Introduction to Atmospheric Science
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Lecture - 22
Saturated Adiabatic and Pseudo-adiabatic Processes

Good morning. So we will continue with the discussion on the wet bulb temperature. It is a very important thermodynamic quantity.

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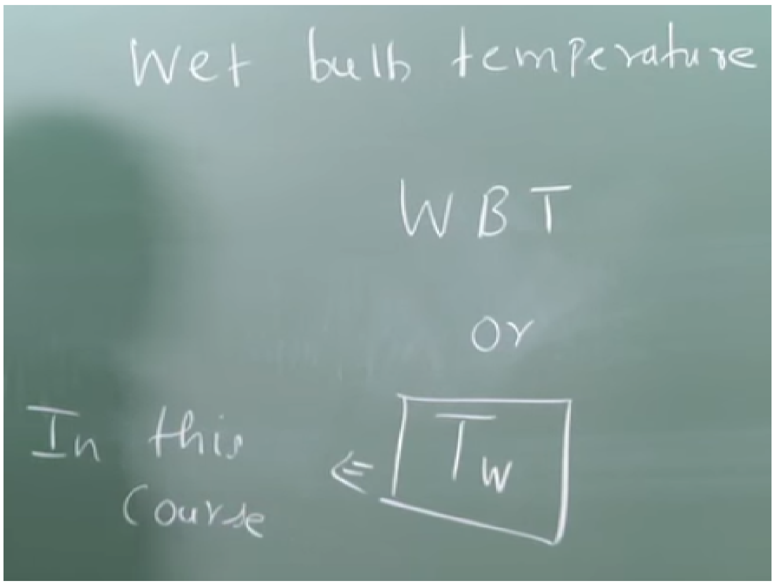

So in literature it is referred to as wet bulb temperature so in this course wet bulb temperature is T w okay. What is a wet bulb temperature? The wet bulb temperature is the temperature to which air can be cooled if it is reaching adiabatic saturation. That means if air has a mixing ratio omega if it can reach mixing ratio of omega s 100% saturation what will be the temperature it will reach. So the dew point temperature is also the is also a temperature which is lower than the T okay which is actually an isobaric cooling.

This is not an this is the wet bulb temperature is not an isobaric cooling. It is an adiabatic cooling. How to determine the wet bulb temperature on the pseudo on the Skew-T ln P chart is something we will discuss a little later okay. So the whole idea is the, if you have got a thermometer with a wick and you have a sling psychrometer you start rotating it, it starts moving what happens is the latent heat of vaporization which is required for converting water to water vapour which will saturate the surrounding air, air very close to the bulb has to come from the air itself.

This leads to so there is a transfer of latent heat and sensible heat. Are you getting the point? So this latent heat is coming from the this latent heat is required for changing the water to water vapour and this heat is taken out from the air itself. Therefore there is a depression in the temperature of the air with respect to its normal temperature or the dry bulb temperature. So the temperature goes down that is the wet bulb temperature. So the wet bulb temperature also sometimes represents the maximum cooling which is possible in a in a desert cooler.

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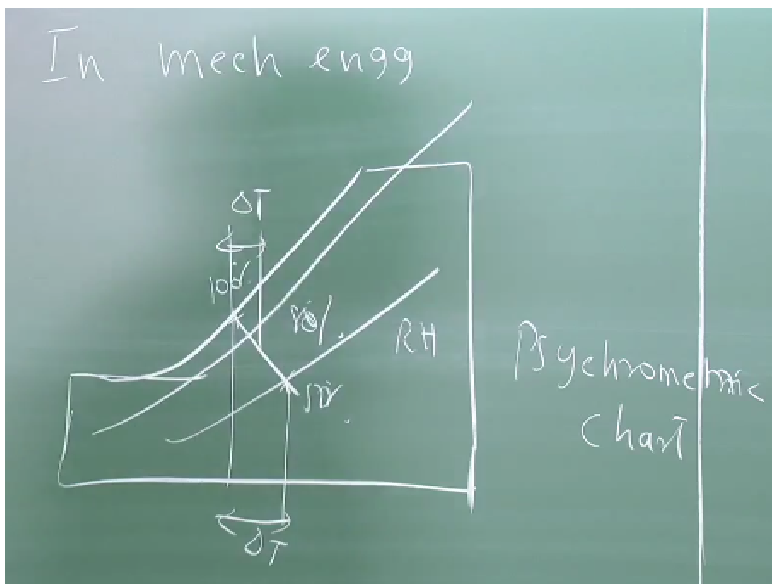

For example in mechanical engineering, you have a psychrometric chart okay. So this is some RH. So let us say from RH 50% to 100% if it goes so this is the cooling which is possible okay. If you consider a situation like Chennai, we saw already that what was the RH yesterday 79, it is already 80% here. So you will get very little cooling. So the relative humidity is very high. The delta T you get by adiabatic saturation is very low.

The delta T dry weather the adiabatic saturation when you proceed when you cool towards adiabatic saturation the effect is high. But we should not be but the desert the cooler air cooler also gives some health issues. We should not always be at 90%, 95% because the comfort is not just the temperature. This room is comfortable because it is maintained at 25 degree C or less and 50% RH. The air plane is a completely different story.

For different reason the RH is maintained at 5 or 10% which we would not have condensation and this thing and it is a very dry environment there. So as the humidity increases generally the discomfort increases. That we have seen okay. 50% RH is okay at 20 degrees. With 50% RH at 25 degrees is very bad dew point okay. Now, if the wet bulb temperature exceeds 35 degree C it corresponds to near death situation.

What was the wet bulb temperature I mean did we calculate the wet bulb temperature yesterday in Chennai; no, the dew point temperature okay. What was the dew point temperature in Chennai? What was the actual temperature, we have a simple rule of thumb right. Wet bulb is equal to dew point + 35 is the limit okay. Sir what happened sir then the story your story is not correct. In somewhere in Chennai it goes to 41 or 42.

When it goes to 41 or 42 the RH will be very low. So it will be ensured that the wet bulb temperature does not exceed 35 degree C. But when it is close to that, animals have got thermoregulatory mechanism. What is a thermoregulatory mechanism? Sweat. Sweat is sensible heat or latent heat? Latent heat. So the latent heat is and then if that is also not enough you will put fan. That is like a sling psychrometer.

So the fan will remove the this thing or you will splash water on your this thing and stand in front of a fan. If there is fever also they will put no one apart from dolo 650 so you can and then they will remove have light clothing or no clothing and then do not put blanket and okay. How about dogs? They put their tongue out. Saliva, what they do is basically cooling man. So that is the cooling. What about the elephants? The elephants flap their ears. It is like a fin.

Fin is d square theta/dx square - m square theta = 0 okay. So it a extended surface heat transfer. They will, high surface area okay so there are some thermoregulatory mechanism which are available which can handle to a certain degree. Otherwise you will have to this thing beyond a certain thing it will be a shock, thermal shock okay. So let us look at the picture here.

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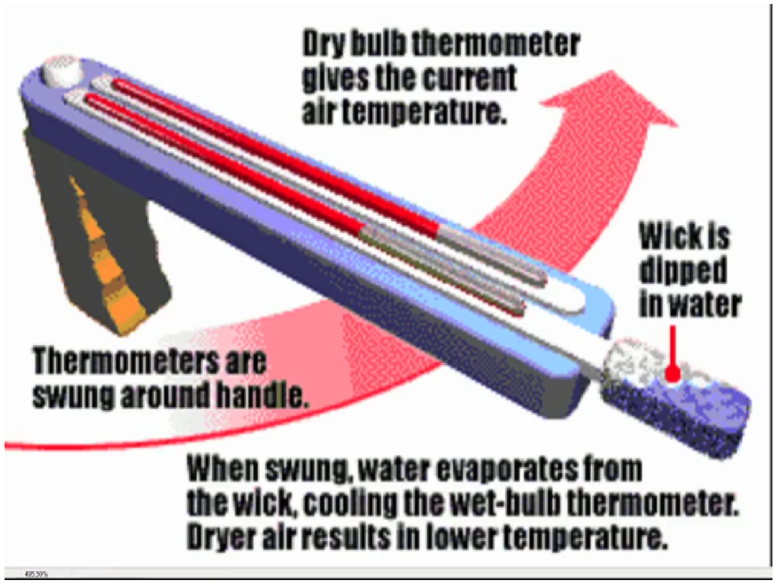

So this is the this is the sling psychrometer used for getting the wet bulb temperature. The dry bulb temperature gives the current air temperature. What is the air temperature now? The air temperature is always measured in shade. It would not be measured in the outside. It has to be it will give some wrong reading just like you take coffee and then check your body temperature okay. It has to be measured in the shade and all these are measured 2 m above sea level, 2 m above the ground okay.

Now this wick is dipped in water and then the thermometers are swung around the handle. Where is the handle here? Okay. You hold like this and you swing it. When swung water evaporates from the wick cooling the wet bulb thermometer; drier air results in lower temperature okay. Now where is the other one? Close. Now.

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Okay, are you able to see this? So this is another. So where is the wick? It is here, the wet cloth is here and he is swinging it here right. He is swinging it here. Are there 2 thermometers? What are they giving wet bulb and dry bulb okay so this is the sling psychrometer okay.

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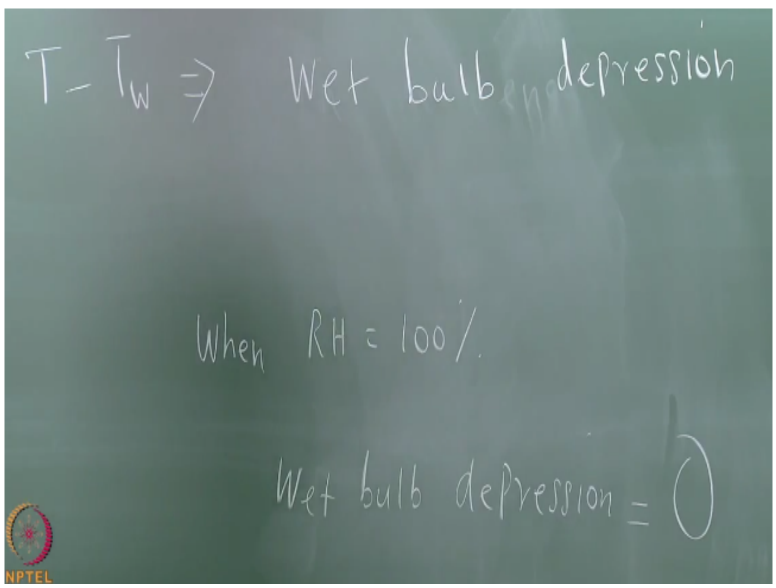

The difference between the dry bulb and wet bulb temperature, suggest a name for this, the difference between the dry bulb and wet bulb temperature, there is a technical name for that. That is called the wet bulb depression. It is the bulb is not depressed right. When RH is equal to 100% wet bulb depression equal to very good that means you have understood. So we agree that the wet bulb temperature is also an indicator of RH or the moisture content in the atmosphere okay.

So the raindrop falling through the sky when it fall through for a sufficient distance it will come to an equilibrium temperature which is corresponding to the wet bulb temperature of the surrounding air. This we have already seen yesterday and then the difference between the dew point temperature and the wet bulb temperature. In the case of dew point you are cooling it with respect to plain surface of water isobarically okay, here it is adiabatic.

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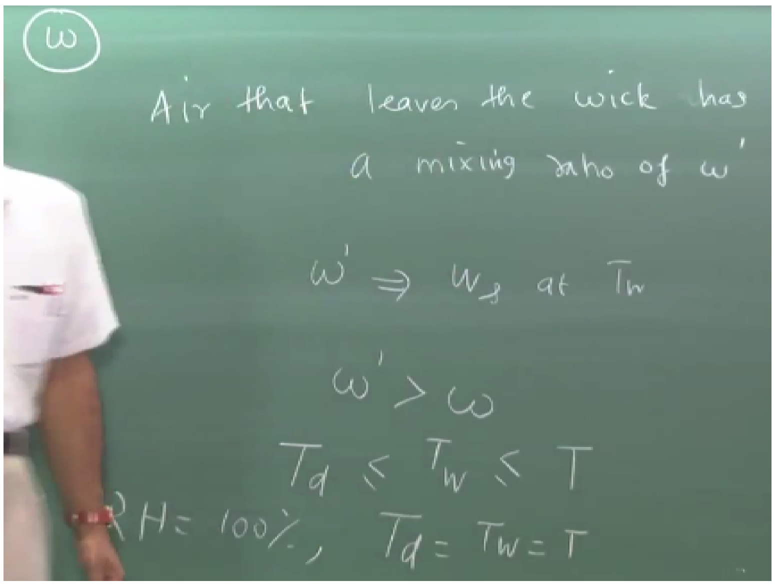

The air that leaves has a mixing ratio omega dash. This omega dash is nothing but please watch this omega dash is nothing but w s at T w. Are you getting the point? The omega dash is nothing but the omega s the saturation mixing ratio corresponding to the wet bulb temp. Now originally the air is having a mixing ratio of omega. Original was omega. After all these operation, your swinging, it has become omega dash. What a simple answer.

Omega dash = omega, omega dash > omega, omega dash < omega. Omega dash greater than very good. Good you understood okay. Now T d, the highest is the dry bulb temperature. The lowest is the dew point temperature, the wet bulb temperature is in between. It is an inequality with equality being applicable in the case of 100% RH. What is the rule for 100% RH? T d = T w = T very good nice.

Now you have to introduce, you have to learn about latent heat. We already introduced it by using the wet bulb temperature. Now we have to find out what are these values corresponding to water, ice. That is water becomes water vapour, what is the latent heat. Water becomes ice, what is the latent heat okay. One is the latent heat of melting. One is the latent heat of vaporization. So now and then we will have to next week we will have to discuss the Clausius-Clapeyron equation.

Does it ring a bell? Somewhere in thermodynamics you studied the Clausius-Clapeyron equation. That decides the shape of the saturation curve, water steam right. That gives a slope right. We will do a formal derivation in the next week. Chaitanya is distributing 2 copies of the Skew-T ln P chart to everybody as I am lecturing. Is that right? So the 2 copies, one for use and the second for preservation for the quiz and okay. You can make more copies if you want. You make copies on your smartphone.

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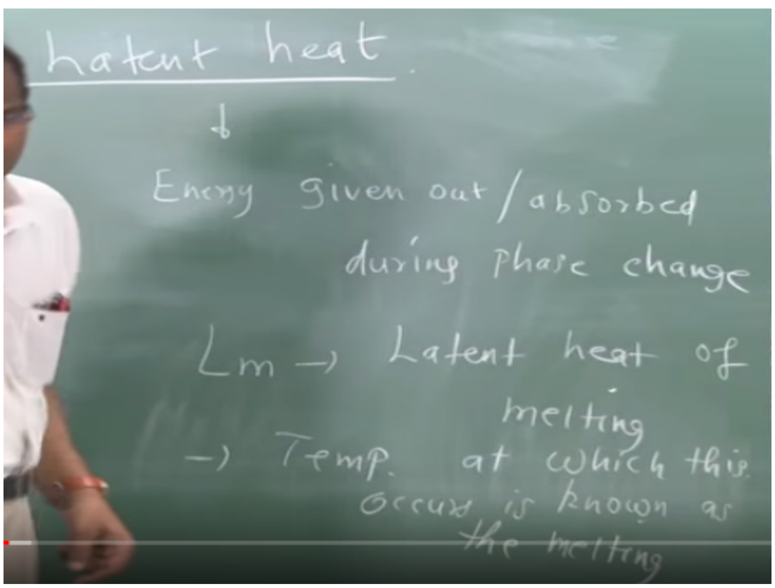

The latent heat is the heat which is given out or absorbed during phase change correct? I should not say heat okay. So first definition. Latent heat of melting Lm, please take down, the heat required to convert, heat this is from physics definition okay heat required to convert 1 kg of material from a solid to liquid phase, heat required to convert 1 kg of material from a solid to liquid phase without change in temperature without a change in temperature. I come again.

The latent heat of melting is the heat required to convert 1 kg of material from solid to liquid phase without a change in temperature okay. Temperature at which this occurs is called the melting point. For air at one atmosphere in 0 degree C the melting point of water is sorry at one atmosphere the melting point of water is 0 degree C. So what is melting point of water sorry melting point of ice.

If somebody says what is the melting point of ice you should say it is a stupid question please tell me the pressure okay. So the melting point of ice at one atmosphere is 0 degree centigrade okay. If water gets converted to ice or ice gets converted into water at 0 degree C the latent heat values are the same. When water becomes ice it is called the latent heat of freezing. When ice becomes water it is called the latent heat of melting. Both the stories are taking place at 0 degree C. They are one and the same. What is the value itself? What is the value itself?

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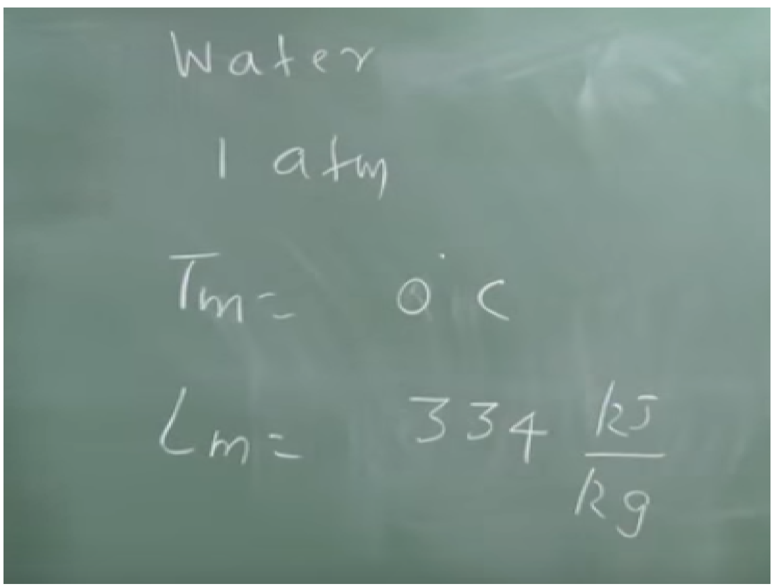

334 kJ/kg. Now latent heat of evaporation of vaporization.

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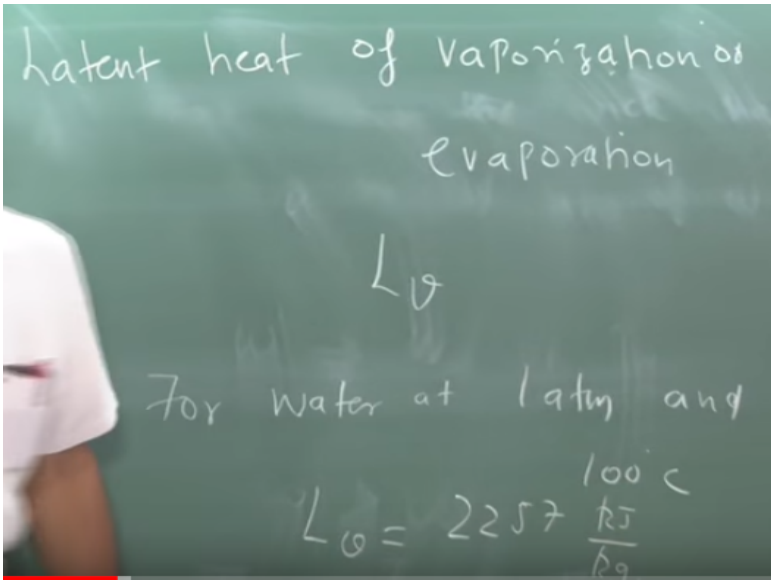

The latent heat of evaporation of vaporization L v is the amount of heat required to convert 1 kg of a material from its liquid to vapour phase. Udit, please take down. Latent heat of vaporization is the heat required to convert 1 kg of material from the liquid to vapour phase without a change in temperature. Take a guess 2257. What is the C p of water, 4.2.

So if water is heated by 30 or 40 degree C from 69 let us say from 59 to 99 water is heated from 59 to 99 what will be heat which is added? 40 into 4.2 correct that is about 160. Heat it a little further 100. Let it reach 100 degree C and it gets converted to steam. At that point what is the heat which will be released or heat added, 2257. Now you know why pressure cooker is much better than the open cooking.

Enormous amount of heat is there correct? People may argue open cooking is very good for pulao, biriyani whatever that is a separate story. But pressure cooker is very good because it exploits L v okay. Now before we go to the saturated adiabat which you have not seen so far. The saturated adiabat is the only line which you have not seen. I think they were the magenta lines or whatever, the only lines which we have not discussed in this course.

Once we discuss the saturation adiabat I will tell you how to calculate the wet bulb temperature. Nobody asked me so far sir how do we calculate the wet bulb temperature. You have got thermodynamic formula available. If you want I can derive it from first principles. I though since we are using the chart extensively we will might as well since this is the first course I did not want to give you very vigorous derivations.

If you want I can derive doing the first law of thermodynamics and then proceed. You invoke enthalpy and then we can get. So you can roughly get you can get an idea no. How do we get the wet bulb temperature? So it will be something like C p into T - T w will be equal to some l v into omega - omega s or omega dash something like that right. Lv is kJ/kg and g/kg that will get cancelled.

So for 1 kg of air the right side will be in kJ. Left side you take C p in kJ/kg/K multiply by delta you will also have kJ/kg. Left side will be kJ/kg and so one term will have C p delta T one will have l v delta omega. The delta omega is what is oh it went off my previous slide was omega dash - omega. So if you got that omega dash - omega into that l v okay that should be the C p delta T.

That will get adjusted. But this is a long story. If you want the derivation I can do it in one of the later classes. But the quick summary is like this alright. The other rule of thumb is that also you got here T + T d by 2. Now I told you ah we look at what is this 1 ton of refrigeration okay. That is an important quantity which we need to know.

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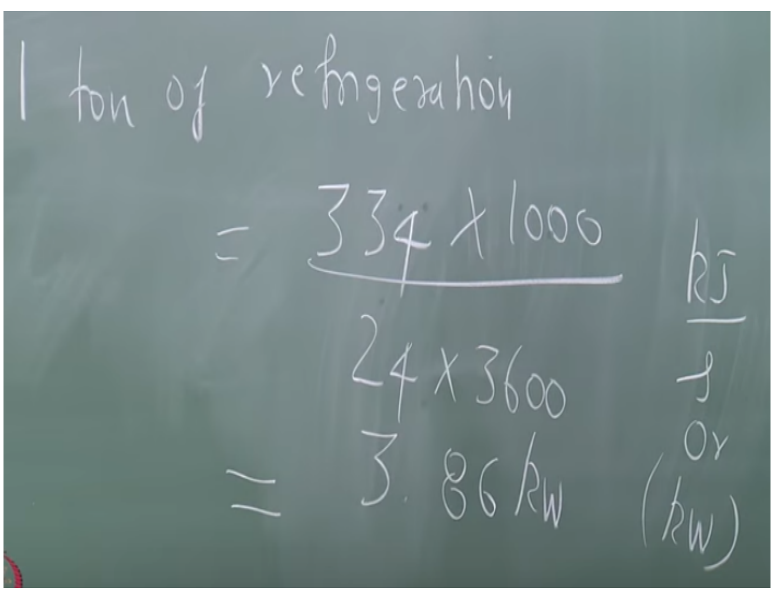

You say 1 ton AC, 2 ton AC. It is not weighing 1000 kg okay. 1 ton of refrigeration is you can take down 1 ton of refrigeration is defined as the amount of heat which is released, 1 ton of refrigeration, you know this already; 1 ton of refrigeration is defined as the amount of heat which is released when 1000 kg of ice at 0 degrees melts and becomes water at the same temperature when 1000 kg of ice melts and become water at the same temperature in a period of 24 hours, that is the spin okay.

What is the l m some 337, 330 where is it 334 kJ/kg into 1 ton is how many kg 1000. 24 hours is how many seconds, what will be the unit; kJ/kg into kg or; some 3 point something. 3.86 kilo watts okay. So in your residence if you happen to have a one and a half ton it is 3.86 + 1.9 that is about 5. 7 or 5.8 kilo watt okay. Normally these have a coefficient of performance around 2.5 or 3 okay.

That means so your 5.5/3 so 1700 watts will be used. For every unit so you will have 1.7 units consumed, 1.7 units of power consumed every 1 hour you run the AC. If it is 6 Rs. per unit so every hour it will be some 11 Rs. The whole night it will be some 100 Rs. So for 30 days it will be 3000 Rs. That is the so the challenge is to be how do we reduce this? You want to reduce your consumption what do you do? Do not use the AC is a very good option.

So slowly increase the limit, instead of 22, 23 you can make it 25, 26 one option. Improve the condenser efficiency this efficiency use whatever mechanic whatever fundas there in finite element analysis whatever you want you do optimize bring out every fancy thing whatever improve the efficiency of heat now they are all made of copper fins. Already they are very efficient.

So you still want to use some other technology whatever and improve your design insulation improve the design of your room, maybe false ceiling and this thing and cut out places where there is entry of air, windows and all that and this thing. You can take care of all this and lot of heat generating this thing you take care, have only CFL. No you go to the next, the game changer is supposed to be the LED lamp right. Go to all this and this thing and so you can reduce it.

So if you do all this you are doing green building design. Not only this you recycle the water this thing and storm rain water harvesting all this then there is a certification which is given to you this is a green house or this thing green building some lead certificates certification something is there right. So you these are strategies. For example you can put a solar photovoltaic cell on the top, on the rooftop okay. We can increase the height.

See previously if you go to Mysore palace and all this there is a natural ventilation because of natural convention. Hot air comes and then it rises. Then there is a loop this thing so as it rises there is a partial vacuum which is coming and then some little bit of cold air will come will seep in. So this is called mechanical ventilation. So now you can go little one step further and you can put exhaust fans then it will become one kind of insulation ventilation which is called natural entry and mechanical exhaust.

You can have mechanical entry and natural exhaust or just bump just ramp it up mechanical entry and mechanical exhaust. Try this with giant air circulators. If that does not work try desert coolers. If all this do not work you will have to use your air conditioners. So I told you in Japan the set point temperature is 26 and 27 in their trains this thing subways all those things. So instead of always looking at 24 or 25.

I do not know what the temperature in this room is now will be. Is there reading somewhere? No idea okay. So is it cold or it is comfortable. Comfortable okay. So if it is if you increase by 1 degree C the norms are changed by 1 degree C. You can actually work out and see how much energy consumption, how much you can have savings alright. Now this is the story about latent heat refrigeration, air conditioning and all that.

Saturated adiabatic and pseudo-adiabatic processes we want to learn about the last set of curves on this Skew-T ln P chart alright. So next 2 classes we will be solving lot of problem because once I tell you how to get this maybe some more derivations are there for wet bulb potential temperature and so on. After we go through that we will solve lot of problems.

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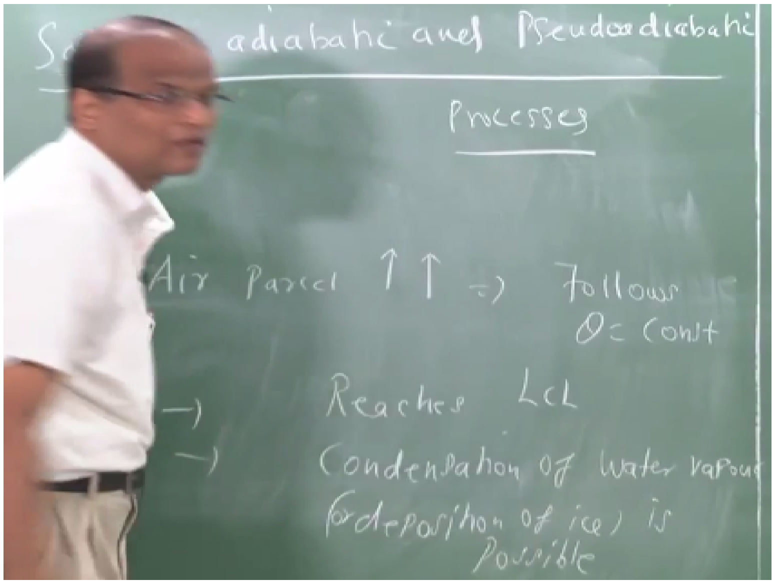

Air parcel is going up, follows which curve? We are always assuming adiabatic, it follows, reaches LCL. Then what happens? Further increase what happens? It is already 100% saturated and further increase the surrounding temperature is decreasing. So what will happen if you lift if it lifts, why should it lift at LCL? Who told you to stop at, there can be some wind and see it can keep rising no? When it rises which curve will it follow. That is a logical question is it not.

Now think about it. After it reaches the LCL there is a possibility that condensation of water vapour or in very cold condition it is also possible that deposition of ice. So what will happen to the lapse rate, the rate of decrease of temperature of the air parcel? Reduces, why? Latent heat enters the picture. The latent heat enters the picture and latent heat is much higher compared to specific heat. C p delta T is lower than L v into whatever omega whatever.

So therefore what happens is the rate of temperature is reduced and it will not follow a dry adiabat okay. So if all the particle so now there are 2 theoretical possibilities.

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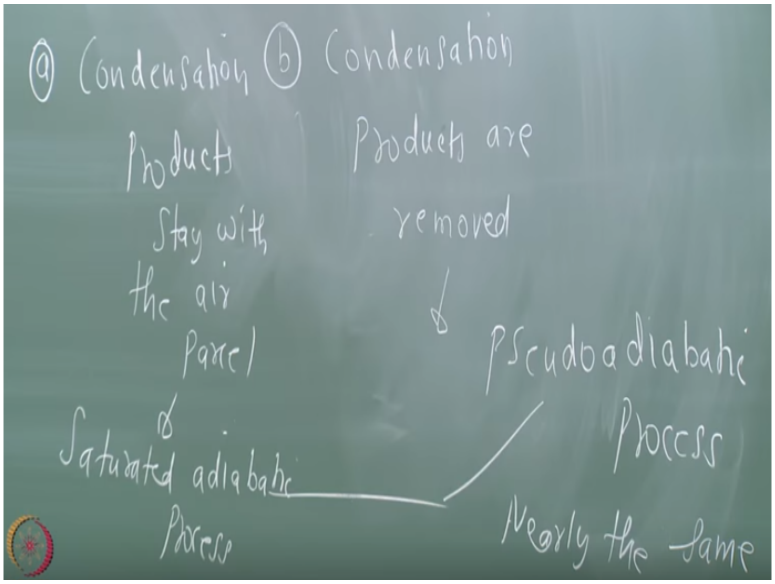

What are the 2 possibilities? Condensation will take place. Please tell me what are the 2 possibilities. What are the 2 possibilities after it has reached LCL. Condensation products stay with the air parcel or condensation products are separated from the air parcel. If they are separated, it is rain okay. So there are 2 possibilities. Condensation products, anyway this is only air parcel is much bigger than the condensation products because this is only 10 to 20 g/kg. The 980 g is just higher correct.

Condensation products stay with the air parcel, condensation products are removed. Then we say if its if it continues to rise and condensation product, do not ask me how there are then you have to look at cloud microphysics all that. If there is a if the situation is such that the condensation products stay with the air parcel then the air parcel will undergo a saturated adiabatic process. But please remember the question of saturated adiabatic process arises only after crossing the LCL. Otherwise, it is still a dry adiabat. In this case what happens?

This is a truly adiabatic process because if you bring somehow forcibly if you bring the air parcel back it is possible that the water will again get converted to water vapour, you can get it back to the initial state. However if you consider the possibility b, consider the possibility b when the condensation products are removed, in this case beyond LCL if it is brought to LCL and brought back to the initial condition it will not be the same as before because the water is gone.

But since the amount of water present in the air is only 10 to 20 g/kg you can still treat it as reasonably adiabatic without much loss of accuracy. Therefore if the condensation products are removed but still if air parcel is rising it is said to follow a pseudo-adiabatic process. But now comes the master stroke okay. It is a tame argument it is a tame end to the story. The amount of heat which is removed by the condensation of this water is very less because omega itself is very small.

Therefore the saturated adiabatic process and the pseudo-adiabatic process are nearly the same okay. I come again the amount of heat which is lost or gained in this condensation process is very small compared to the net heat content or energy content of the air parcel simply because of the small content of water vapour which is like 10 or 20 g/kg okay. It is 20 in 1000. Therefore this and so the saturated adiabatic and the pseudo-adiabat are one and the same.

There is no pseudo-adiabat on the if you want you can develop a chart that will be the 6th or 7th line it will already it is a confusing chart it will become more confusing, we can develop it. We can develop theoretical we can develop thermodynamic formula and okay. So saturated and pseudo-adiabatic nearly the same. So we can solve both type of problems using the chart correct. What about the saturated adiabatic lapse rate?

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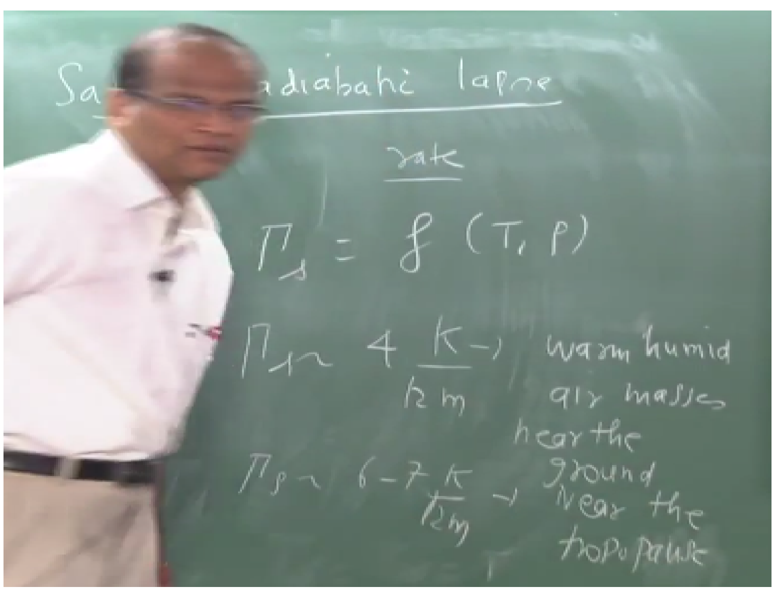

If you recall sometime in August we derived the dry adiabatic lapse rate which was just g by C p 9.81 divided by 1004, 1.004 or something. So you got something like 9.5 K per km but that kind of temperature change does not happen in the atmosphere because it is never dry okay. So the saturated lapse rate is a function of both temperature and pressure okay so it varies typically around 4 K per km near the ground near the troposphere.

Sorry, sure everything is troposphere tropopause correct okay. So the lines that show processes with constant lines which consider this air parcel which is following a saturated adiabatic proves are called saturated adiabats okay. They are also called as pseudo-adiabats because they are one and the same. So let us see those lines and then what we will turn around and calculate the bulb wet bulb temperature for Chennai's condition okay. Now, that where is that.

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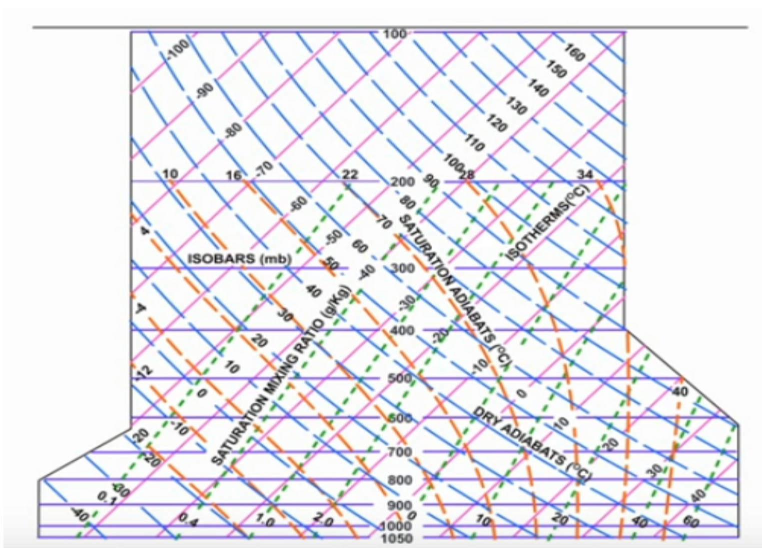

Coordinate system of the Skew-T, Log-P Diagram

This will also benefit the people who bunked yesterday's class okay. Coordinate system of the Skew-T ln P diagram. So we revisit this, the pink lines are the isotherms, the isobars, saturation mixing ratio, omega s, saturation adiabat. Now you got it. This is the line these are the set of curves which we never used thus far. Dry adiabat that is it.

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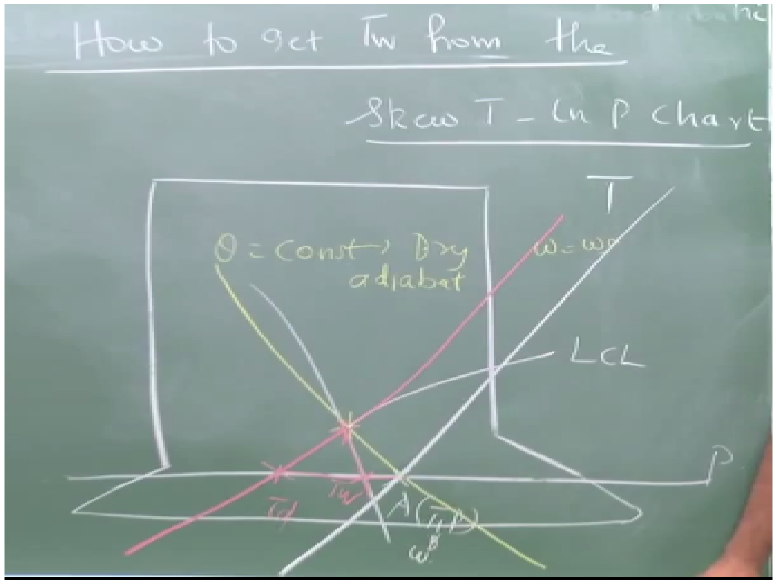

Okay P. T was going like this? Our point, our reference point A. A(T p) very good. E will have a omega correct which can be found on the saturation mixing ratio. Now find out where that omega equal to omega s and then no omega will be specified there will be omega which is specified. One moisture quantity has to be specified. Treat that omega equal to omega s and find out where that line is. Are you getting the point? This what am I calculating?

What am I calculating? Dew point? No wet bulb is eventually. Now, T d okay, dry adiabat. This is omega equal to omega s. So the omega equal to omega s line under dry adiabat line meet at this point. What is this? Okay this is the LCL the lifting condensation level. Now we say that it is undergoing a saturated adiabatic process okay. So that saturated adiabatic process is I do not know it is something like this or I do not know how it goes. Now watch carefully.

Retrace the path from the LCL back to the original pressure but now using the saturated adiabat if it crosses the original isobar at some point that is the T w. Understood? So in simple English, you cannot get the T w until you get the LCL. You cannot get the LCL until you get the dew point. So the starting point is the dew point. To get the dew point, you require one of the moisture parameters either RH or omega or T d itself okay.

I will repeat once more and then next 5 minutes we will calculate the wet bulb temperature corresponding to yesterday's Chennai condition and end the class alright. I okay so there is a isobar here. There is isotherm here. You fix the condition. So this will be the temperature and pressure. There will be a corresponding omega which is given or Td which is given. Assuming that omega is given then take that omega into omega s and find out where that omega s line cuts the isobar of the original that your original pressure.

That will be the T d the dew point temperature. From dew point you just go all the way up on omega on the omega s and draw that curve. Now from here you follow a dry adiabat because an air parcel will get lifted according to the dry adiabat. Now these 2 curves will intersect at this point called the LCL. From the LCL if it is lifted further it will follow the saturated adiabat. Now to calculate the wet bulb temperature I do not lift it I bring it back.

I bring it back to the original pressure so it will intersect my original isobar which will be 1000, 1013 or what have you and it will cut at a place which lies in between T and T d. That is T w okay. Akil, any doubt. Problem number 36. Determine the wet bulb temperature problem number 36 determine the wet bulb temperature determine the wet bulb temperature for Chennai on 23rd September from the data given. Determine the wet bulb temperature for Chennai or wet bulb temperature in Chennai for 23rd September from the data given.