Introduction to Atmospheric and Space Sciences

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Lecture – 28
Cloud Formation

Hello dear students. In continuation with our discussions on the Formation of Clouds, in the last lecture we have learned about various variables or various parameters to define or to quantize the amount of moisture that can be present in an air parcel and how this can be used to define the relative humidity. And then we have realized that there are various methods by which you can achieve saturation in the given air parcel right.

So, today in this class what we will try to understand? We will try to see what are the methods by which you can lift an air parcel. So, that it achieves saturation and how this can lead to the formation of clouds. So, we will look at few thermo dynamical aspects about the formation of clouds in general ok. Now so, how exactly do the convective clouds generally form? I mean so, now we have realized that if you rise an air parcel in the atmosphere because we have seen that in the troposphere up to let say 10 or 15 kilometers the temperature decreases with the altitude.

So, in order to achieve saturation you have to decrease the temperature; that means, you do not have to do anything, but you if you can lift an air parcel in the atmosphere, the air parcels temperature will naturally decrease allowing saturation to happen at particular height right. So,the thermo dynamical aspect of this is that I mean what why would the temperature decrease of the air parcel, what happens to the pressure, what happens to the volume. These things are very important and we should understand the details of it.

So, pressure is essentially the weight of the atmosphere that is above you right. So, as you go of lesser and lesser atmosphere is present and then as a consequence the weight, the pressure will decrease as we go up.

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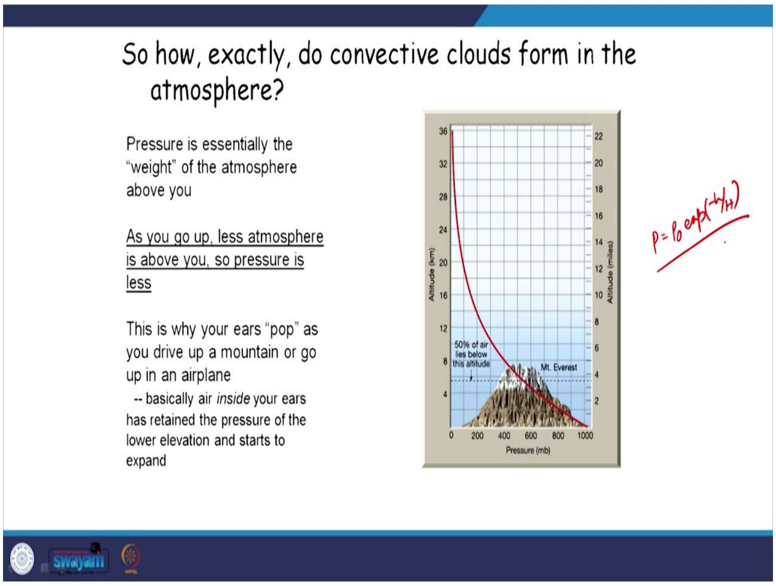

And we have also seen that the atmospheric pressure decreases as an exponential factor with respect to the scale heights ; that means, P naught is the pressure at the surface and small h is the height at which you want to calculate the pressure and capital H is the scale height ok

Now, so this is why generally as the pressure decreases, you start experiencing. Let say as you go higher in the altitude what generally happens, the outside pressure is lower than the pressure that is let say in in your ear. So, generally there is a pressure difference. So, that is why you your ears will pop when you when you move to a very high altitude region right.

So, what happen what exactly happens? Let us considered a parcel of air at let say 1000 millibar that is at the ground at the surface where the pressure that is 1000 millibar.

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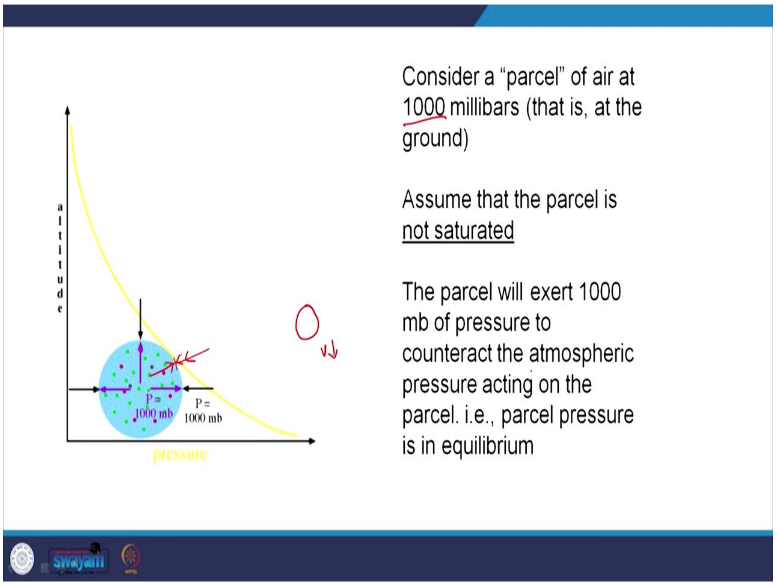

Now, assuming that let say this parcel is not saturated; that means, the saturation the vapor pressure inside this air parcel is not equal to this vapor pressure at saturation.

Now, what should you do? Either you should decrease the saturation vapor pressure or you should increase the vapor pressure. So, that they can become equal then you have a saturation. Now, let say there is an air parcel which is existing at the surface and this air parcel is not saturated.this air parcel will exert 1000 millibar of pressure to contract the atmospheric pressure. So, the volume of this air parcel is fixed. So, that the pressure that is existing inside the air parcel becomes equal to the pressure that is outside. That means, so, this pressure that is inside is equal to 1000 millibar just. So, this volume the volume is limited by this interaction.

So, pressure that is exerted from the air parcel on the surface on the atmosphere is equal to the pressure that is exist that is exerted by the atmosphere on the surface of the air parcel. Now if this air parcel is experiencing more force let say, then the air parcel will shrink . That means, when the air parcel shrinks the volume of this air parcel is going down; that means, there is lesser volume with the same number of molecules.

So, the molecules will impart more amount of force on the surface building up more pressure right. So, there is an equilibrium again. So, when the pressure outside is more, the volume will decrease. So, that it can exert more pressure on the surface like that, but eventually an equilibrium has to be reached. Now, at this point of time when the air parcel is on the surface, it is exerting a pressure of 1000 millibar on the atmosphere.

So, it will exert 1000 millibar of pressure to counter the atmospheric pressure acting on the parcel that is the parcel pressure is an equilibrium with the atmospheric pressure fine.

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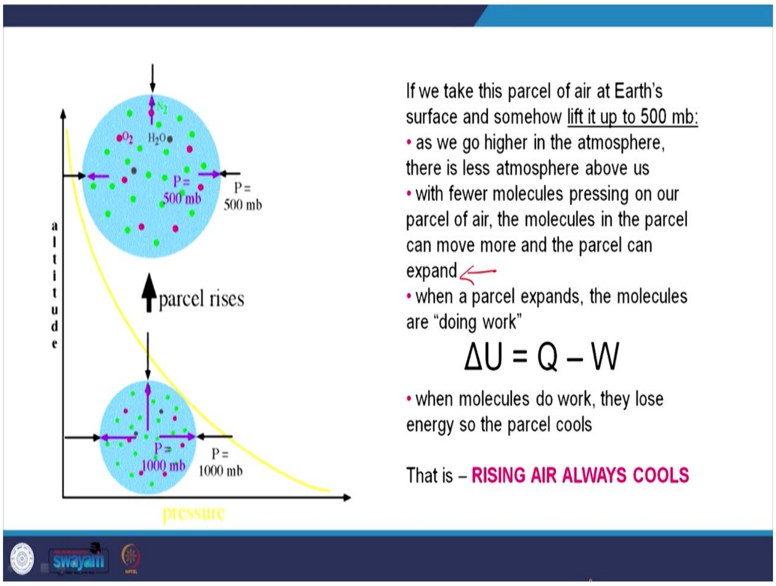

Now, what happens? Let say if you rise it now if you take this air parcel from the earth surface let say and lift it up to pressure let say a 500 millibar pressure, what happens? As we go higher in the atmosphere the pressure is decreasing; that means, the amount of force that is experienced by the wall of this air parcel is decreasing.

So, as it starts to experience lesser and lesser amount of force, then the air parcels volume will increase because it does not need that much amount of momentum transfer on the walls by the molecules inside to counteract the pressure that is built up by the atmosphere on the outside of the air parcel right. So, as we go higher in the atmosphere, there is even lesser of the atmosphere that you encounter as you go up.

So, as a result with fewer molecules pressing on the parcel of air from the outside, the gas will expand as such the molecules can move more freely and the parcel will expand, yeah. So, now, the point is when the air parcel moves or starts to rise , it was unsaturated to begin with, but as the parcel rises the atmospheric pressure decreases and the pressure inside the air parcel should also decrease. Because this this is the basic idea of the air parcel is that wherever you keep this air parcel this will behave as if the pressure outside this air parcel is equal to the pressure inside this air parcel. That means, it is perfectly in equilibrium with the surroundings that is the basic idea of the air parcel.

So, when the air parcel starts to move further up into the atmosphere, its volume will keep on increasing. So, that its pressure becomes equal right. Now, this volume increase can simply be termed as expansion in thermo dynamical terms the expansion is happening with the air parcel, the air parcel is expanding ; that means, the molecules are doing some work. So, right.

So, even from the first law of thermodynamics we can say that the change in the internal energy is equals to Q minus W; Q is the heat supplied and w is the amount of work that is done. When the molecules do work, they lose energy right; when the molecules do some work, they lose some internal energy. And as a result the parcel so, there is a net decrease in the internal energy of the system, what is our system? Our system is air parcel.

So, simply put as the air parcel rises, its volume increases. The increase in the volume can be seen as if the molecules of the gas inside are doing some work if there is a positive work if w is non zero, this w has to be at the expense of decrease in the internal energy. When the internal energy decreases, the temperature of the air parcel decreases so; that means, that as the air parcel rises the temperature will decrease see. To begin with we have not actually talked about the temperature at the parameter of temperatures.

So, our idea was only confined between pressure and volume. But if the pressure is decreasing exponentially with respect to height in the atmosphere so, as to compensate this decrease of pressure the this air parcel should always expand as it goes up. This expansion is seen as work done by the molecules.

So, you have taken away some energy from the air parcel. So, the air parcel will now cool. So, eventually I mean in essence what we can say is that as the air parcel rises, its temperature will decrease right.

Now the from the first law of thermodynamics, delta U is the change in the internal energy, Q is the amount of heat that is added to the system, W is the amount of work done.

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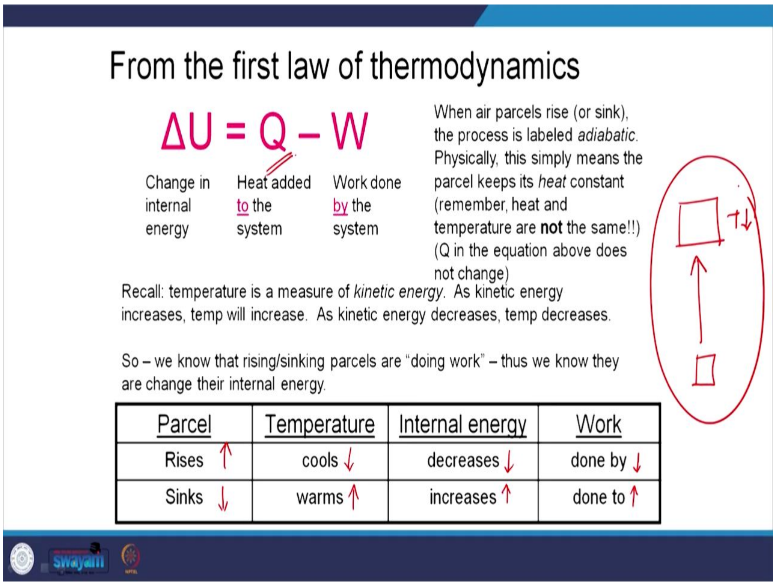

So, if we add some amount of heat it will change the internal energy of the system and then there can also be some amount of work done right. So, when the air parcel rises or sinks for that matter the process is labeled as adiabatic physically, the simply means that the parcel keeps its heat, it is not transferring any amount of heat with the surroundings.

Now, if you want to complicate it, you can simply say that it can absorb some heat it might have observed some heat from the surroundings, then why should the air parcels volume decrease or increase, then why should the air parcel be cooler as it rises things like that right.

So, the temperature we know very well that the temperature is a measure of the kinetic energy of the molecules. As a kinetic energy increases, the temperature also increases right and as the kinetic energy decreases the temperature also decreases. So, now, what we know that the rising air parcels are doing work thuswe know that, they are changing their internal energy. So, this work that is done is at the expense of internal energy because you are not adding any heat right, you have kept Q as a constant. That means, you are not giving any heat to the system; that means, that whatever the work that is done is at the expense of internal energy so, right.

So, as the parcel rises the, the temperature comes down inside the air parcel and the this is at the expense of decrease in the internal energy and work is done by the system. I mean the molecules are doing work and even when they do work, their energy is going down. This energy going down is reflected in the temperature decrease and when the parcel sinks what happens exactly opposite will happen? When the parcel is sinking, its volume is decreasing.

That means, if the volume is decreasing, why is this volume decreasing? It is decreasing to compensate or to counter the pressure that is more on the outside; that means, that the molecules now are travelling even more faster the work is done on the molecules when the molecules are travelling faster their kinetic energy is more. Then when their kinetic energy is more, it also reflects by on its temperature becoming more.

So, here the sinking air parcel warms . So, the temperature will increase and the internal energy of the system will also increase in proportion to the temperature increase. And in this case work is done on the molecules of the air parcel by the atmosphere. In the earlier case work is done by the molecules of the air parcel right. So, this is the basic difference.

So, what you can understand from this is that when you take an air parcel above let say into the atmosphere with the with respect to the height, then this air parcel will of course, expand and its temperature will decrease. This is the mechanism; this is the third important step or third important constituent in the formation of clouds because we require lower temperatures to be present for the formation of clouds.

So, how do you get lower temperatures? you can get lower temperatures by rising an air parcel from the ground to a higher altitude right. So, this process is very much essential for the formation of clouds. Now, so decrease of temperature is also given with a very important physical parameter which is called as the lapse rate. Lapse rate gives you the amount of temperature decrease if you travel into the atmosphere with respect to height.

So, how many degrees of Celsius; let say the temperature will drop by when you travel a certain distance is generally given as lapse rate. So, this lapse rates are very I mean there are variety of lapse rate, there are dry lapse rates, there are moist lapse rates things like that.

Now, lapse rate is always the decrease in the temperature, but not increase in the temperature. Lapse rate you should always remember that lapse rate always gives you how much will be the temperature decrease when you travel a particular distance into the atmosphere vertically upwards let say.

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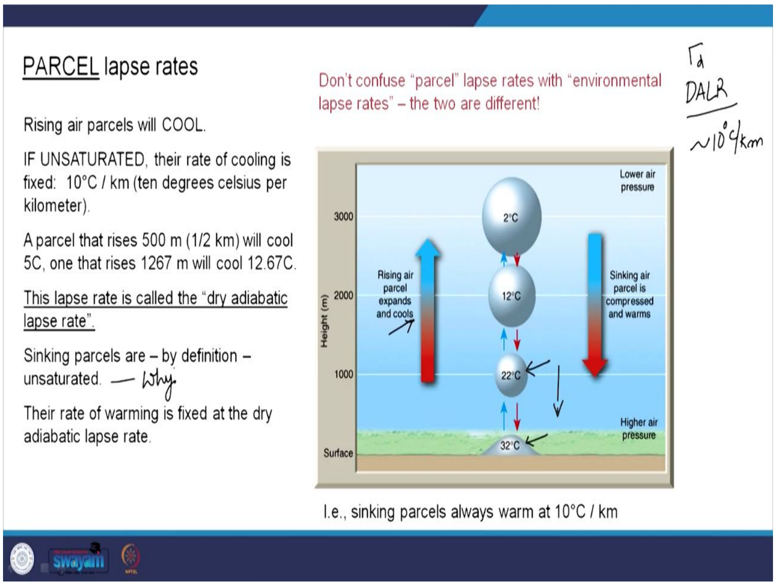

So, the rising air parcels will cool. Now, if the air parcel is unsaturated like we started in the beginning, the rate of cooling that you can get by rising. It is fixed. this is called as the dry adiabatic lapse rate the rate at which the temperature decreases when you travel upwards is called as the dry adiabatic lapse rate ok.

So, this is approximately 10 degree Celsius for every kilometer that you travel upwards. So, when you travel 1 kilometer the temperature would have already decreased by 10 degree Celsius. Now, a parcel that rises for example, a parcel that rises 500 meters which is a half a kilometer will cool by 5 degree Celsius. And let us if you make a similar relation a parcel that will rise 1267 meters will cool by a temperature of 12.67 degree Celsius ok.

So, this lapse rate is called as the dry adiabatic lapse rate. So, you always remember this this is also given by gamma d; gamma d is the dry adiabatic lapse rate ok. So, now, if you see this picture what you see is let say this thermal bubble that is originating at the surface is at the 30 degree Celsius. When it rises by 1 kilometer 1000 meters, its temperature has come down to 22 degree Celsius right.

Now, this the air parcel is still unsaturated; that means, getting saturation severely affects the rate at which the temperature decreases within the air parcel that is a difference story, we will get there right. So, rising air parcel generally expands as it rises and it results in cooling very good and sinking air parcel. If you bring the air parcel again downwards; if you bring this air parcel downwards, the temperature will increase now. How will it increase? It will increase at the same rate ah, let say 10 degree Celsius per kilometer.

So, the sinking air parcel are by definition are unsaturated and their rate of warming is fixed at the dry adiabatic lapse rate right. So, the sinking air parcels are by definition unsaturated I mean this is a very important question. So, why is that sinking air parcel are by definition unsaturated? See theanswer to this question is that you want to reach saturation when you decrease the temperature of the air parcel.

The means by which you can reach saturation, how do you achieve decrease in temperature, you can achieve decrease in air parcel temperature only by rising it. If the air parcel is sinking; that means, if it is coming down it is clearly departing away from the saturation; that means, the parcel is unsaturated. So, as simple as that ok.

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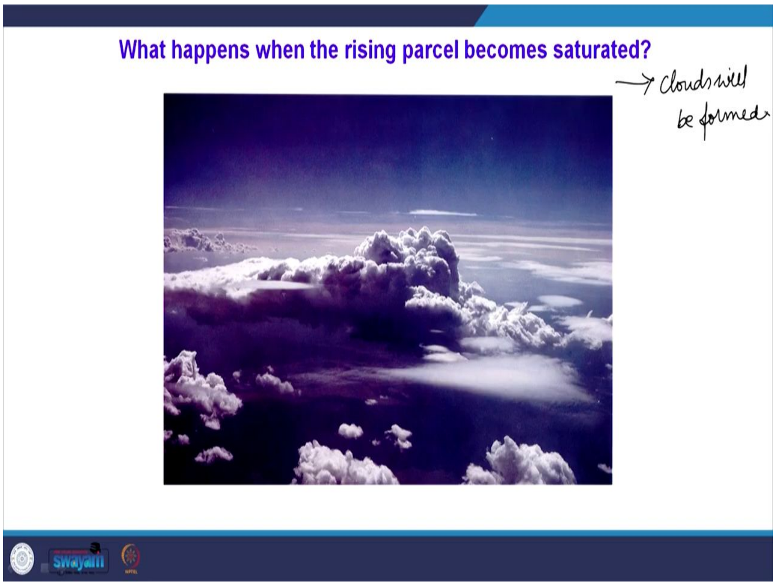

Now, what will happen when the air parcel become saturated? see, air as long as it is in the gas phase it is it is something that you would not see optically it is transparent right, but when it become saturated it condensers. And when condensation happens, it will form or there will be phase transition from the gas phase to the liquid phase. Liquid phase in the sense tiny droplets of water will be formed and this tiny droplets of water or the collection of this very very small or tiniest droplets of water is called as a cloud.

So, what happens when the air parcel become saturated? The answer to this is clouds will be formed right.

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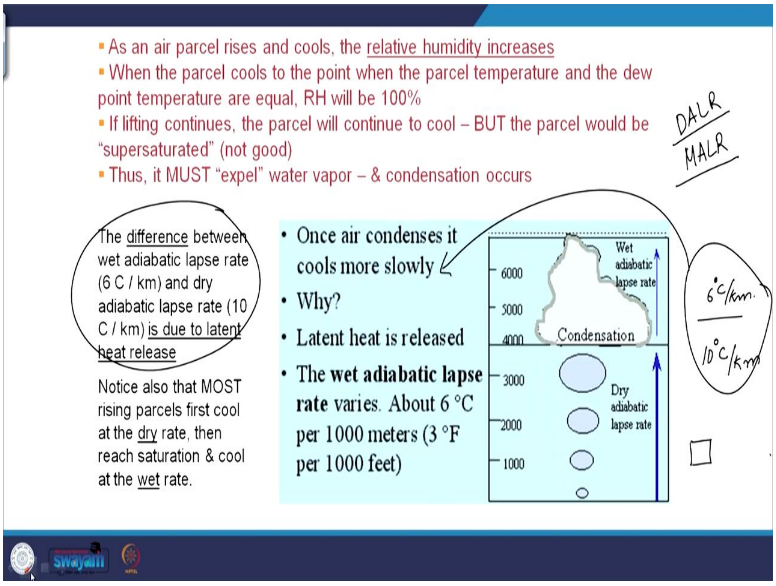

Now, let see what else is there about this cloud formation. So, as an air parcel rises and cools or let say rises and cools, the relative humidity increases of course. So, when the air parcel cools to the point that the parcels temperature and dew point temperature are equal, then you say that the relative humidity is 100 percent. If you continue lifting it even beyond this particular point, the parcel will continue to cool, but the parcel would be supersaturated which is not good or which is not favorable for the formation of clouds.

So, thus it is must to expel water vapor and expel water vapor and by the means of expelling water vapor, you are talking about the formation of clouds; so, which is the favorable condition for the formation of clouds. Now, the difference between the wet adiabatic lapse rate is 6 degree Celsius and dry adiabatic lapse rate is 10 degree Celsius.

So, this is a very very important aspect I mean dry adiabatic lapse rate is so long, when the saturation is not reached, but when the saturation is reached you call it as MALR which is called as moist adiabatic lapse rate, . We have seen that the moist adiabatic lapse rate will be less than the dry adiabatic lapse rate. Why does it happen?

So, up to a particular point before condensation happens, the temperature is decreasing at 10 degree Celsius per every kilometer. After this particular point the temperature decreases at a rate of nearly 6 degree Celsius per every kilometer. So, there is a difference I mean why the rates are different let say. So, once air condense just it cools more slowly so; that means, the consequence of this is that after condensation, the air will cool more slowly.

So, why I mean why is this happening? So, now, the point is , let say if the answer to this question is very simple why does the rate decrease?

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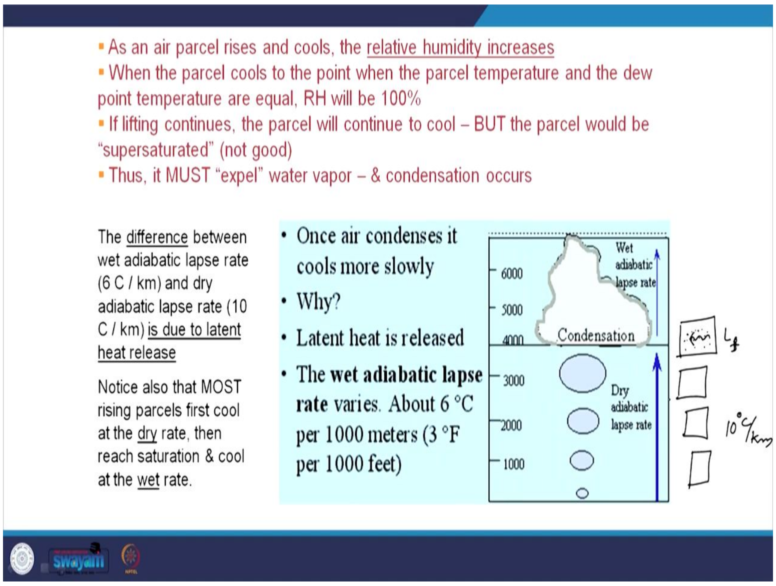

Now, let us consider an air parcel here right. Now, this air parcel as it goes is expanding and its temperature is decreasing at 10 degree Celsius per every kilometer fine. As it travels to a particular point, it reaches saturation and tiny droplets of water will be formed which we call as clouds.

Now, at this point of time due to the property of water to be existing in different phases and transforming from one phase to another phase depending on the conditions of pressure and temperature, there is something called as latent heat of condensation . So, when the water condenses, it will release some heat into the parcel. So, now, the temperature is decreasing at a particular rate, then at certainly at a particular point there is an amount of heat that is added to the system. So, the temperature decrease is now countered by the temperature increase.

So, due to this two factors acting in the opposite direction, the temperature decrease after reaching saturation will be lesser in comparison to the temperature decrease before reaching saturation this is the difference why the temperature will decrease at 10 degree Celsius per kilometer below the particular altitude. And after this it decreases at 6 degree Celsius per kilometer and most importantly this is the reason. So, now you should also notice that most rising parcel first cool at dry adiabatic lapse rate, then reach saturation and then cool at the wet rate (Refer Time: 20:42) ok.

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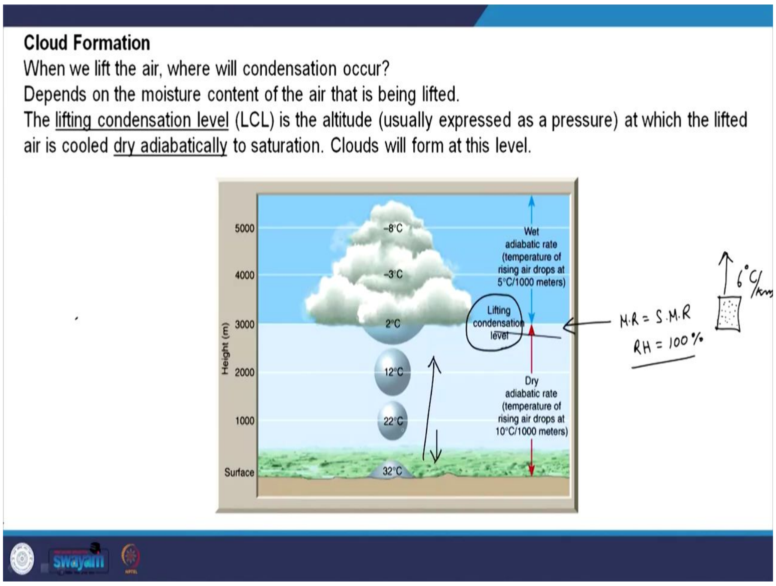

So, what is idea of cloud formation now? Cloud formation is an aspect which happens when the air become saturated. Now, if you see this picture what you see is the air is forming into a bubble let say as it rises you are able to see that the temperature is decreasing at a rate of 10 degree Celsius per every 1000 meters right.

So, this is the point where mixing ratio is equal to saturation mixing ratio or this is the point where the relative humidity is 100 percent; that means, this is the point by decreasing the temperature you are able to reach a height at which the air is saturated. What is the immediate consequence when the air is saturated? the immediate consequence is it will it will allow condensation; condensation is the formation of clouds.

So, the height at which the air is saturated and allows condensation is generally called as the lifting condensation level. So, this is a very important definition in in atmospheric physics which is called as the lifting condensation level. Now, when the lifting condensation level happens, suddenly within the this particular air parcel that is a collection of tiny droplets of water right. After the formation of this tiny droplets of water, the air parcel will may actually continue to rise into the into the higher altitudes of atmosphere.

Now, surprisingly the temperature above this particular point above LCL will just be 6 degree Celsius per kilometer, but not 10 degree Celsius per kilometer. This is due to the addition of latent heat by the condensation of water vapor into liquid droplets. So, these are the basic ideas about cloud formation and how we can define various lapse rates, how this lapse rates are different and at which particular altitude the lapse rates will differ and what is the reason for them to differ right.

So, in the next class we will try to understand what will happen if the atmosphere is kind of stable, what kind of vertical movement of the air parcel is permitted in each of this stability condition. And more importantly we will try to understand this figure simply says that this air parcel is rising this figure simply says that this air parcel is rising in the altitude right.

So, we will we will try to look at the physical mechanisms which will allow this air parcel to rise. Something will not just rise in the atmosphere because this air parcel is rising against the gravity, I mean what could be the mechanism which could be driving this vertical lifting ok. So, we will try to understand all that in the subsequent classes ok, yeah.