Introduction to Atmospheric Science
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Lecture - 16
Skew-T ln-P Chart

Okay, so good morning. So in the last class we discussed the Poisson's equation and we proved a set of I would not call it as theorems, proved a set of equations or relations which are going to be very useful in our study of atmospheric thermodynamics okay.

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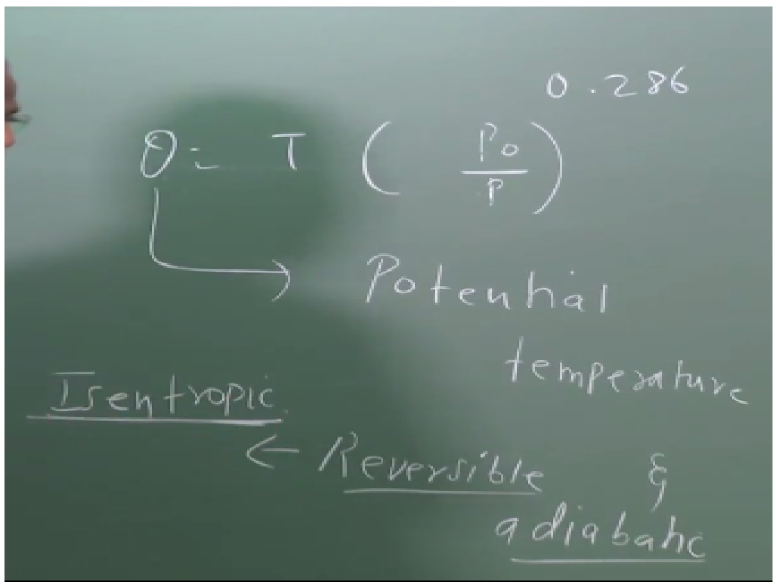

The first was that theta is okay. From initial temperature of T to P if adiabatically expand or compress to a standard pressure of 1000 hPa, the temperature which the air parcel finally take is the potential temperature. Then, what is this reversible and adiabatic? We are just having a quick a 3-minute recap of whatever we did yesterday okay. Reversible. Adiabatic is the heat transfer is 0 okay. That is one of the assumptions in the air parcel also it is adiabatic.

Reversible means, it is reversible. That means the process can be reversed. If we take a piston cylinder arrangement, if you compress it from position a to position b, it is possible for you to expand it from b to a okay. So by definition, a reversible process is very slow. Fast process cannot be generally reversed. So we call it as a quasistatic process okay. If a balloon is there, filled with air; you take a pin and prick it. Then the air comes out.

It is an instantaneous process. It is irreversible because if you assume that the work done in pricking is almost 0 okay then there is no work done involved in the process. There is a inflated balloon which has got air inside. You just prick the balloon, then the air went out. Now you have a deflated balloon. You go to the fellow who does your cycle puncture and close that hole. Try inflating it again. You cannot do it without some work.

This is the concept of reversibility. So this balloon pricking which is a fast process is irreversible. So many processes if they are irreversible means irreversible in time. We cannot reverse it, irreversible generally in the context of time we say. In thermodynamics irreversible means we cannot raise it back without some change either in the system or the surroundings or both okay. So reversible in adiabatic, somebody said it is also called isentropic okay.

It is isentropic but since we have not introduced entropy, I did not want to mention, but since all of you are, there is no need to feign, there is no need to feign ignorance. Let us say, this you all know this. So but I promise that we will revisit this and do the second law after some classes, isentropic okay. So lines joining points with constant pressure are isobars. Lines joining points with constant temperature are isotherms okay.

Lines joining points in a heat transfer problem with same heat flux are called isoflux. Lines joining points in a map which receive the same rainfall are called, isobar, surrender ha; same rainfall.

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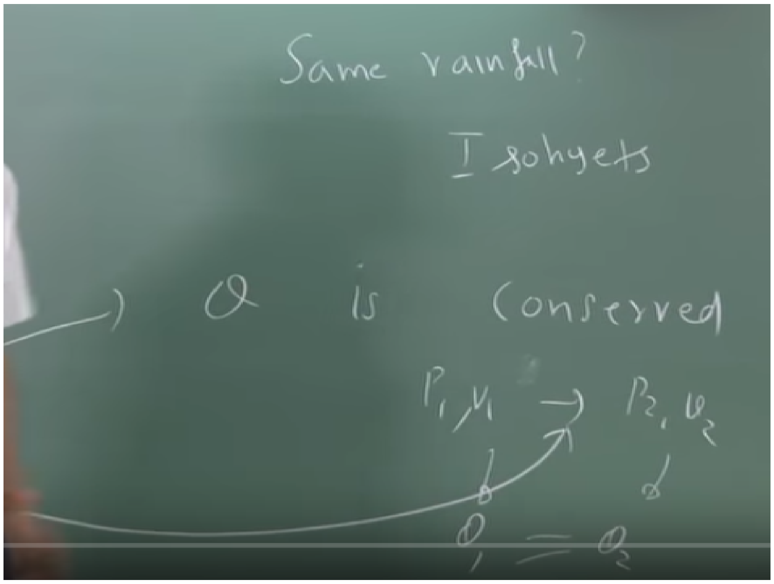

They are called isohyets. If you study optimization, if there is an objective function which is profit, if it join lines having same profit they are called isoprofit lines. If it join points having the same cost, your optimization problem is a function of x1, x2, x3, and x4; x1, x2, x3, x4 are your variables and y is the constant, y is your cost, y = y1, y = y2, if you have joined these lines these are called isocost lines. So if it is a cost, it is isocost.

If it is profit, it is isoprofit, isoefficiency. Isobreakthermal, breakthermal efficiency. If you put it in the parameter space you plot it. So generally you can call them as isoobjective contours okay. Like that we can have a class on iso for one hour, but now that is not central to our discussion here. So we will get back to this. So for a reversible and adiabatic process we proved that theta is conserved. Theta is conserved means what?

Theta remains the same throughout okay. So we already proved that if you have got P 1 V 1 to the power of gamma no from P 1 V 1 it is going to P 2 V 2 and the route is this. You are taking this route. Then, the theta 1 and the theta 2 are nothing but the. This we proved in yesterday's class. Then we solved a very interesting problem of a, what is that, air outside the cabin, 250 hPa okay.

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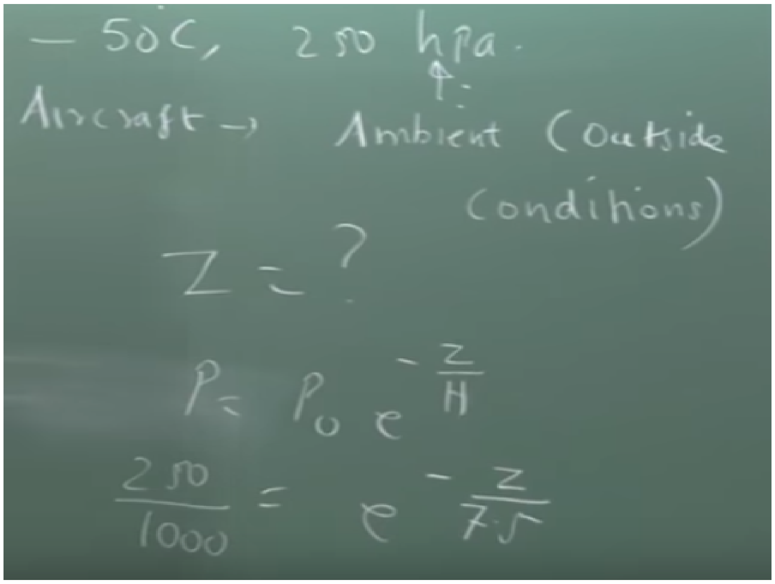

Minus 50 degree centigrade okay. Now, I am doing an on the spot innovation. Problem number, problem no. 23. The previous one was 22 no, what a dumb question. Sorry, the 22 was that aircraft problem okay. Revisit the aircraft air, revisit the aircraft cabin air problem whatever or revisit problem 22; b what is that? This is 23.

Revisit 22 b very good okay it looks like a something in which we argue in the court of law. Revisit 22b. Determine the height at which the plane is flying. Do not ask me what is the scale height. You know, you are all already done one and a half months of atmospheric science, more than one month, one and a half months. Some scale height, you use 8 km or 7 and half? 7 and half, 8 whatever.

In the quiz also if you use 7 and half or 8 I will give marks, now do not worry. I will start looking at the papers today. I have already worked out the solutions okay. So we will assume that P not is some 1000 right. Z 2 - Z 1? Did you do that? E to the power of minus no, P - P not we will use that. This is also okay. This comes from hydrostatics right. So 250 e the e the minus, watch out z is in kilometers now. Ya, please tell me Z equal to.

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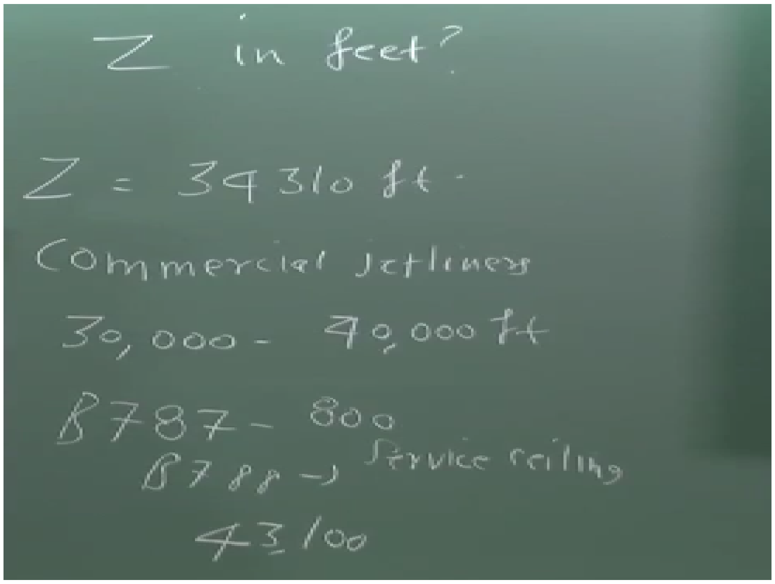

One meter is 3.3 feet. Ya, what will this be? 34000, okay. So commercial jetliners fly at an altitude of 30000 - 40000 feet okay. For example the B787 Dreamliner, it is actually 787 800 okay. It is also called B788 Boeing 787 Dreamliner 800 series. Now 787 900 series is going to come, 787 1000 series is going to come okay. So the service ceiling is 43100 feet. If you go above that, if you take the air from outside, compress this thing and already it is very low right 250 hPa.

If you go to 43000, we can actually work it out. But then it will, it is not central to our okay. Will it not be a brilliant idea if the planes fly at 1000 or 2000 feet so that we can avoid all crashes? What is the answer? What is the answer to that question? Why are planes flying at 35000 40000? No traffic there or why is it yes it is more economical why? Drag is very less because what will be the density of air? So the viscous drag is very less. So they will do this right? Okay.

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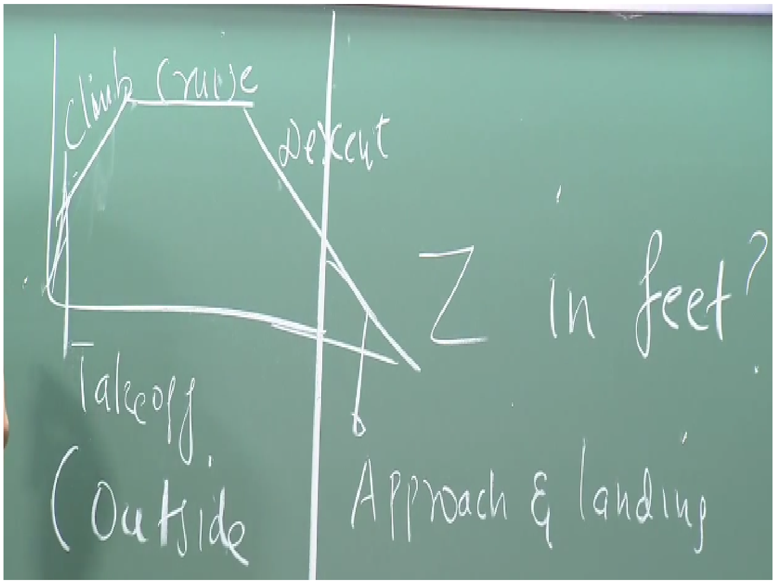

So I think they will take off, climb, cruise, descend and it is approach and landing. So they require the full throttle power for this okay, a reasonable amount of power for this and at cruise they will reduce the throttle. Then they will do it further and then but then when they are landing they should be at the same condition as take off because any emergency they should be able to take off again.

So landing is not sir why cannot we land at 10 km 20 km, it will stall, lead to accident. So what is the typical landing speed of a 788 or Boeing 737? Takeoff and landing speed? 250 - 300 kms. They will reduce it to 250 or sometimes when they do all these maneuvers and the speed decreases so much, if you have travelled many times you will know that as he approaches the runway he will again increase the speed to prevent the stall. Then you will think what did he go nuts.

Why he is doing, why is he doing that? Because he has to be at that condition. If he is too fast then he can do what is, he will do what is called a go around. He will come and then again he will go. Once you do that half an hour is gone. Then he has to climb and this thing air traffic control clearance. There will be other you will be in a sequence. Then you will do what is called chakkar. You will do this and then he will get the permission and then sometimes, now it is not happening.

Sometimes you can just approach, the ATC will see that you have not deployed your gear because something happened okay. If you have not deployed your wheel ATC will say hey. It has happened in Chicago and all. Then he will go around. Then either there is problem or he simply slept or he simply forgot. But nowadays it is all piloting for dummies right. It will say, it will just go on beeping, deploy gear or it will deploy automatically at 2500 feet okay.

So it will but most of the landings are now instrument. It is guided with a computer. But in order to preserve their skillset sometimes they switch to manual so that they you can so that they do not lose their skills. Can we use the pseudo, can we use a chart or a thermodynamic diagram to understand this better and can we solve this problem using an pseudo adiabatic chart.

We got a sneak peak of this on the television already but we will go through we will I will just tell you the theory behind this diagram and how we can use this diagram to solve this. So the next 20 minutes or so I will just explain what are the coordinates of this diagram. Then I will give you one copy of the chart. You will revisit problem 22 a, b, 23 whatever. You will solve the same problem using the pseudo adiabatic chart.

Then you will find out the difference between your competition which you did yesterday and this. That is because of the approximation and then we will see what are the disadvantages in this chart and what is the next step forward, what will be a better chart. Is that okay? Fine.

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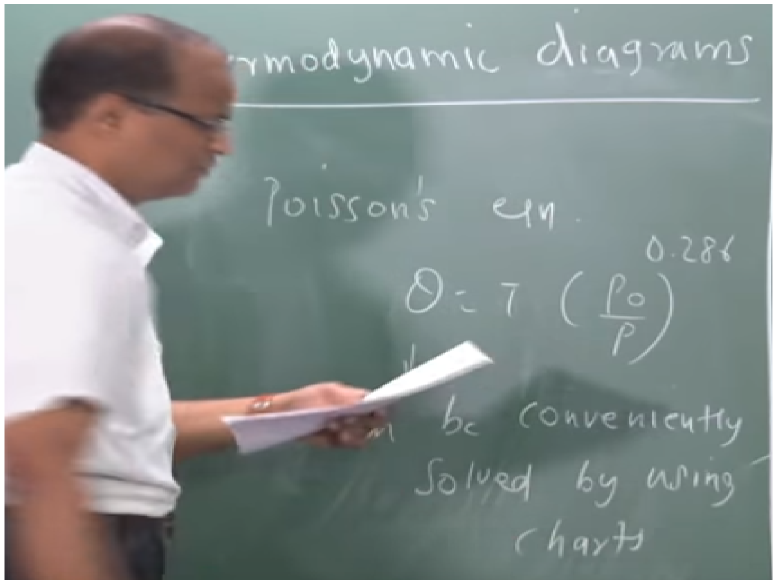

The Poisson's equation, what is the Poisson's equation, I already told you. If I not formally stated this, this is the Poisson's equation. The equation for potential temperature theta is called the Poisson's equation, can be conveniently solved using charts. Of course, when you use the chart, approximation will be there. As usual because charts are easier to use it is widely used in meteorology. Which is widely used in meteorology? Such kinds of charts okay.

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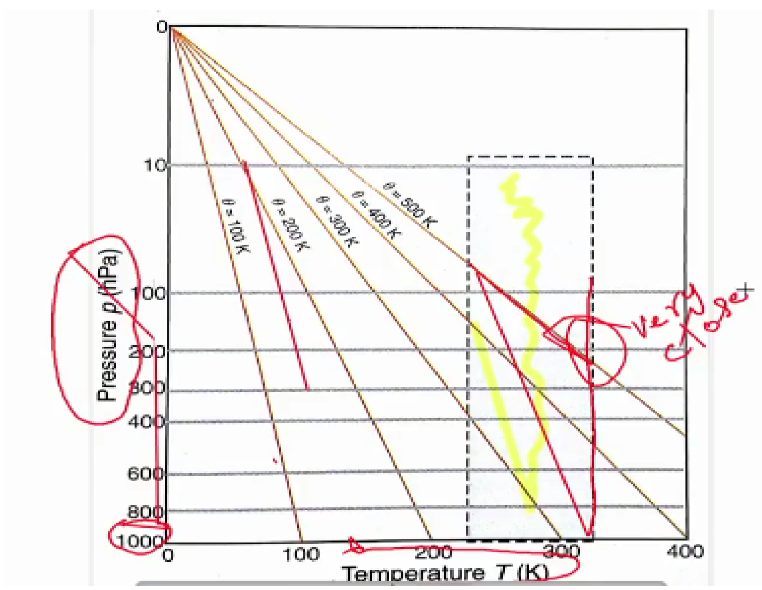

Now is it possible to, I will sit down. Now okay so this is what is called the pseudo adiabatic chart okay. The pseudo adiabatic chart has got pressure, where is the pseudo adiabatic chart. No, not this one. Yes, I want to write down okay. So this is the pseudo adiabatic chart where the pressure is the ordinate and temperature is the, why did that line come okay. So pressure is the ordinate and temperature is the abscissa okay.

So isotherms are straight line joining points having same temperature. On the pseudo adiabatic chart isotherms are vertical lines please write down. On the pseudo adiabatic chart isotherms are vertical lines. Isobars are horizontal lines okay. Now, how do I, let this be there. How do I make you believe that the theta lines are like this, sloping downwards. So let us start working the working out the map right.

So we already saw this. Pressure, isobars are like this and it is somewhat log scale right pressure. Temperature is linear scale and 0 to 400 is the range of temperature which you usually encounter okay. I am switching to the blackboard again.

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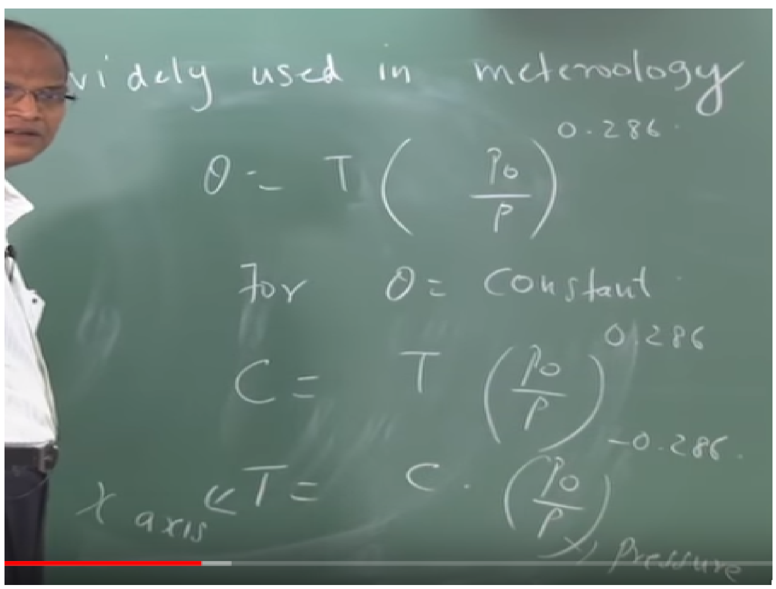

Now, theta, for theta equal to constant C equal to okay. So T equal to C into okay. So T is an exponent can be related to the log. So this is pressure. So this is the equation of a constant theta line. So constant theta line will be a line which is sloping downwards. They are oriented at an acute angle relative to the isotherms okay.

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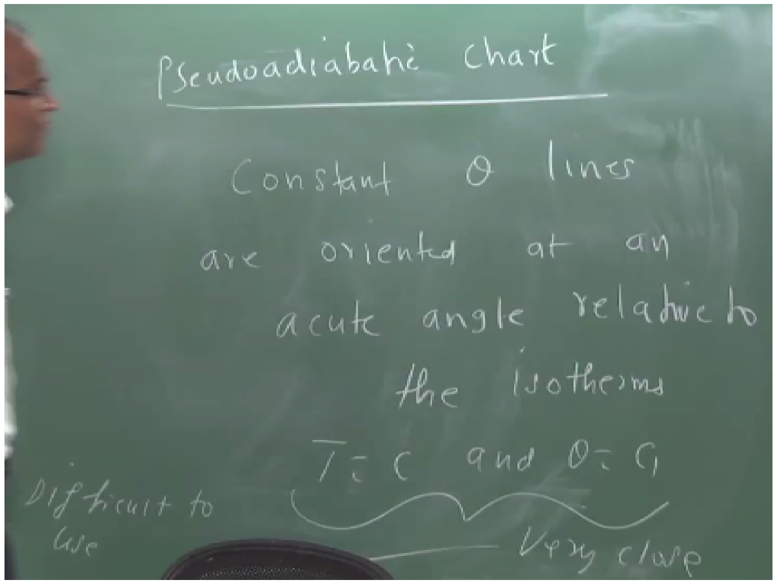

So, sir why are you saying pseudo adiabatic. It is pseudo adiabatic because we are not considering moist air. We are considering dry air. So the actual adiabatic will come tomorrow. So now this is a because it is assuming the we are assuming mass of water vapour is 0 right now. You have to introduce that. So if you have to introduce that it is not so straightforward. I have to tell you what is mixing ratio, what is specific humidity, what is relative humidity, what is saturation pressure, vapour pressure; you have to get deeper into moist air thermodynamics okay.

That is actually like psychrometry okay in mechanical engineering. So pseudo adiabatic chart, constant theta lines are. Okay what is so there is something very peculiar about this chart, what is that? Y axis. The 1000 is down and 0 is up please note thousand one thousand is here. So 1000 is here okay 0 is here. It is connecting this. Let me try something. These are the art of messing up a tablet PC okay alright. So the theta lines are, I think I need to train up.

The theta lines are the theta lines are sloping downwards okay. Now there is some region indicated here. Okay this region. What is special about the region, green colour. No, no that is because I used some ink. What is special about that region? Not comfort. That is the region where we are interested in atmospheric science. That is the region of interest in atmospheric science.

Now the funda is the isotherm is like this, yes and the dry adiabat is like this, very close. They are very close. It is very confusing. So it is not a very good chart for use but it can be used with limitation. This is overcome by what is called a Skew-T ln-P chart okay. What is the problem? So difficult to use.

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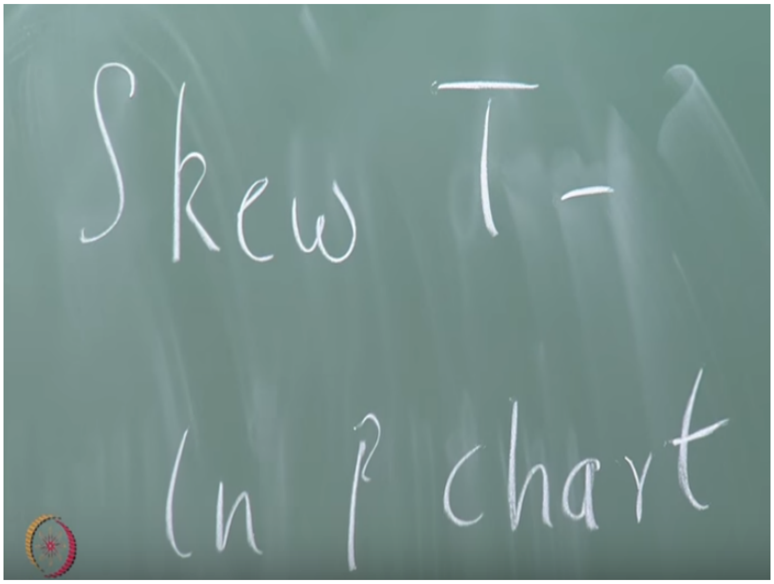

So the next chart which people have developed is called the Skew-T ln-P chart okay. Before we go to the Skew-T ln-P chart now so problem number 20, problem 24. Solve problem 22 using the pseudo adiabatic chart. Compare your solution with that obtained before. Solve problem 22 using the pseudo adiabatic chart. Compare the solution of compare the solution with that obtained before.

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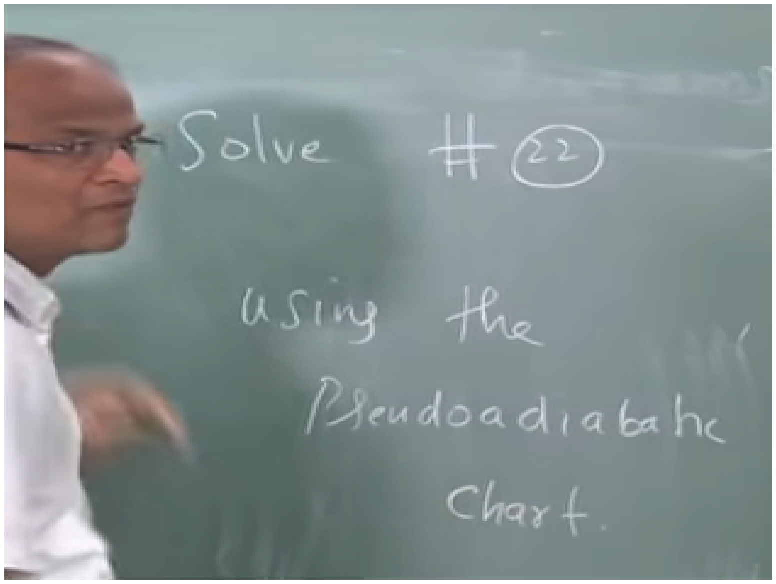

This both parts a and b okay. So in the quizzes and exam I leave it to you. Whichever is convenient you can either use the formula or the chart. Which will be more accurate? Ya formula is more accurate but which is fast but this log is a problem okay. See if you want to use it repeatedly I mean if you there are many computations to perform, chart may be little bit advantageous; using the using a pseudo adiabatic chart okay.

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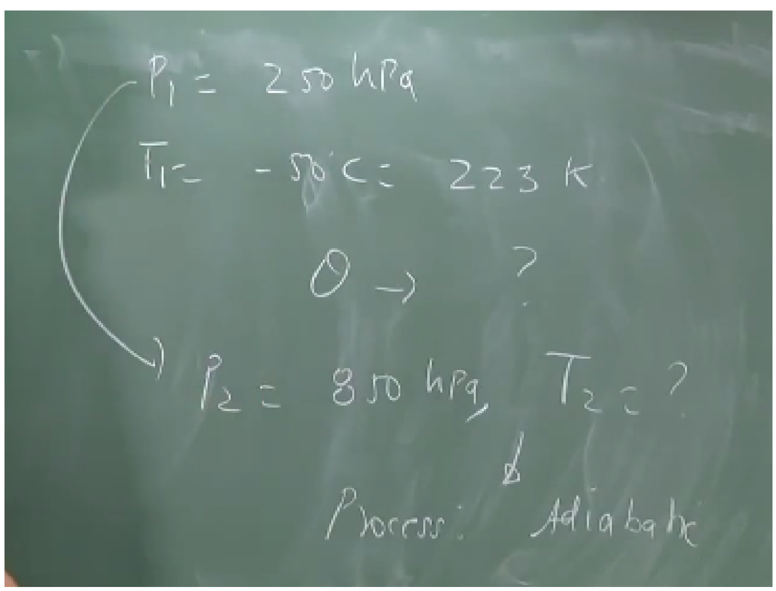

So P 1. The question is like this. Outside air is 250 hPa and - 50 degree centigrade, 223 Kelvin. What is the potential temperature theta. Not using the formula but the formula which has been replaced or replaced by a chart or a diagram, it is a chart. Then this air is then compressed. Why is it compressed? Whenever pressure increases, it is called compressed okay. So from 250 it is becoming 850. We want to know the corresponding temperature.

You already know the solution, theta and T 2 from yesterday's class. Now, some interpolation you have to do. Have you done it already? Please do it now. Then I will show it there. Yes, shall we start? Ya where is this now.

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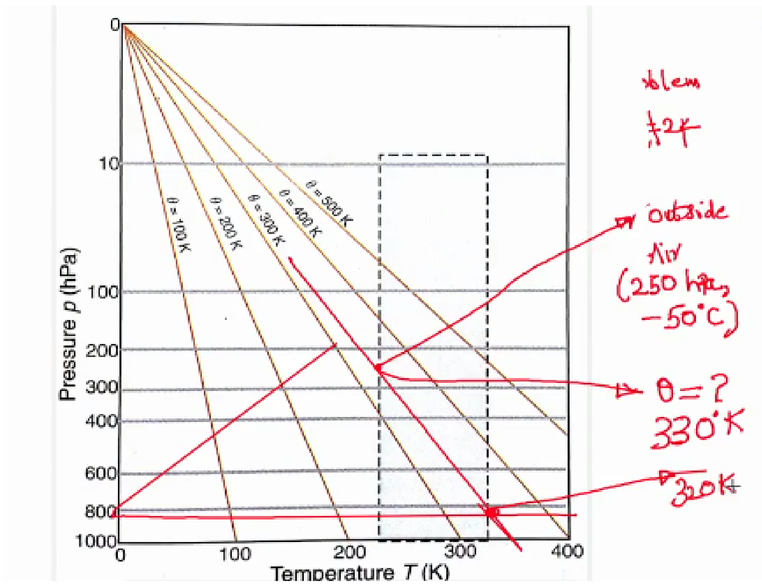

250 and 223, is it this this line okay. That it is okay 250. So that is. Oh what happened? Went off. It erased the whole thing. Okay this is that is outside air. I realize that it is not suited for my speed. It has to be treated with respect. 250 hPa - 50. Now please help me. I do not know how to, is there a scale. Now this is really tough. What is the theta now? We have to look at some theta which is in this.

Then we will, do not say that that theta is the same as what we got in yesterday's class. Ya you just interpolate. Now, theta is 331, you are having 6 by 1 vision. What is it, approx? 330 is okay, 330 okay, 330 Kelvin. Now this is expanded oh compressed. Compressed means you are going down in the pseudo adiabatic chart. Expanded means you are going up. What is the route? You have to follow the route of constant theta okay.

If you follow the straight line it is basically isotherm. If it go horizontally, it is isobar. That sloping line going downwards is adiabatic, very good. So now there is no scale but still we will manage. We have to go to 815? First you have to draw the, I will try something now. It is 850? So this is called the IIT way of doing things. There. Yes, what is that? 320. What did you get yesterday, 316, okay not bad. If you get 316 I will cut mark. 3, 320 fine.

Very good, okay. So this problem also erased. That does not matter. So this is the way to solve a problem with the pseudo adiabatic chart okay. Shall we proceed with the next one? Now you, the problem is as I already told you these are very close. This vertical and the not the vertical and the horizontal, they are far off. The vertical and the sloping theta lines are very close and everything maybe get clattered up. You cannot get clarity when multiple process are there.

Here there is one process. When the cloud is air parcel is going up, it is condensing, it is coming down and the wind is blowing and we want to represent all this. You want to track the air parcel which is undergoing a to b to c, d, e, f and all that, it will become very clattered up. So we need a better diagram. So they developed this Skew-T that is skewed temperature and ln of pressure chart okay. Let us go to this Skew-T ln P chart which will be the do or die chart for you in this course okay, yes.

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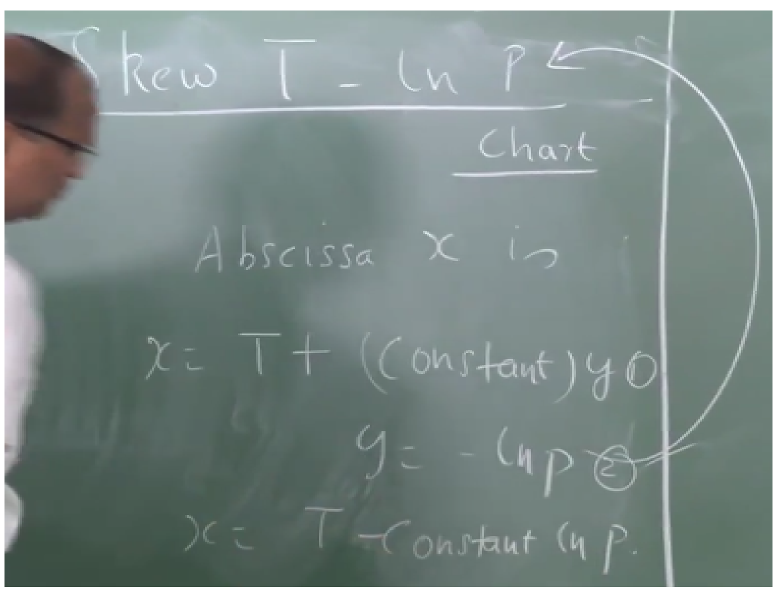

Skew-T ln P chart, skewed means skewed means it is inclined; generally, biased towards the side, skewed right, okay. Now, the abscissa is abscissa x equal to t plus constant into y okay; x and y are the two, x is the abscissa and y is the ordinate. Now I am telling you y is - ln P okay. So x equal to T - constant into ln P, equation number 1; y is equal to ln P is equation number 2. T-constant, okay.

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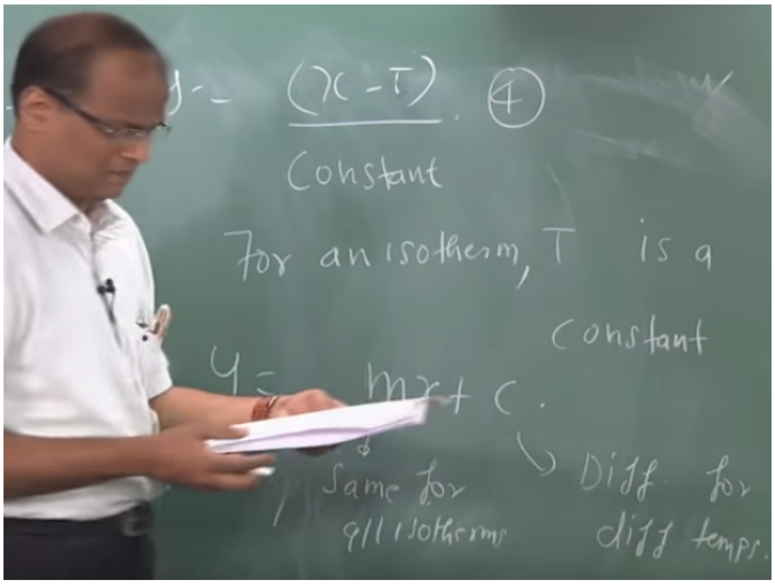

So actually y is like, we can also say that y is equal to x - T by constant that is - ln P correct? For an isotherm, T is constant. Therefore, y equal to y is equal to mx + c. So where m is the same for all isotherms; c is different for different temperatures, this c right that is T/c okay. So isotherms are straight parallel lines. On a Skew-T ln P chart isotherms are straight parallel lines that slope upward from left to right okay.

Sorry, isotherms and the Skew-T are then, I need to show you this. How to get the other file? Show desktop? Yes, can. I want this to be in full page, not this, you can crop this, can you? No, I want only this to be shown on the screen. Zoom. Okay, I will manage with this okay. You go back. You stopped the recording no? Okay.

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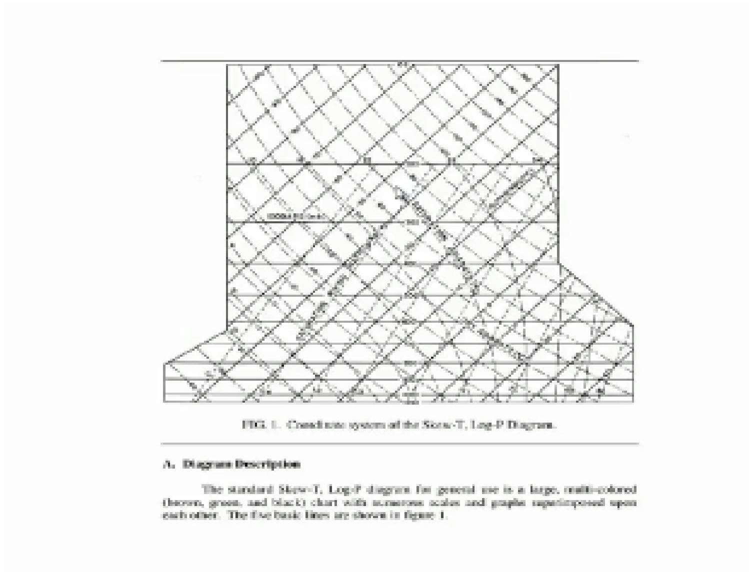

Okay, so this is the Skew-T log P or ln P chart okay. The isotherms in the pseudo adiabatic chart, the isotherms and the isobars are perpendicular to each other but the pressure was logarithmic okay. Here also the pressure is logarithmic. Bottom you have high pressure. Top you have low pressure. Can you see the pressure, 1800 okay; no you cannot see. I will give you the chart but it is already 10:46. Tomorrow class we will see. Anyway now you believe me okay.

So the pressure is all horizontal lines. The temperature should be vertical lines but they are inclined at 45 degree so it is that is why it is called a Skew-T ln P chart. What is the advantage of this Skew-T ln P chart? Basically it spreads out so that you have got you got a good area to work with and solve problems. Instead of this isotherms and theta constant theta lines getting cluttered up you get some more working space for this.

Now, problem number 25. How does a dry adiabat or a pseudo adiabat look on a Skew-T ln P chart? Problem number 25, how does a dry adiabat or a pseudo adiabat that is constant theta line look on a Skew-T ln P chart? You are already able to see that. No, you cannot see that from there. Okay.

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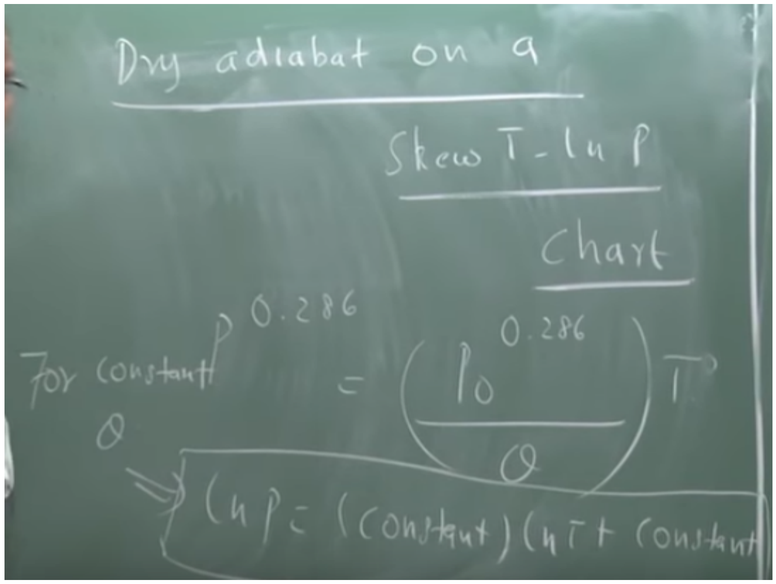

Quick, we will finish it, we will, I will just tell you this and so what is the equation for this? P, so for constant theta agree? I just used the Poisson equation, take log on both sides and then I say ln P equal to constant theta is a constant, ln T into constant plus some constant okay. Plus constant is coming, yes. If the new chart at the coordinates ln P and ln T then dry adiabat would be a straight line. Watch my arguments very carefully.

If on the Skew-T ln P chart, both the temperature and the pressure were to be natural log the dry adiabat, the equation of dry adiabat is straight line, it will be a straight line but whereas the pressure is ln of P the temperature is not ln of T. Therefore constant theta line will be curved downwards. The constant theta lines will be curved downwards in a Skew-T ln P chart while they were straight lines pointing downwards in the pseudo adiabatic chart okay.

So just hang on for 2 more minutes. I will not take attendance, you go to the next class right yes so but I will just draw this and then leave.

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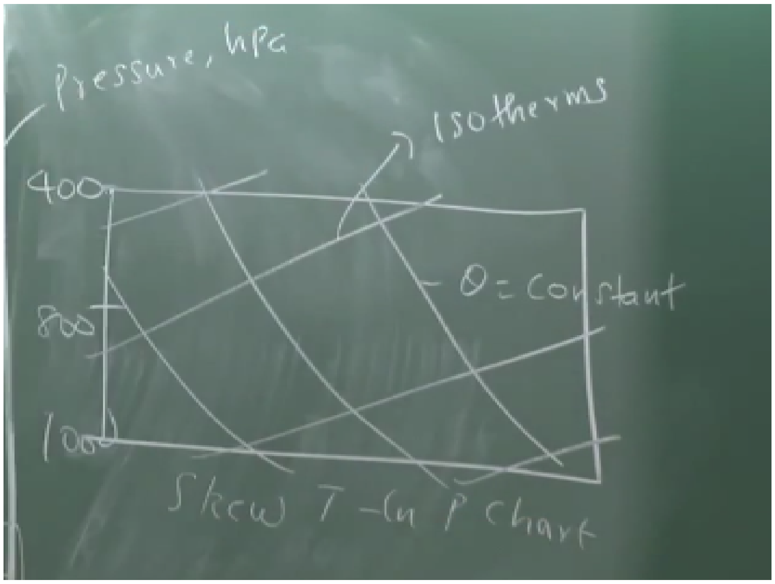

1000 isotherms are straight lines but skewed okay. Skew-T ln P chart. I come again Skew-T ln P chart. A very important quantity theta is sloping downwards. Then we will introduce one more quantity called saturated adiabat so which is not the pseudo adiabat which is actually adiabat for a moist air.