Introduction to Atmospheric and Space Sciences

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Lecture – 24
Saturation Mixing Ratio and Relative Humidity

Hello, dear students. So, so far we have discussed various important aspects of Atmospheric thermodynamics and in the last class we have seen what are the humidity variables and how do you define saturation with respect to the vapor pressure or with respect to plain surface of ice or plain surface of water right.

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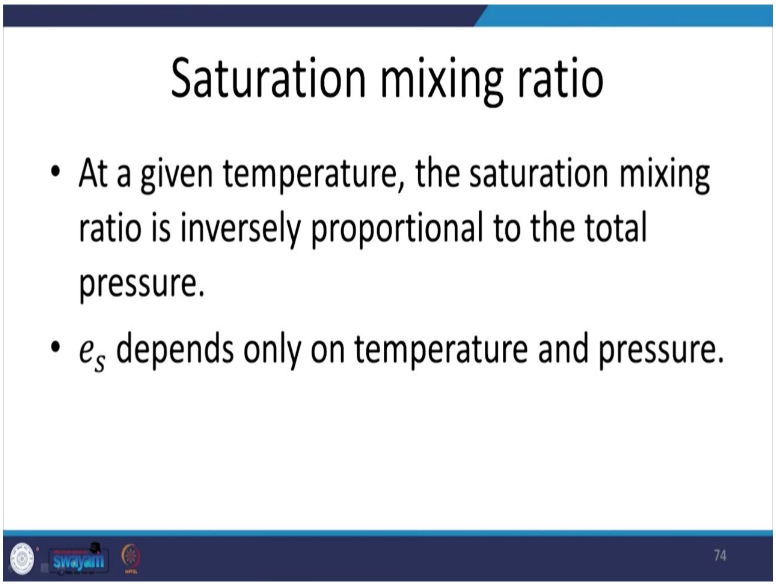

Saturation mixing ratio

- At a given temperature, the saturation mixing ratio is inversely proportional to the total pressure.
- e_s depends only on temperature and pressure.

So, one important conclusion that we should take from the last class is that at any given temperature the Saturation Mixing Ratio is inversely proportional to the total pressure and there saturation mixing ratio or the amount of moisture that the air parcel can contain can hold will always depend on the temperature right.

So, this is the basic idea. So, you increase the temperature the amount of water vapor that can be held by the parcel will be more; that means, by increasing the temperature you are increasing the point of saturation. So, saturation is only when whatever the air parcel can hold to its maximum ability right.

Now, in the last class itself we have seen that we do not have to physically add moisture to be able to reach saturation, we can rather decrease the temperature and say that at the existing temperature at the existing level of moisture itself we achieved the saturation. So, we defined what is called as a mixing ratio and we defined a what is called as a saturation mixing ratio and these two things are equal we call it as saturation right.

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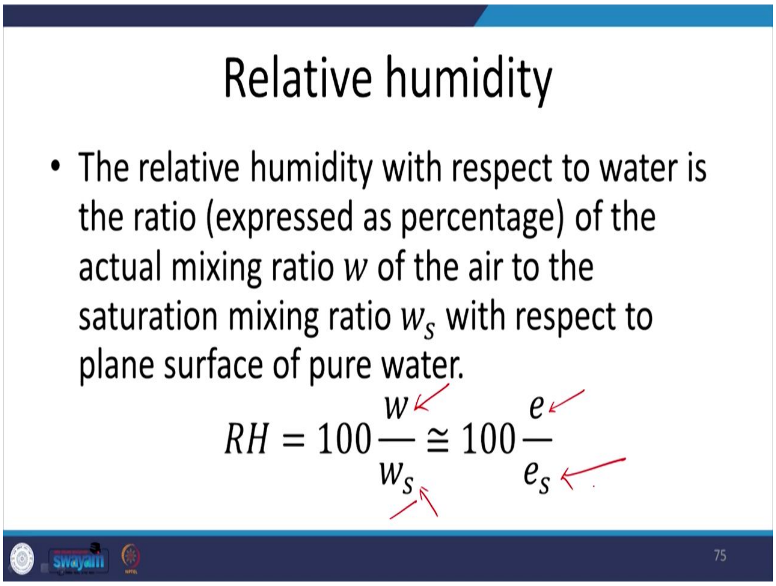

Relative humidity

- The relative humidity with respect to water is the ratio (expressed as percentage) of the actual mixing ratio w of the air to the saturation mixing ratio w_s with respect to plane surface of pure water.

$$RH = 100\frac{w}{w_s} \cong 100\frac{e}{e_s}$$

So, in today's class we will discuss several important temperatures, we will discuss what is called as equivalent potential temperature, we will discuss how the temperature varies with respect to height inside an air parcel if you take an adiabatic picture into consideration right. So, relative humidity is also a very important parameter to define the existing amount of moisture content in a given situation right.

So, the relative humidity with respect to water is generally expressed as a percentage. So, you must have seen in many of the weather displays or in your applications you must have seen what is the existing humidity at a particular point and at a particular time right. So, relative humidity is always expressed as a percentage and it is the ratio of the actual mixing ratio; actual mixing ratio that is existing inside the air parcel to the saturation mixing ratio with respect to plane surface of pure water.

If you take an air parcel at a particular pressure and then within this particular pressure and a given temperature or a constant temperature if w_s is the amount of moisture that is required to reach saturation and w is the existing amount of moisture, then the relative humidity is simply a ratio of mixing ratio to the saturation mixing ratio expressed in terms of percentage right.

So, w is the mixing ratio that we have seen right and w_s is the saturation mixing ratio and you write it in terms of vapor pressure you expand w as the amount of water vapor to the amount of air or amount of water vapor to the amount of dry air. So, you will get the same expression for the relative humidity in terms of vapor pressure existing vapor pressure and vapor pressure at saturation. So, always remember relative humidity is always expressed as a percentage what is existing to what should be existing for saturation, that is it right.

Another very important let us say temperature which is relevant for discussions on stability or discussions on atmospheric formation of clouds. So, the dew is called as the dew point. So, dew point is the temperature at which or to which the air must be cooled at constant pressure for it to become saturated with respect to plane surface of water right.

See, here one very important thing is while you while you try to understand dew point you do not talk about adding moisture. Dew point is not about physically adding moisture and then reaching saturation, dew point is about the fact that if you decrease the temperature you are moving towards the saturation with the existing amount of moisture itself right. So, the dew point is the temperature to which an air parcel must be cooled at constant pressure for it to become saturated with respect to plain surface of water right.

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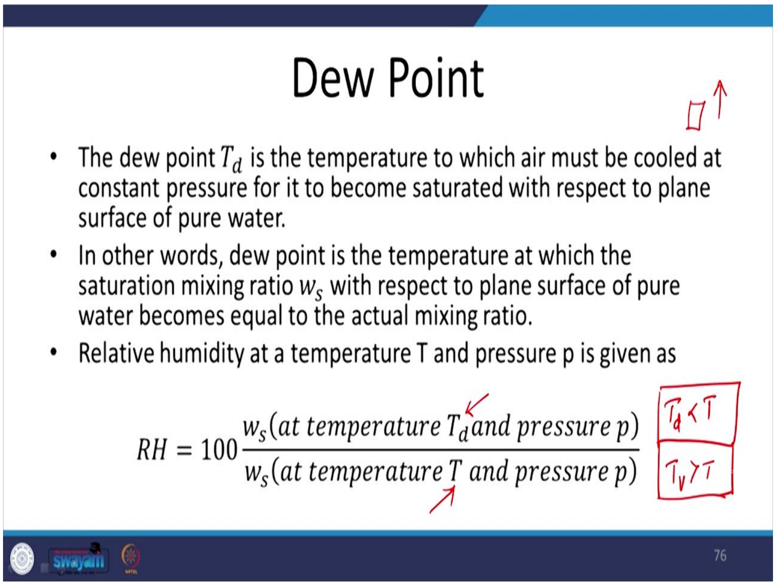

Dew Point

- The dew point T_d is the temperature to which air must be cooled at constant pressure for it to become saturated with respect to plane surface of pure water.
- In other words, dew point is the temperature at which the saturation mixing ratio w_s with respect to plane surface of pure water becomes equal to the actual mixing ratio.
- Relative humidity at a temperature T and pressure p is given as

$$RH = 100\frac{w_s(\text{at temperature } T_d \text{ and pressure } p)}{w_s(\text{at temperature } T \text{ and pressure } p)}$$

$\boxed{T_d < T}$

$\boxed{T_v > T}$

Now, very importantly when you talk about air parcel you should always remember that we are talking about an adiabatic picture. Adiabatic pictures allows no transfer of mass through it is walls or no transfer of energy or no addition of heat right; that means, if the air parcel is to be cooled, then how do you achieve it I mean where is the energy going out? Right. So, if the air parcel is rising in the atmosphere if it is rising adiabatically then what happens? The air parcel the rise of the air parcel it should be at the expense of decrease in the internal energy of the air parcel right.

So, as the air parcel rises it will decrease its pressure. So, it will lose its temperature right and as a result of this temperature being lost, the saturation is achieved right. So, simply put dew point is that temperature to which you cool the air to become saturated with respect to the surface of pure water. Or in other words, dew point is the temperature at which the saturation mixing ratio w_s with respect to plane surface of pure water becomes equal to the actual mixing ratio; actual mixing ratio is the one which is existing as it is right if you would not express relative humidity in terms of dew point temperature.

So, relative humidity at a temperature T and pressure p is given as relative humidity is equals to hundred times I mean as a percentage w_s the saturation mixing ratio at a temperature T_d and p and saturation mixing ratio at a temperature T and pressure p right. So, T is the existing temperature and T_d is the dew point temperature and T_d is always less than T right.

So, and one more very important thing is we have seen the virtual temperature is always greater than the actual temperature right. So, at some point there are few more temperature parameters we may want to understand how these temperatures are more or less in comparison to the actual temperature right. Since you are saying that dew point is that temperature you reach by decreasing, then T_d should be less than the actual temperature right.

So, the relative humidity is just a ratio of saturation mixing ratios, but at two different temperatures; one, at a dew point temperature, two, at a temperature T right. Now, if you are not adding moisture physically then obviously, the saturation mixing ratio at the lower value of temperature will always be less than 1, I mean less than 100 percent right. So, that means, that relative humidity reaching 100 percent and can never be ideally greater than 1 right.

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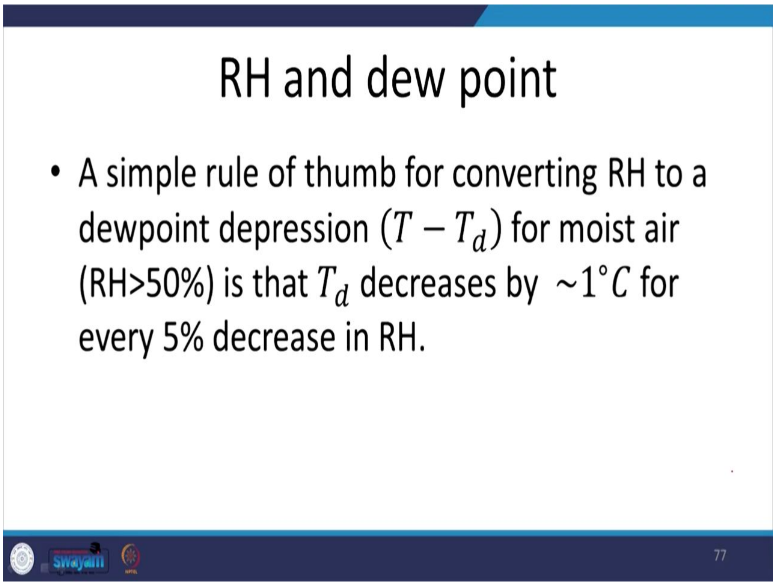

RH and dew point

- A simple rule of thumb for converting RH to a dewpoint depression $(T - T_d)$ for moist air (RH>50%) is that T_d decreases by $\sim 1^\circ C$ for every 5% decrease in RH.

So, the simple rule of thumb I mean how do you connect the relative humidity and the dew point is that. A simple rule of thumb for converting relative humidity to a dew point depression I mean the difference T minus T_d for moist air which is at least a relative humidity greater than 50 percent is that the dew point temperature decreases by 1 degree Celsius for every 5 degree decrease in the relative humidity right.

So, this is the difference, I mean the by what magnitude you should decrease the temperature is the dew point depression right. So, simple rule of thumb is the dew point temperature decreases 1 degree Celsius for every 5 degree Celsius decrease in the relative humidity. This is how the relative humidity and the dew point temperature can be connected right.

Another very important temperature is which is called as the frost point. Just like we defined dew point we can also define the frost point. So, dew points definition was based on pure surface of water So, you are talking about a process in which vapor liquefies or you are talking about phase between vapor and liquid right. Frost point speaks of the phase between a vapor to solid right.

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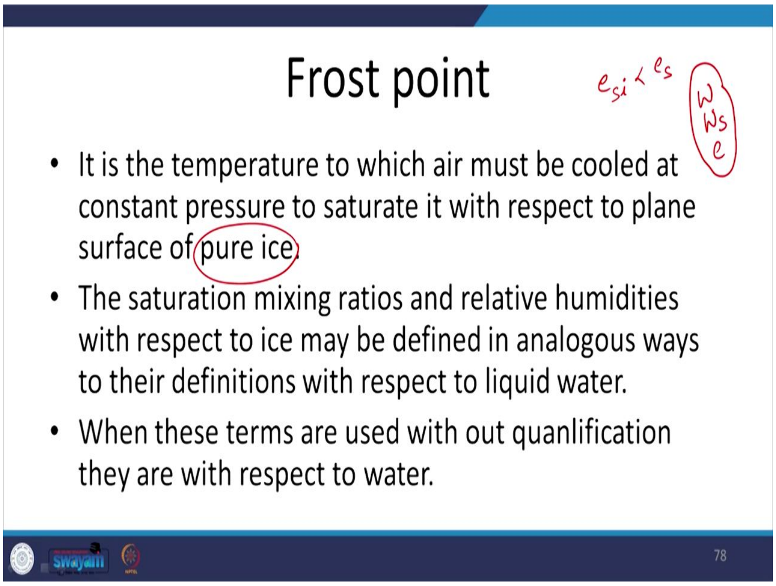

Frost point

$e_{si} < e_s$

w
ws
e

- It is the temperature to which air must be cooled at constant pressure to saturate it with respect to plane surface of pure ice.
- The saturation mixing ratios and relative humidities with respect to ice may be defined in analogous ways to their definitions with respect to liquid water.
- When these terms are used with out quanlification they are with respect to water.

So, it is the frost point is the temperature to which air must be cooled at constant pressure to saturate it with respect to plane surface of pure ice. So, this is even this is very important in the sense we talk about pure ice, I mean there is a topic again there is a separate discussion that we will have what will happen if you have something else if you do not have pure ice ok.

But, for now what we can take it for granted is that just like we define dew point as the point of temperature to which you cool the air, so that it becomes saturated with respect to plain surface of pure water. You define frost point as the temperature to which air must be cooled at constant pressure for it to become saturated with respect to plane surface of pure ice right.

So, just for recalling the facts in our earlier discussions we have seen that the vapor pressure due to pure surface of plain ice will always be less than the vapor pressure due to plain pure surface of plain water. So, the point is it will take more energy to melt the ice and then subsequently this melted ice or water becoming vapor and attaining equilibrium with the surface right. So, obviously, the vapor pressure due to e_{si} . So, that is what we have seen vapor pressure let us say e_{si} will always be less than e_s due to surface of water right.

So, having said that the saturation mixing ratios under relative humidities with respect to ice may be defined in analogous ways to their definitions with respect to liquid water we have defined that saturation mixing ratio. So, what is saturation mixing ratio? It is the maximum amount of moisture, it represents the maximum amount of moisture content that can be available if you have air in contact with ice no water as it is right.

So, that is how we can define all the moisture parameters just like we did for the case of water we can extend those for the case of ice as well, but you always remembered that the saturation mixing ratios or saturation vapor pressures off with respect to ice will always be less than those with respect to pure water right. So, let us say so, when these terms are used without quantification they are generally refer to with respect to water.

So, what it means is that when you talk about saturation mixing ratio or let us say when you talk about mixing ratio or when you talk about saturation mixing ratio let us say when you talk about vapor pressure or things like this. Generally we do not always say that mixing ratio with respect to pure surface of water saturation mixing ratio with respect to pure surface of water. So, we do not say all these things rather when we say saturation mixing ratio it is always meant, it is always implicit that it is with respect to water, but not with respect to ice.

So, what did we learn so far? We learned that what are the moisture parameters and these moisture parameters simply define or simply quantify the existing moisture content in a air parcel and when do you say they are saturated and if they are saturated is there any other way to reach saturation things like that alright. So, one important conclusion that has emerged out of this discussion is that in order to reach saturation you do not have to physically add moisture into the air parcel. You can simply decrease the temperature and then reach saturation right.

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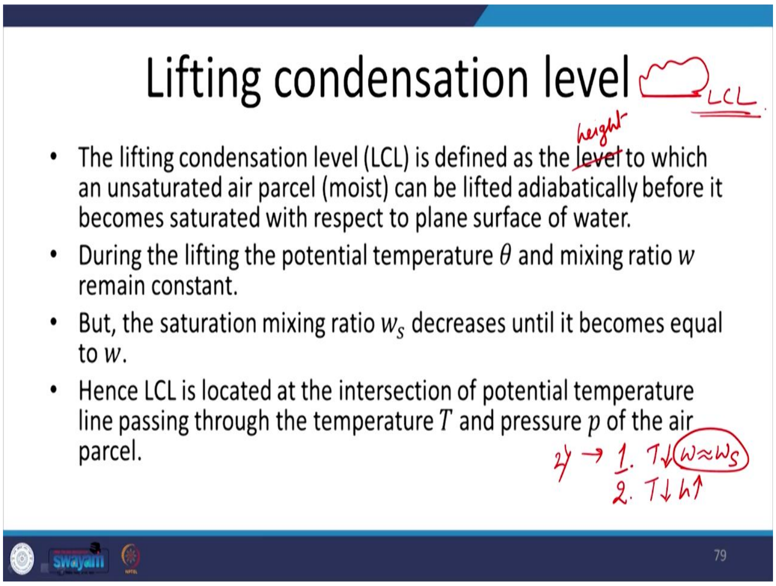

Lifting condensation level

LCL

- The lifting condensation level (LCL) is defined as the ~~level~~ height to which an unsaturated air parcel (moist) can be lifted adiabatically before it becomes saturated with respect to plane surface of water.
- During the lifting the potential temperature θ and mixing ratio w remain constant.
- But, the saturation mixing ratio w_s decreases until it becomes equal to w.
- Hence LCL is located at the intersection of potential temperature line passing through the temperature T and pressure p of the air parcel.

2) → 1. T↓ $\boxed{w \approx w_s}$

2. T↓ h↑

So, lifting condensation level is a length dimension or is a particular height which exploits this idea of decreasing the temperatures and reaching the saturation right.

So, lifting condensation level is defined as the level as the height or let us say as the height actually we generally use it in atmospheric stability discussions or cloud formation discussions right. So, lifting condensation level is defined as the height to which an unsaturated air parcel can be lifted adiabatically before it becomes saturated with respect to plane surface of water.

So, this exploits two different aspects; one of which let us say you decrease the temperature your mixing ratio becomes equal at a particular temperature to saturation mixing ratio. The second aspect that it exploits is that in the atmosphere temperature decreases as you increase the height. So, if you want to attain saturation with the same amount of moisture you should decrease the temperature and decrease of temperature must be done or can be done when you rise in air parcel right.

So, that is why the lifting transition level is the height to which you rise an unsaturated air parcel adiabatically before it becomes saturated with respect to plane surface of water. So, always remember we will come back to this point in our discussions on cloud formation. So, there we will realize that lifting condensation level LCL, is always the bottom of the cloud. So, cloud will always form with its base at the LCL. Now, LCL will depend on a on many important parameters that is a different story, but lifting condensation level or generally referred to as LCL is always the bottom of the cloud right.

So, ; the during the lifting the potential temperature and mixing ratio remains constant. Why is the mixing ratio constant? Mixing ratio is constant because it is adiabatic you are not allowing any mass transfer through the walls right. So, mixing ratio that remains a constant. And, the potential temperature remains a constant because it is adiabatic in nature, the rise is adiabatic in nature.

And, the formulation of potential temperature was such that if an air parcel is rising or sinking in an adiabatic picture what will be it is temperature when it reaches when it tries to reach the pressure of the sea surface right, but generally the saturation mixing ratio decreases until it becomes equal to w right. So, here, you are not changing w rather you are decreasing w_s to a level such that itbecomes equal to w right.

So, hence we can say that the lifting condensation level is located at the intersection of potential temperature line passing through the temperature T and pressure p of air parcel. This is just to analyze the thermodynamic diagrams of the atmosphere right.

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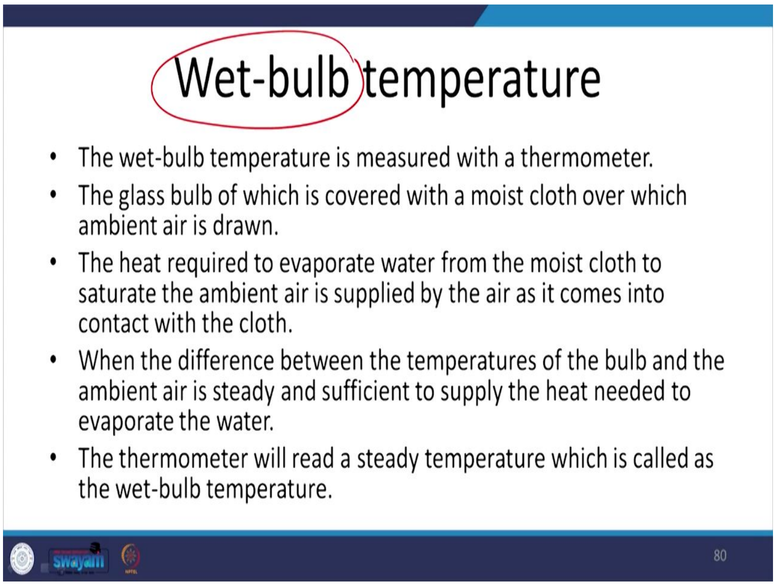

Wet-bulb temperature

- The wet-bulb temperature is measured with a thermometer.
- The glass bulb of which is covered with a moist cloth over which ambient air is drawn.
- The heat required to evaporate water from the moist cloth to saturate the ambient air is supplied by the air as it comes into contact with the cloth.
- When the difference between the temperatures of the bulb and the ambient air is steady and sufficient to supply the heat needed to evaporate the water.
- The thermometer will read a steady temperature which is called as the wet-bulb temperature.

And, one more very important temperature that we also call as wet-bulb temperature. What do you mean by wet-bulb temperature? So, this is a specific name I mean it is very important in atmospheric stability or atmospheric thermodynamic. So, this is the name is justified by the process that you do to measure this temperature right. So, this is wet-bulb temperature. So, wet-bulb temperature is measured with the thermometer.

I mean, how do you do it? Let us say the glass bulb the thermometer generally has a glass bulb in which there is mercury and depending on the temperature the mercury will expand and expand into the into the pipe or in to the into the tube, where the temperature is pre calibrated and depending on the temperature the expansion is calibrated and you will read the value of temperature right. So, the wet-bulb temperature is generally measured with a thermometer.

The glass bulb is covered with a moist cloth over which ambient air is drawn. Simply you just take a thermometer, you wrap the glass bulb or you cover the glass bulb with a with a cloth which is wet I mean which is soaked in water right. Now, if it is soaked there is moisture on it right there is moisture on it and the if it is a closed enclosure the moisture on the liquid that is on the cloth will evaporate with time right. So, if it has to operate it needs some heat. So, the heat there is a required to evaporate water from the moist cloth to saturate the ambient air is supplied by the air as it comes in contact with the cloth right.

So, to begin with you give a thermometer, there is no moisture in the in the environment as the air comes close and touches or interacts or as it passes through the cloth it gives some heat so that the liquid evaporates and as this process continues slowly and steadily there is moisture buildup in the atmosphere. And, it will come to a limit when the cloth which is with water rises it is temperature or it is temperature is increased to the point that it is equal to the temperature of the environment.

Then, the air does not have any amount of energy that it can give to the cloth and rise its temperature right. So, basically thermodynamically equilibrium is achieved between the temperature of the cloth and the environment. So, when the difference between the temperatures of the bulb and the ambient air is steady and sufficient to supply the heat needed to incorporate air you reach an equilibrium state. So, the thermometer will then read a steady temperature which is called as a wet-bulb temperature.

So, you make the bulb wet by wrapping a wet cloth around it and you allow enough amount of time so that the air is in saturation with respect to the bulb. So, there is no more normal transfer of energy between the environment or the atmosphere under the work. So, this saturation or this equilibrium temperature is generally referred to as the wet-bulb temperature right.

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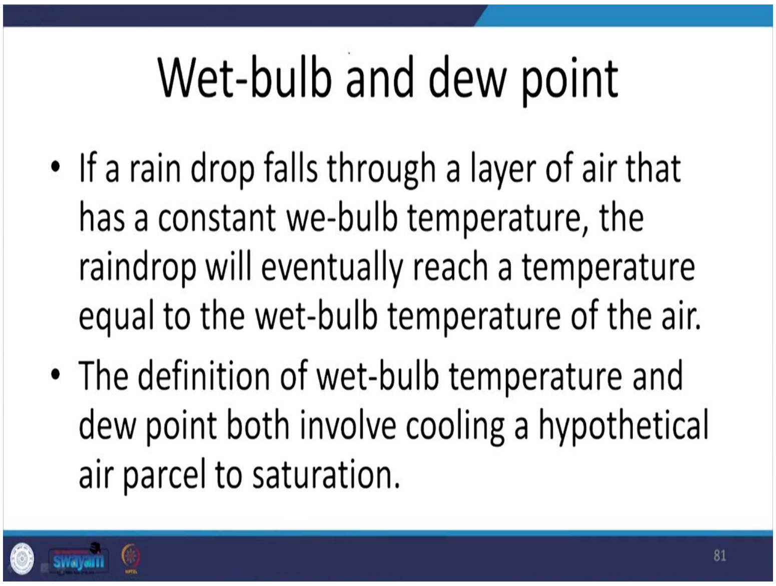

Wet-bulb and dew point

- If a rain drop falls through a layer of air that has a constant we-bulb temperature, the raindrop will eventually reach a temperature equal to the wet-bulb temperature of the air.
- The definition of wet-bulb temperature and dew point both involve cooling a hypothetical air parcel to saturation.

Now, this the wet-bulb temperature can be closely connected with the dew point. Let us say if a raindrop falls through a layer of air that has a constant wet-bulb temperature if you have a raindrop which falls through a layer of air that has a constant wet-bulb temperature, then the raindrop will eventually reach a temperature equal to the wet-bulb temperature of the air.

So, raindrop is falling if the environment through which it is falling does not have moisture. It has more temperature then due to its temperature the bulb the raindrop will evaporate slowly and steadily giving the out moisture as long as there is no difference in the temperature. When these two temperatures are equal you call that particulartemperature as the wet-bulb temperature of the air ok.

So, the definition of wet-bulb temperature and the dew point both involve cooling to a particular hypothetical air parcel to a particular temperature or to a particular saturation right. So, both of them are similar in a way that both of them needs the air parcel to be cooled, so that it reaches saturation; that means, you are decreasing the saturation mixing ratio inside the air parcel to the level of the existing mixing ratio inside the air parcel both of them are the are the same idea right.

Now, so far we have seen various values or various parameters of temperature I mean how is this wet-bulb temperature what is dew point temperature, what is frost point, what is the relative humidity, what is virtual temperature, what is potential temperature so on and so forth right.

Now, one very important thing is there is always a phase transition that we generally talk about. Phase transition is evaporation of let us say evaporation of water into vapor right. So, or a phase transition when this vapor condenses and forms water again or vapor crystallizes and forms ice or water crystallizes and forms ice. So, this there is always a phase transition right.

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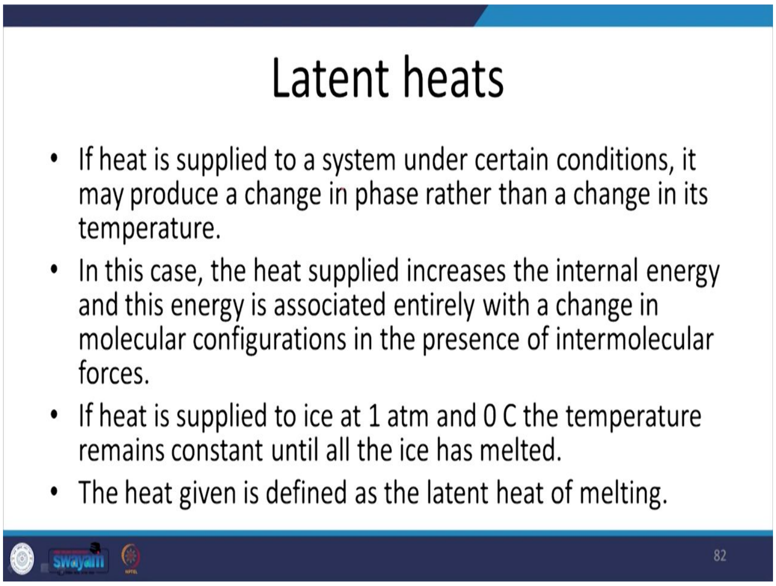

Latent heats

- If heat is supplied to a system under certain conditions, it may produce a change in phase rather than a change in its temperature.
- In this case, the heat supplied increases the internal energy and this energy is associated entirely with a change in molecular configurations in the presence of intermolecular forces.
- If heat is supplied to ice at 1 atm and 0 C the temperature remains constant until all the ice has melted.
- The heat given is defined as the latent heat of melting.

Let us say, what is the idea of latent heat. The idea of latent heat comes from the fact that if the heat is supplied to a system under certain conditions and it may produce a change in the phase rather than change in its temperature. So, generally what happens according to the first law of thermodynamics whenever you supply heat you are you are giving energy into the system, this energy increase should always accompany a temperature change that is the conservation of energy.

So, unlike if the heat supplied to a system under certain conditions not always if it if this heat is not able to raise the temperature, but rather produces a phase transition or phase change then it is something which is very different I mean then we have to talk about latent heats. So, in this case the heat supplied increases the internalenergy and this increased internal energy is associated with a change in the molecular configuration in the presence of intermolecular forces, but not increasing the kinetic energy of the molecules right.

So, the heats that is supplied is able to increase the internal energy the heat that you give is able to give molecules energy to overcome the intermolecular forces triggering what is called as a phase transition. Let us say for example, if heat is supplied to ice at one atmospheric pressure and 0 degree Celsius; 0 degree Celsius is the freezing point so where you do not have water rather you have ice. But, if it is I mean the pressure is more or less then the things are different.

But, if it is at standard atmospheric pressure 1 atmospheric pressure and if you have 0 degree Celsius and if you have water you will have ice right that is it, but when you heat the ice generally what happens? The temperature of the ice will remain at 0 degree Celsius as long; as long as all the ice is melted and water is formed. So, this heat that you give is defined as the latent heat of melting right simple.

So, the latent heat of melting is defined as the heat that has to be given to a unit mass of material to convert it from the solid to liquid phase without changing the temperature. So, you take 1 kg of ice at 0 degree Celsius and 1 atmospheric pressure, the temperature will not change as long as the ice is not melted completely. Once the ice is melted at that particular point the temperature of the melted water has come out of the ice is at 0 degree Celsius.

Once the ice has melted completely then the temperature increase will change. So, whatever the heat that you have supplied so far till that point has just been able to make the phase transition between the solid and liquid possible that is it. So, this heat is called as the latent heat. So, this is the latent heat of melting because this heat is given to make the intermolecular forces disappeared so that the molecules becomes free and they behave like a fluid right.

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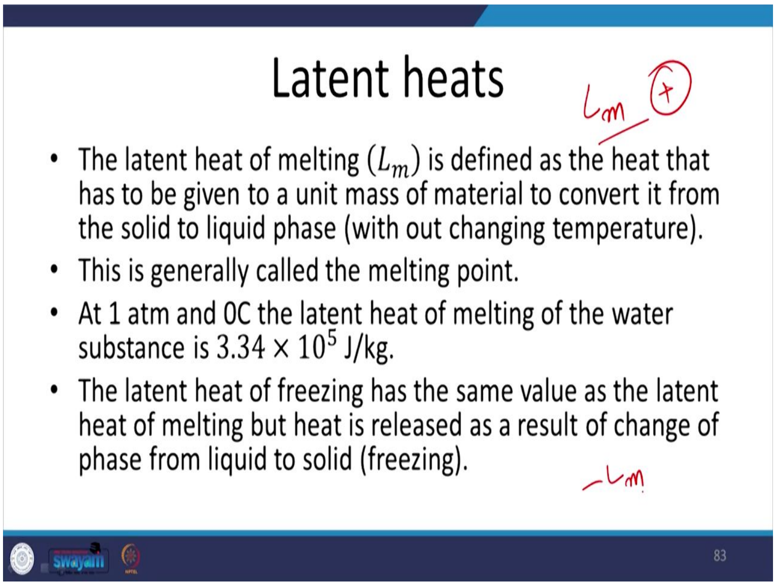

Latent heats

L_m ⊕

- The latent heat of melting (L_m) is defined as the heat that has to be given to a unit mass of material to convert it from the solid to liquid phase (with out changing temperature).
- This is generally called the melting point.
- At 1 atm and 0C the latent heat of melting of the water substance is 3.34×10^5 J/kg.
- The latent heat of freezing has the same value as the latent heat of melting but heat is released as a result of change of phase from liquid to solid (freezing).

$-L_m$

So, this is generally called as the melting point. I mean melting point now; now that you talk about melting point we should remember the Clausius–Clapeyron equation which says that when you change the pressure the melting point will change right. But, so, not to complicate the things we will say that at 1 atmospheric pressure and 0 degree Celsius the latent heat of melting of water is 3.34 multiplied by 10 to the power of 5 Joules per kg.

So, if you take 1 kg of ice and if you want to melt this completely without changing the temperature or if you want to create water at 0 degree Celsius you should supply 3.35 multiplied by 10 to the power of 5 joules of energy for this phase transition right. So, the latent heat of freezing also has the same value in a different ways.

So, latent heat of freezing has a same value as the latent heat of melting, but the heat here is not given is rather released. Heat is rather released as a result of the change of phase from liquid to solid right.

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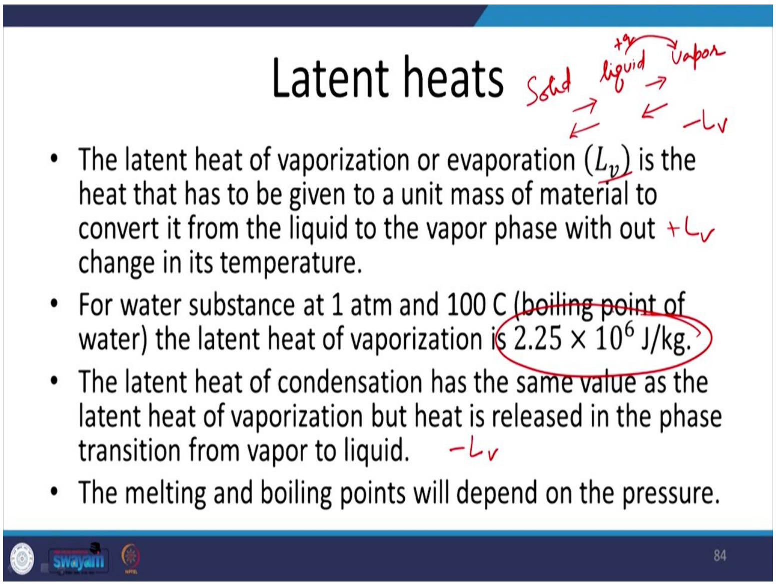

Latent heats

- The latent heat of vaporization or evaporation (L_v) is the heat that has to be given to a unit mass of material to convert it from the liquid to the vapor phase with out $+L_v$ change in its temperature.
- For water substance at 1 atm and 100 C (boiling point of water) the latent heat of vaporization is 2.25×10^6 J/kg.
- The latent heat of condensation has the same value as the latent heat of vaporization but heat is released in the phase transition from vapor to liquid. $-L_v$
- The melting and boiling points will depend on the pressure.

So, some more facts about latent heat: so, the latent heat of vaporization or evaporation L_v is the heat that is that has to be given to a unit mass of material to convert it from liquid to vapor phase right. So, that means, that you always remember so, let us say L_m , L_m is the latent heat of melting; latent heat of melting is positive when let us say this can be the other way also.

Latent heat melting is the heat given to water for melting it if you take it the other way. If you are freezing let us say 1 kg of water into 1 kg of ice the heat that is released should be taken within with a negative let us say L, yeah.

So, similarly the latent heat of evaporation or vaporization; so, the vaporization is creating vapor out of water. So, this phase transition from this liquid to gas phase; so there is solid, liquid, vapor. So, water like works like this right. So, latent heat of liquid to vapor you have the give heat this is plus L_v let us say and if the vapor condenses and forms liquid in the heat is released this also has the same value as latent heat of evaporation or vaporization, but this should be with a negative sign indicating that heat is being given out right.

So, the latent heat of vaporization or evaporation is the heat that has to be given to a unit mass of material to convert it from the liquid to vapor phase without any change in its temperature. For water at 1 atmospheric pressure and 100 degree Celsius we talk about freezing at 0 degree Celsius 100 degree Celsius we talk about a boiling of water right. So, the latent heat of vaporization is 2.25 multiplied by 10 to the power of 6 Joule per kg.

The latent heat of condensation has the same value as the latent heat of vaporization, but heat is released in the phase transition from vapor to liquid. So here in this phase it is plus L_v and here it is minus L_v , but anyhow the value is still the same 2.25 multiplied by 10 to the power of 6 Joule per kg is still the same. So, you take 2 point 1 kg of water at 100 degree Celsius, then in order to convert this into vapor without changing the temperature you should supply this much amount of heat.

So, the melting point and boiling point will again depend on the pressure right. So, this is some discussion about latent heats and various different values of temperatures which will be used at in our discussions ahead right. So, we will stop here we will continue our discussions in the next class to discuss about pseudo adiabatic processes and how we can derive relation for the saturated adiabatic lapse rate.