguish the colour?

So this is gamma d. So can you fill up the equality or any gamma s; gamma s > gamma? Greater than, if it is steeper here; so many times I told you it is height versus temperature not temperature versus height. Gamma s < gamma. Gamma so gamma lies between gamma s and gamma d okay. What happens to the story now okay. Let us say that the parcel is lifted all the way okay. It will follow the dry adiabatic lapse rate up to the point A.

So point A is now the point A is LCL correct. Now this fellow is at this point. He rises further. When he rises further he will follow which slope? Gamma s. So I will do some tricks now. So gamma s is here watch. So I will move the notebook like this, he is following like that okay. What is the funda there? This is parallel to this correct? Now, at a particular point this fellow cuts that he cuts that gamma curve itself okay.

He cuts that gamma curve gamma is the surrounding air and the parcel is starting from O okay. He cuts here and that point where he cuts is called LFC, level of free convection okay. So that point let us call it as B. When it crosses here the situation is different. Are you getting the point? When it cross B, the situation is different. The white line is coming to the right of the orange line okay. So you can write down in telegraphic language.

Consider a parcel O that the parcel O cools dry adiabatically up to the point A. If you want, you can write down in telegraphic language. The parcel at O cools dry adiabatically up to the point A which is the LCL. So the parcel at O cools dry adiabatically till it reaches A which is the LCL. Point number 2. Further lifting produces cooling at the rate gamma s okay. I put point 2. I said point 1 and 2? Okay. Please insert point 1A. What is this, air.

What is this originally that pink colour is the parcel. Point 1A is at point A. At point A the parcel is cooler than the surrounding air agree? Very much clear right. Correct. Vivek Kumar Gupta, is it fine? At point A orange line is the parcel sorry pink line is the parcel, orange line is the surrounding air. At point A parcel is cooler or colder what did I say? Colder okay cooler okay. Point A is cooler than the ambient air okay. Point 2 is over.

That is further lifting produces cooling at the rate of gamma s. Point 3, if air is sufficiently moist, if the air is sufficiently moist the saturated adiabat if the air is sufficiently moist the saturated adiabat passing through A will cross the temperature sounding. My reference point is orange line. Will cross the saturated what did I say will cross the temperature sounding. Amit you got it? Which will cross?

If the air parcel is sufficiently moist, the saturated adiabat through A will cross the temperature sounding here. It may not happen always, the way we have drawn it, it happens. Point number 4, point of intersection is B. Point 4, the point of intersection, it is point 4 right, the point of intersection is B. Point 5, above B the rise is automatic, it is not under your control. Above B the rise is automatic. So what is the story. If what is the story of the conditional stability.

If gamma s is less than gamma is less than gamma d so if gamma s you can write down if gamma s is less than gamma less than gamma d vigorous convective overturning will occur. If gamma s is less than gamma less than gamma d vigorous convective overturning will occur if forced vertical motions lift the air parcel beyond LFC okay.

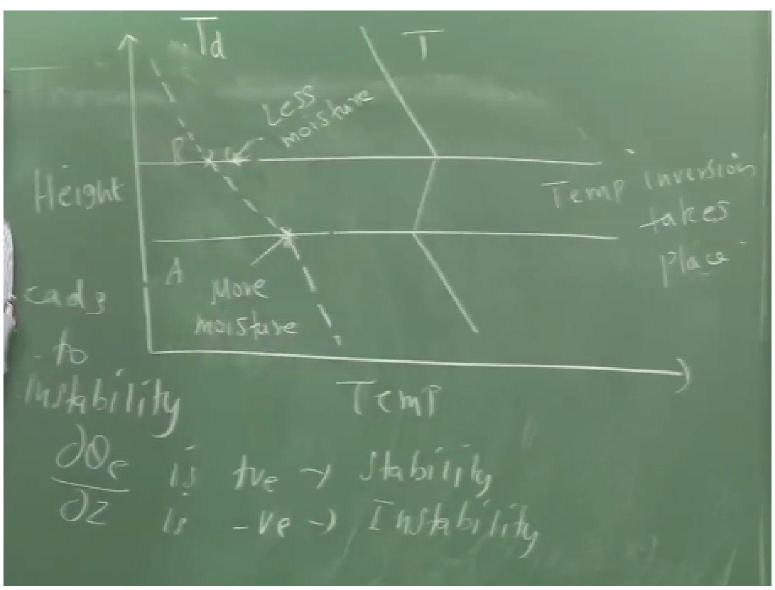
If gamma s is less than gamma is less than gamma d vigorous convective overturning will occur if forced or induced vertical motions are strong enough to lift the air parcel beyond LFC okay. So if you are able to achieve this up to B then it will be, violent convective overturning will occur. There some weather will occur I mean weather phenomena may occur. Is it okay. So this is as far as conditional and convective stability is concerned.

(Refer Slide Time: 36:57)

So analogy is so you know this right. Stable, unstable, neutrally stable correct. Neutrally stable is if you do not trouble it too much it is alright. If you trouble it beyond, up to here it is okay when you come back. If you push it beyond this it is not always stable. That is, alright. I mean I would not say neutrally stable, conditionally stable alright. In our air parcel this is represents the LFC. It will again go nuts if it crosses the LFC alright.

Now the potential for the instability is also related to the vertical stratification. Now let us look at some more advanced concepts.

(Refer Slide Time: 38:33)



I am considering a layer of the atmosphere AB okay. What is the problem with the layer AB? Temperature inversion takes place. That means generally with high temperature will decrease AB is little funny okay. So something is happening. So this is called a inversion layer. That can take place in the atmosphere for various reasons okay. Let me plot the dew point temperature on the left hand side okay. So here okay.

So there is more moisture. I think I have not the slope should be slightly okay. So now it is okay. It is all the same? Forget it. So here it is more moisture. Here it is less moisture. Now watch the arguments. I have given you the sounding. The temperature generally decreases in the inversion layer AB the temperature increases. After the inversion layer it again becomes normal. However the dew point temperature rapidly decreases with height in the inversion layer.

Did I draw it like that? I am supposed to have drawn okay. The dew point temperature rapidly decreases with height and in the layer AB and B represents the top of that layer and A represents the bottom of that layer, watch there okay. Now the, the layer B the layer AB is the air parcel and now when you are lifting; the air parcel is getting, the air parcel means let us say it has got this height of AB and it is getting lifted.

Now, the air parcel at A will reach the LCL very quickly because it is more saturated. But at B it will not reach LCL that fast. But they are together it is the same air parcel. So it leads to complication. So an air parcel starting at B will cool dry adiabatically through a deep layer before it reaches its LCL. Are you getting the point. If you divide, if you divide into several layer or strata each of this you can consider an air parcel starting from this layer.

Air parcel starting from this. So an air parcel starting at A will reach the LCL much faster than an air parcel starting at B basically because of the inversion and basically because at point A it more saturated compared to point B. Therefore when the inversion layer is lifted the top cools more rapidly, the top cools more rapidly because the top cools dry adiabatically whereas the bottom after it reaches the LCL it has to cool following the saturated adiabat.

The top cools more rapidly than the bottom and what happens is the lapse rate gets disturbed. Lapse rate gets disturbed. So sufficient lifting can cause this whole layer to become conditionally unstable okay. So basically leads to instability. So what is the criterion for this? Doh theta e by doh is at positive. So in the exam if I ask you a question where I give you the height where I give you the pressure and the temperature and I also give you the dew point.

So at each of these levels you will find whether gamma s < gamma < gamma d for conditional stability. Gamma < gamma d for unsaturated air, saturated air so that problem will take half an hour for you to solve. One problem is going to come in the end sem. So if you want to get conditional if you want to get this conditional and convective stability there is no other choice but for all those layers you have to get the LCL and the LFC.

And whether the LFC is within that LCL and LFC are within that layer and all that you have to do. The alternative is to look at the theta e and find out for the inversion layer whether the theta e, doh theta e by doh z is negative. Are you getting the point? So long as you are so long as you are below the LCL from the first few layers that T is less than T d the first few layers you can just use basic thing gamma < gamma d, gamma > gamma d.

Then wherever the inversion occurs you have to occur you have to use more fundas. Then you have to look at the convective stability which is given by this, doh theta e by doh z. But throughout larger areas of the tropics the theta e doh theta e by doh z is negative in many places. But the convection is not breaking out because sufficient lifting is not taking place to release the instability. Are you getting the point? I will come again.

In many places in the tropics, in many places in the tropics this condition is satisfied but we do not see so much rain that instability and the weather activity is not taking place basically because the other condition is we should have induced vertical motion where this parcel is lifted beyond the level of free conduction. Then vigorous overturning will take place okay. Do not get into all this in the exam.

In the exam what I will do is I will give you a sounding. Sounding means it will be typically like this. Station A, pressure 1000, temperature 30, dew point 21. Station B, 970, 25, 21. Station C 900, 18,16. 800, 16, 16.5 like that I will. Then I will ask are the layers AB, BC, CD stable, unstable or neutral. Which layers are convectively unstable? So if you have to have convective unstable if you have to find something is convectively unstable what do you do?

You have to find the LCL, you have to find the. So I will decide, if you want to solve this full question it will take 40, 45 minutes okay. Or I will ask you to just not to worry about the convective stability. Out of this 7 points A, B, C, D, E, F and I will say whether AB, BC, and CD are stable. I do not know. It depends on my mood okay. Otherwise the full problem will be to look at the stability of the whole sounding okay and there will be fun when there is an inversion which is taking place okay. It is well within your limits.

Theta e you know how to find out or theta e I have given equation I have given an equation for you. So you can find the theta e for that layer. So it will be highly involved if you have to get into the convective instability okay. Is that clear? That completes our this chapter I mean in atmospheric thermodynamics first law everything is over. We will have to do the second law from tomorrow.

Since Carnot cycle and all that you know we will quickly go through all this Kelvin-Planck statement, Clausius statement. Then we will get on to the Clausius-Clapeyron equation which links the latent heat okay which concerns the latent heat because latent heat is important in the atmosphere.