Introduction to Atmospheric and Space Sciences

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Lecture – 36
Measuring Precipitation

Hello dear students. So far we have learnt what is precipitation, when does it precipitate and in how many different ways it precipitates. Let us try to understand how precipitation can be measured, what are the relevant equipment that we can use to measure precipitation then we can understand how a particular droplet which is the cloud droplet grows in size to become a rain droplet.

We will also try to understand what factors influence in the formation of rain droplet or what factors will probably not saying as influence, we can say that what factors will accelerate the growth of rain droplet or what factors will decelerate the growth of droplet right.

So, when it comes to measuring precipitation generally, we talk about let us say how much amount of rain has occurred, how much water has been delivered. Let us say this is the idea that let us quantify this much has rained in millimeter or in centimeter or in cubic volume right. So, liquid precipitation is generally measured in 100s of an inch so the basic unit ok. So, rain gauge it is typically the equipment or the apparatus that you use to measure the amount of rain.

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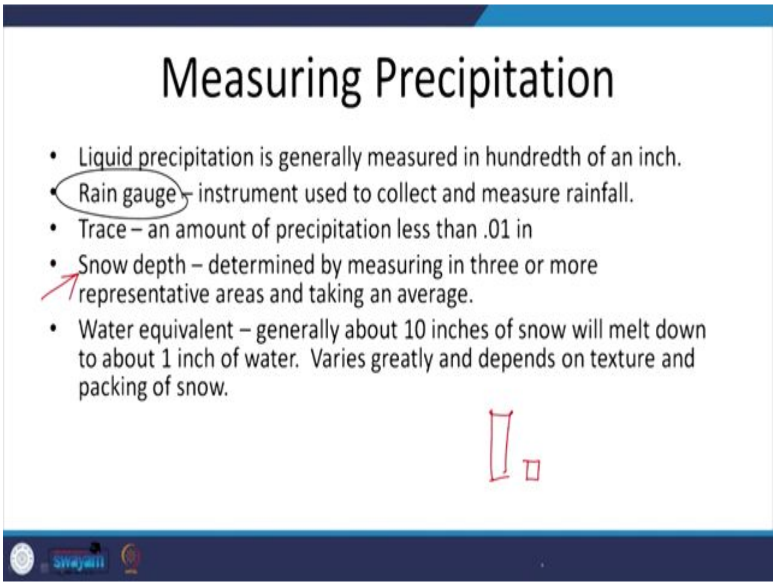

So, this is the instrument that is used to collect and measure rainfall. So, this will not be able to tell you how much has it rained per second or per hour. It will be able to tell you over the given period of time how much has it rained. So, on a typical calibrated surface let us say how much has it rained right. So, let us say an amount of precipitation which is less than 0.01 inch right.

Let us say if you want to quantify snow, if you want to quantify, just like you have quantified the rain in the units of inches you can also quantify this snow how much amount of snow has happened. So, determined by measuring in three different or more different areas; let us say how the depth of snow that has occurred over a period of time then you take an average right. So, what is the equivalence between the amount of snow and the amount of rain?

So, water equivalent generally about 10 inches of snow in a calibrated area will melt down to 1 inch of water. So, this is a very usual conversion unit and this varies greatly and depends on texture and packing of the snow naturally right. So, how do you pack the snow over 10 inches if you say you can pack any amount if you keep compressing the snow and then the conversion will be different right.

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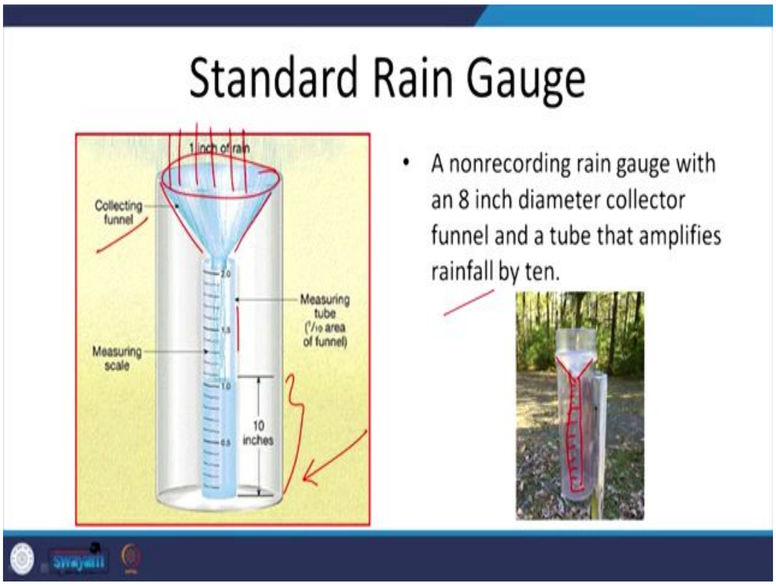

So, the standard rain gauge is the instrument which is used to measure the average amount of rainfall. So, what does it contain; it contains a small measuring tube on which the scale is drawn an inches let us say how many inches or whatever it is. And you have you call this as a measuring tube where the water is collected with the help of a let us say a funnel and whose diameter is mentioned diameter is given .

So, this is the collecting funnel which collects the water, this has to be obviously, kept outside where it rains right. So, a non recording rain gauge with an 8 inch diameter collector funnel and a tube that amplifies the rainfall by ten. So, this is the basic description of the equipment. So, this is where it is raining and it will keep collecting the rain and over a particular time period you will know at the end how much has it rained.

So, you keep it in the night and then you say that in the morning that it has rained 2 inches let us say 2 inches or 2 centimeters or to 20 millimeters or anything right. So, this is the typical schematic of the standard rain gauge and in the actual practice it looks something like this. So, you have you see the funnel here where the rain is getting collected and then it is filled into this measuring tube on which always there is a calibration right. So, you keep it anywhere that you want to measure the rain.

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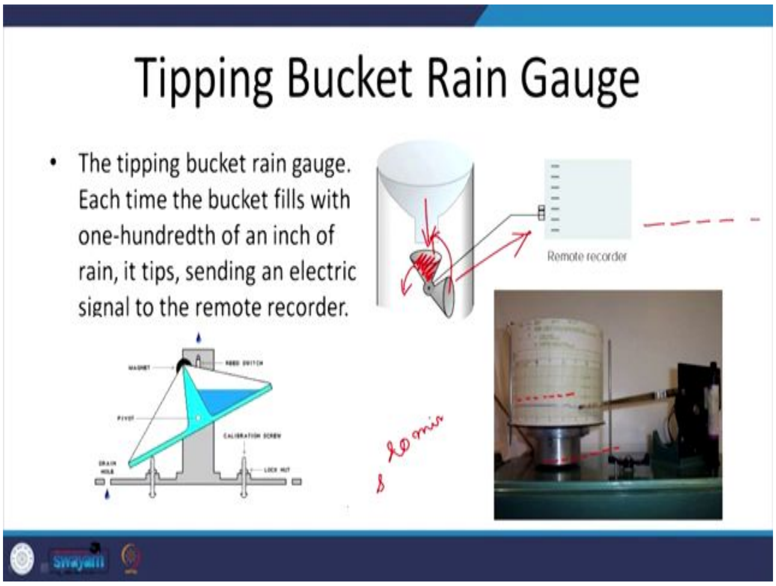

And another way of measuring the rainfall or the rate of precipitation, the rate of precipitation is let us say if it rains for 1 hour; how much has it rained per minute is the rate of precipitation. So, one very famous or very well known equipment very well known instrument; is the tipping bucket rain gauge. In which what you have is you have water being dispensed into these buckets which can tip in the sense when once this bucket gets filled this will tip in one direction getting this other bucket into the place of water dispenser right.

So, this every time when this bucket tips it will send a signal to the remote recorder it will mark one unit. So, the when another bucket tips one unit like this. So, you have this plotter which keeps plotting one division every time the bucket tips. So, what does it indicate? So, for a given amount of time let us For 20 minutes you will see how many divisions that you can see on the plotter.

And by knowing the how much amount of water is dispensed in each bucket you can understand you can calibrate it is such that how much amount of rain has occurred for a minute or for an hour anything right. So, this is where you can measure the total amount of precipitation over a period of time and also calculate the average rate with which rain is precipitating over a given period of time right. So, the tipping bucket rain gauge each time the bucket fills with one hundredths of an inch of rain it tips sending an electric signal to the remote recorder.

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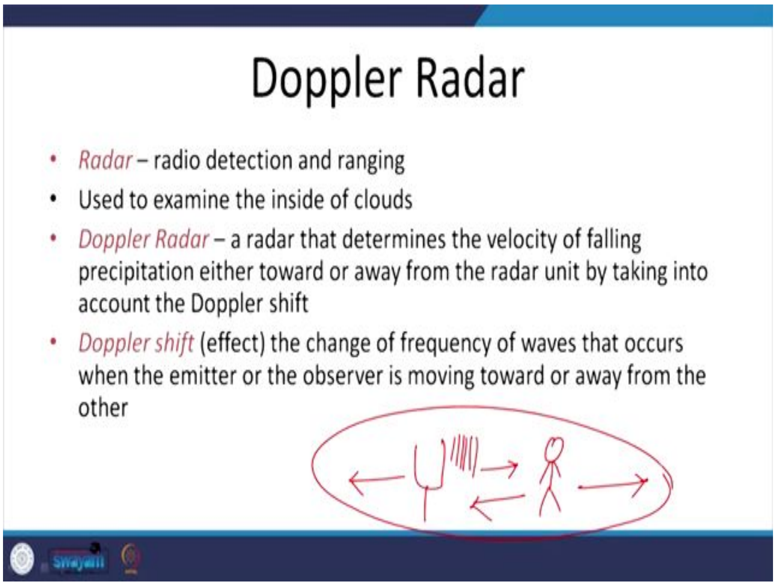

So, this is what the basic working of a of a simple tipping bucket rain gauge right. A more accurate or more scientific method of a measuring rain or precipitation is with a Doppler radar. So, what is a radar? Radar is a is an instrument which uses the technique of radio detection and ranging. So, basically it sends out radio waves and depending on the reflection of these radio waves and when they travel back. The average time delay tells you so many things about what you are having in your surroundings right.

So, Doppler radar it can be used to examine the inside of the cloud. So, how much amount of water is present inside a cloud and all these things can be calculated or can be measured using a Doppler radar. A radar, determines the velocity of falling precipitation either towards or away from the radar unit by taking into account the Doppler shift. So, by using the Doppler shift you can calculate, what is the rate at which the precipitation is happening; what is the velocity of the droplets things like that.

So, Doppler shifts, what is Doppler shifts? So, Doppler shift is the change in the frequency of the waves when does this change, occur change occurs when emitter or observer is moving towards or away from the, from the from the source. Let us say you have a source like this and you have an observer like this. So, if this is emitting signal, the change in the frequency when the observer moves towards the source or when the source moves towards the observer or when the observer moves away from the source or when the when the source moves away from the observer, in all these 4 different cases or as a matter of fact things happening simultaneously there.

Let us say for example, source and observer are independently moving away from the each other or independently moving towards each other and the observer is moving away from the source, but source is moving towards the observer in all these cases the frequency that is going to be observed by the observer will be different than the actual frequency. The shift that comes into picture is called as the Doppler shift that is it.

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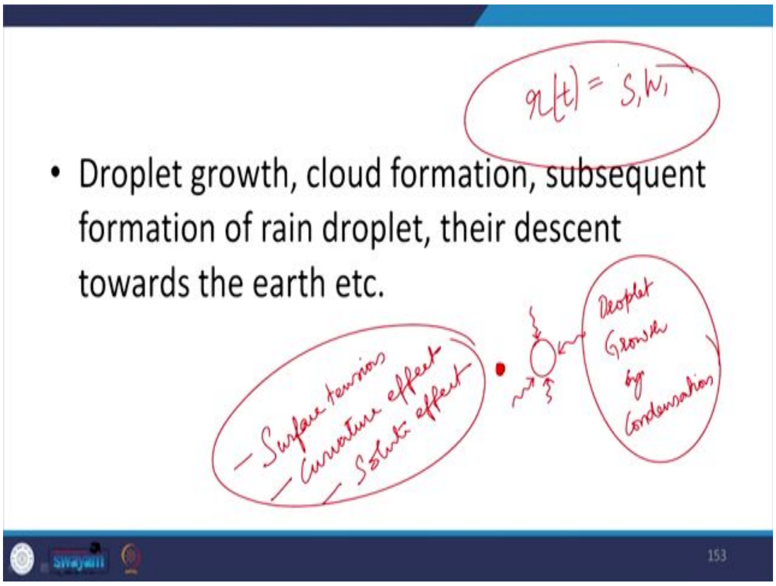

So, Doppler radar is a more accurate way of measuring various parameters related to clouds the amount of precipitation that can be expected or the amount of the rain or the cloud cover so many other things right, so that was something about the basics of how the rain could be measured right. Now we will see what are the physical processes which play a very important role in deciding the precipitation rate, or in deciding how much amount of vapor will form or will condense to form a droplet.

So, this will be topics related to droplet growth cloud formation or subsequent formation of rain droplets or they descend towards the earth. So, we will try to understand what it takes for this very small droplet which is the cloud droplet to grow the size of rain droplet when water vapor condenses into it right. So, this regrowth is called as droplet growth, this growth is called as the droplet growth by condensation, growth by condensation.

So, we will try to understand what is this process and how this process is controlled by things such as let us say surface tension. So, what is the role of surface tension what is the curvature effect we will try to understand what is the curvature effect we will try to understand what is the solute effect and then we will try to understand how we can bring them altogether by simple mathematical derivation. So, that we can say what is the rate at which the radius of the droplet grows with respect to time.

That means if we are able to write down a relation for the radius of the droplet as a function of time and write this relation in terms of parameters. Such as let us say what is the amount of saturation? What is the amount of moisture content? What is the amount of humidity? What is the role of dew point temperature so on so forth then our object to is done. So, we will lead towards the mathematical treatment of the droplet growth by condensation right.

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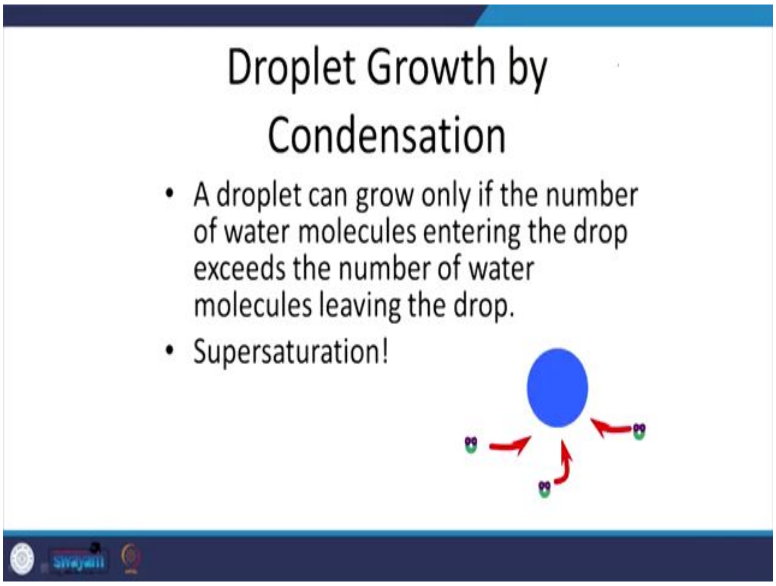

So to be able to do that let us start from the from few very basics let us say. So, droplet growth by canonization a cloud droplet can grow only if the number of water molecules that are entering into the droplet, exceeds the number of water molecules leaving the drop; obviously. So, at any given point this droplet is of course, is in the ambience of the atmosphere. So, the atmosphere is existing at a particular temperature.

So, this particular temperature the water molecules are of course, trying to get into the droplet. So, they have to cross the surface tension barrier anyway there is a different story, but they have to cross and they have to get into the droplet. Now if that that has to happen.

So, this droplet is in the ambiences as and is always evaporating; that means, there are few water molecules which are always trying to escape away from this drop.

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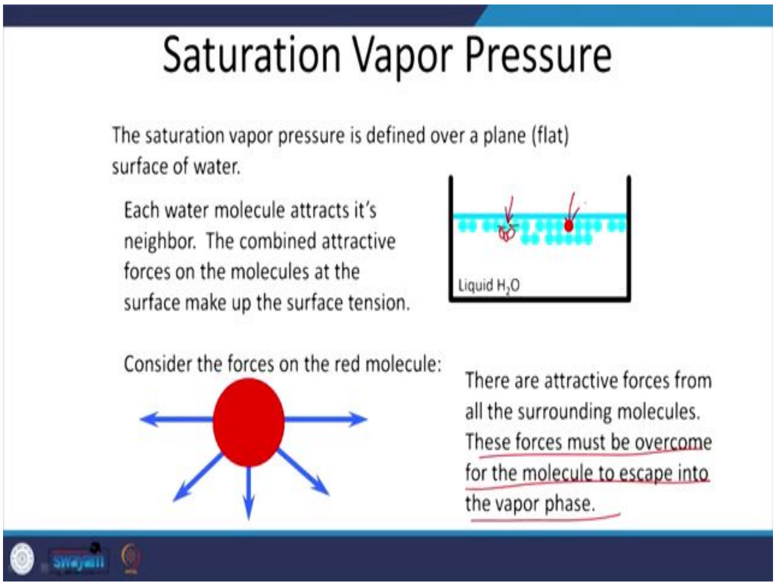

So, when these two rates are equal the water droplet will never grow and when it is more than that it will grow; obviously, right. So, you call this particular point as let us say saturation and you define saturation vapor pressure as let us say with respect to a plane surface of water. So, while we were defining a various moisture parameters we made a remark saying that we are defining the saturation vapor pressure with respect to plane surface of water or plane surface of ice that is very important in the sense that we do not talk about the role of curvature.

I mean how curvature will increase the overall area over which molecules are separated let us say. So, each water molecule let us say if you have a surface each water molecule attracts its neighbor. So, you consider any molecule here it is attractive it is attracting this one and this one or let us say this one or this one or this one like that. The combined attractive forces on the molecules at the surface make up the surface tension right, surface tension. We already know for very basics that what is surface tension right.

So, we let us consider the forces on the red molecule. So, you consider this molecule which is given here the red molecule. So, there are attractive forces from all surrounding sites molecule these forces must be overcome for the molecule to escape into the vapor right. So, if this molecule is to be taken out I mean if it wants to evaporate into the vapor phase then it has to overcome the binding forces that are by the neighbors right obviously.

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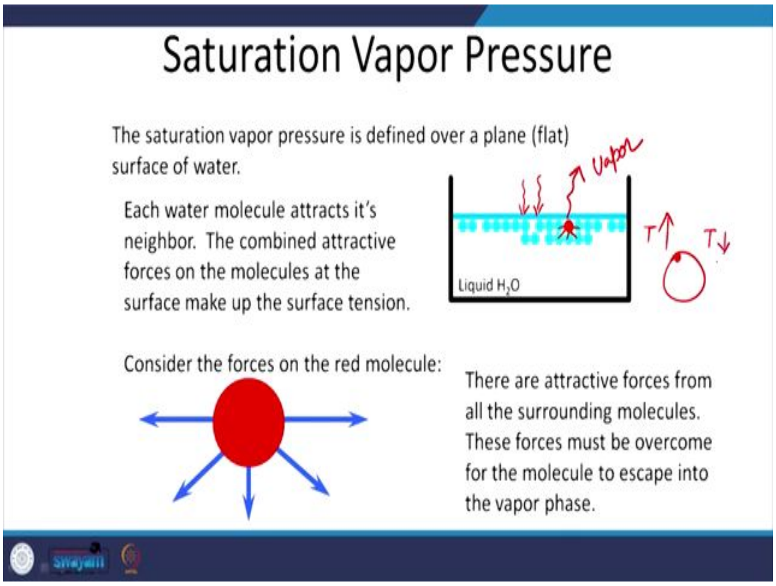

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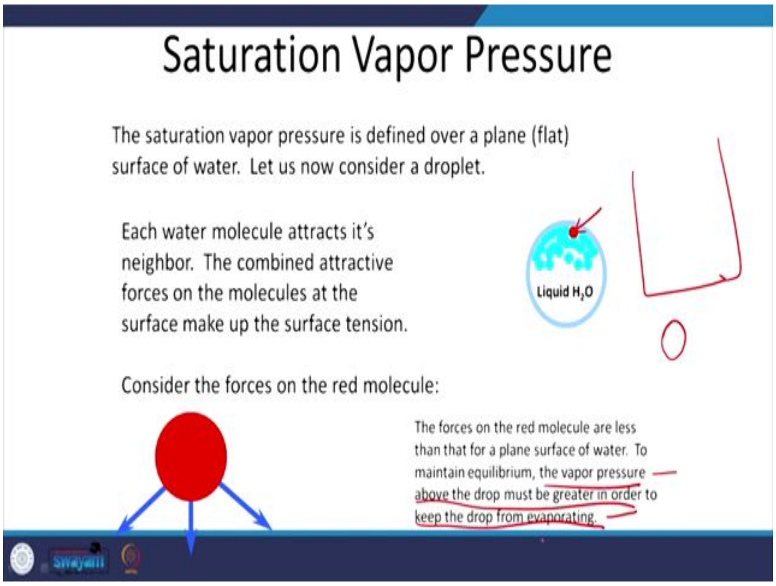

So, the saturation vapor pressure is defined over a plane surface of water if you do that. Now what is saturation vapor pressures . So, this is a vapor that is existing here and this is the liquid. So, the vapor is exerting some pressure on the surface right. When do you call it saturation when the rate of evaporation and the rate of condensation are equal you call it as the saturation. And the obviously, the pressures that is exerted at that point is the saturation vapor pressure over a plane surface of water.

Now, let us see the same situation in a droplet. So, you do not have a beaker in which you have kept the water rather you have a droplet in which there are many number of molecules. So, now, let us consider one molecule again our target is this red molecule the saturation vapor pressure that we define was with respect to the plane surface of water. So, now, here in this case each water molecules attracts its neighbors I mean the idea of force is still the same each molecule attracts its nearest neighbors.

So, the combined attractive forces on the molecules of the surface make up the surface tension again. So, consider the forces on the red molecule; the forces on the red molecule are less than that for a plane surface of water. I mean visually you can appreciate the fact that it is sharing neighborhood with little or less number of molecules in comparison to the case where it was in the plane surface of water right. So, the molecule is bound by attractive forces to a lesser extent.

So, to maintain equilibrium the vapor pressure above the drop must be greater in order to keep the drop from evaporating right. So, vapor pressure from the other side right the vapor pressure above the drop must be higher in order to keep the drop from evaporating. So, we do not want the droplet to evaporate and become gas right. So, that is why the vapor pressure must be greater than the magnitude.

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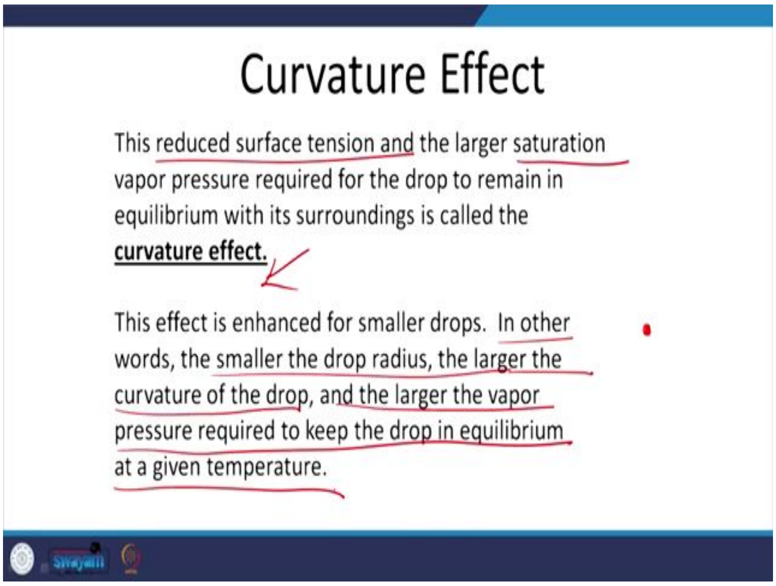

So, the reduced surface tension and the larger saturation vapor pressure required for the drop to remain in equilibrium with its surroundings is called as the curvature effect. So, this is the basic idea is surface tension. So, the idea of surface tension here over the surface of plane surface of water was that, this molecule is attracted by many molecules right. So, the surface tension is let us say is larger in this case when it is a droplet each molecule is not sharing its neighborhood with many molecules.

So, as a result the surface tension in this case is lesser when it is a droplet right. Now, so this is one aspect about the surface tension. Now when you extend this aspect towards the vapor pressure as such let us say, what happens? So, in the plane surface of water because the surface tension is larger you need more amount of energy to be given to the molecule to be able to evaporate right.

But when you draw the same analogy onto the droplet you will need less amount of energy for the molecule to evaporate; that means, the surface tension has to be more to be able to stop the molecule from evaporating right. So, this effect which comes into the picture although it is a single phase I mean only water even in the surface or in the droplet just because of the curvature that is brought into the picture the saturation vapor pressure will be lesser in this particular case.

So, the reduced surface tension and the larger saturation vapor pressure required for the drop to remain in equilibrium with its surroundings its called as the curvature effect. So, the effect is enhanced for smaller droplets in other words the smaller droplets the smaller the radius of the droplet, what happens? Smaller is the radius of the droplet automatically the average number of molecules a molecule will be attracted when the droplet becomes even smaller the average number of molecule each molecule will share a boundary or neighborhood will be even smaller that means the surface tension will even be smaller right.

So, the effect is enhanced for smaller drop in the sense that in other words the smaller the droplet radius the larger the curvature of the drop and the larger the vapor pressure required to keep the drop in equilibrium. That means, you have to have more amount of vapor pressure to be able to keep the droplet intact. If you want to evaporate it then we are looking in the other direction we do not want to discuss this right.

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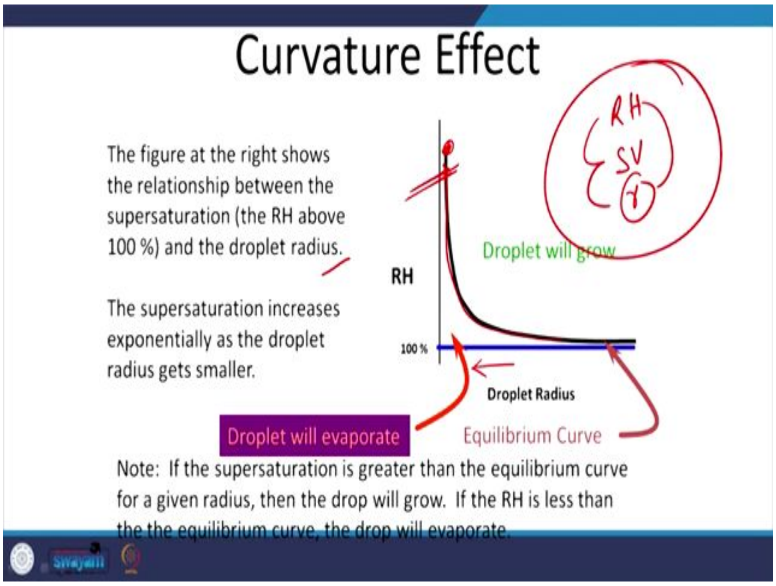

So, the curve is this effect is called as the curvature effect. So, the figure that on the right hand shows the relation between the super saturation and the droplet radius. So, what is super saturation? Super saturation is the idea when the relative humidity crosses 100 percent a. The super saturation increases exponentially as the droplet radius gets smaller.

So, this is a small droplet radius and the super saturation increases exponentially this is the exponential growth that you see. So, eventually at this when the super saturation increases to very large values at this heights at this relative humidity automatically the droplet will evaporate. So, if the super saturation is greater than the equilibrium curve for a given radius. So, the radius is optimized against the relative humidity the relative humidity is optimized against the saturation vapor pressure right.

So, the relative humidity, the saturation vapor pressure, and the radius of the droplet these 3 are interconnected in the sense I mean one has to do; obviously, with the other right. So, these 3 create what is called as the curvature effect. So, if the super saturation is greater than the equilibrium curve for a given radius then the droplet will grow. If the relative humidity is less than the equilibrium curve and the droplet will evaporate right.

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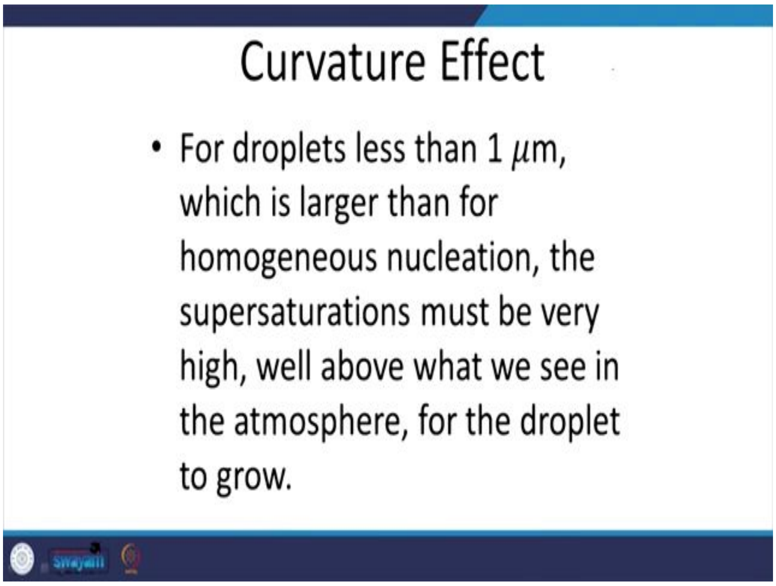

So, for droplets whose size is less than one micrometers which is larger for homogeneous nucleation. The super saturation values must be very high well above what we see in the atmosphere for the droplet to grow. So, this is in the case of homogeneous nucleation; homogeneous nucleation is the one which happens in the absence of any cloud condensation nuclei or any foreign particle. So, this is the case of homogeneous nucleation.

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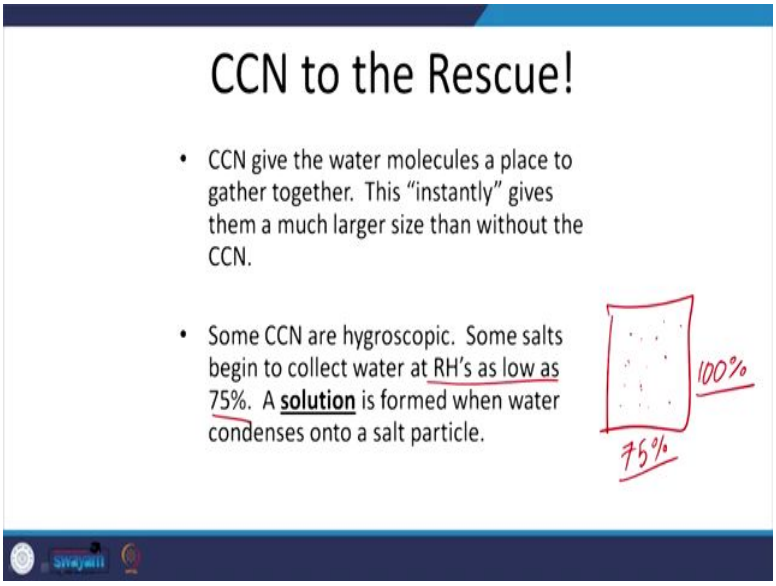

But in reality we would never realize the homogeneous nucleation because it happens nearly at 400 or 500 percentages for RH which do not really exist right. So, before the saturation reaches that particular point we always have the cloud condensation nuclei existing in the atmosphere; that means, we never have an ideal or a perfectly clean atmosphere where the atmosphere is completely devoid of the cloud condensation nuclei.

So, cloud condensation nuclei comes to the rescue and form the droplets. So, the cloud condensation nuclei give the water molecules a place to gather together; that means, a place to fall on to right this instantly gives them a much larger size than without the cloud condensation nuclei right. So, there is some cloud condensation nuclei are hygroscopic I mean they have the tendency to dissolve in water they have the tendency to be attracted with water. Some salts begin to collect water at relative humidities as low as 75 percent itself.

So, you keep the water droplets you keep some cloud condensation nuclei 100 percent of course, it is understandable, but within just nearly 75 percent itself these small particles will start attracting the water molecules and once they start attracting the water molecule it will add in the formation of droplets right.

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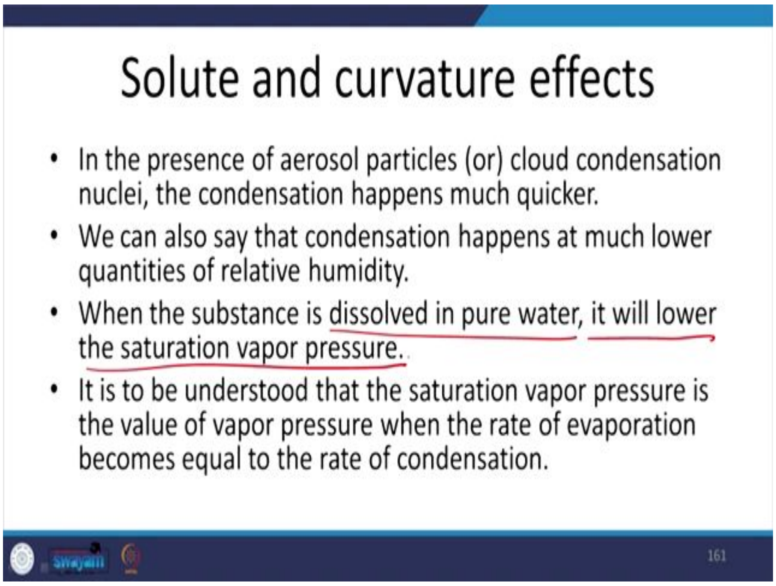

Now, we talk about what is called as the solute and the curvature effects. So, in the presence of aerosol particles or cloud condensation nuclei the condensation happens much quicker very fast. We can also say that the condensation happens at much lower quantities of relative humidity just like we see. We saw that at 75 percent itself some cloud condensation nuclei will start attracting the molecules right. When the substance is dissolved in pure water it will lower the saturation vapor pressure, this is where it starts becoming interesting in the sense.

When a substance is dissolved in the pure water, it will lower the saturation vapor pressure. Let us see how? It is to be understood that the saturation vapor pressure is the value of vapor pressure when the rate of evaporation becomes equal to the rate of condensation. The simple idea which we have spoken of many number of times just to be sure the vapor pressure the pressure that is exerted by the vapor over the surface of water when there is equal amounts of evaporation and condensation right.

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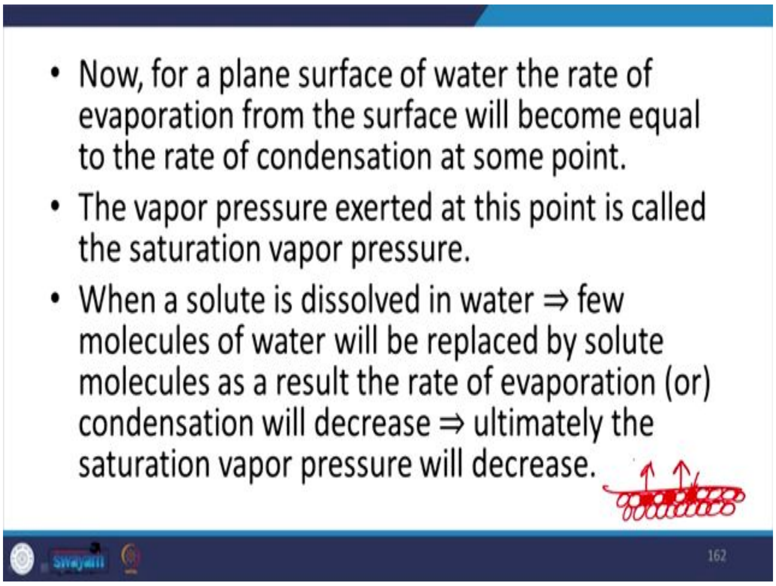

Now, let us imagine for a plane surface of water the rate of evaporation from the surface will be equal to the rate of condensation at some point which you call it as saturation. Now the vapor pressure exited at this point is called as saturation vapor pressure when a solute is dissolved in water you take any substance you dissolve it in water. if it is soluble you will get dissolved few molecules of water are kind of I mean they are replaced by solute molecules as a result the rate of evaporation of water molecules will eventually decrease right.

So, previously you had only water molecules at the surface right. Now these water molecules are the ones which will break free and evaporate right. Now, what happens if you replace these molecules with a solute molecule some of them, some of them not all of them. Now this molecules can; obviously, not evaporate this one only this one can evaporate right. So, what happens you are reducing the rate of evaporation; that means, you are pushing the saturation away.

So, you need more amount of time to build up so that the rate of operations and the saturation is reached right. So; that means, that ultimately the saturation vapor pressure is decreased. So, the point where you call it as saturation is now coming down. So, this is the basic idea of solute effect. So, water impurities and their effects on the evaporation rate comprises, what is called as the solute effect. So, some solute molecules occupy the surface sites that would otherwise be occupied by water molecules right some of them.

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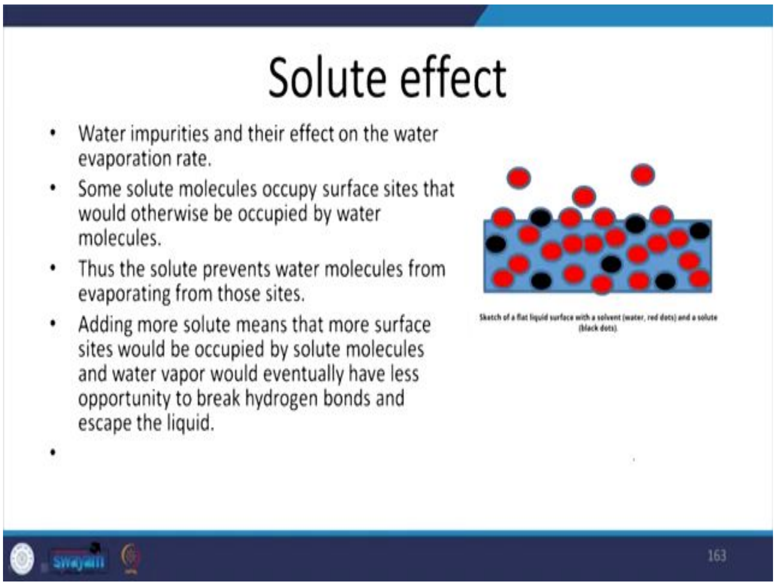

So, in this given diagram what you see is that the red circles are the water droplets and the black circles are the solute droplets. So, the surface is shared by both of them right. So, thus the solute prevents water molecules from evaporating from those sites; because the sites are occupied now by the solute. So, adding more solute means that more surface sites would be occupied by the solute molecules and water vapor would eventually have less opportunity to break the hydrogen bonds and escape from the liquid right.

So, this is the basic idea of the solute effect . So, because the evaporation rate is now lowered the rate at which the molecules are evaporating is lowered, which means that there will be net condensation until the water vapor flux to the surface matches the water vapor flux leaving the surface the basic idea is still the same right.

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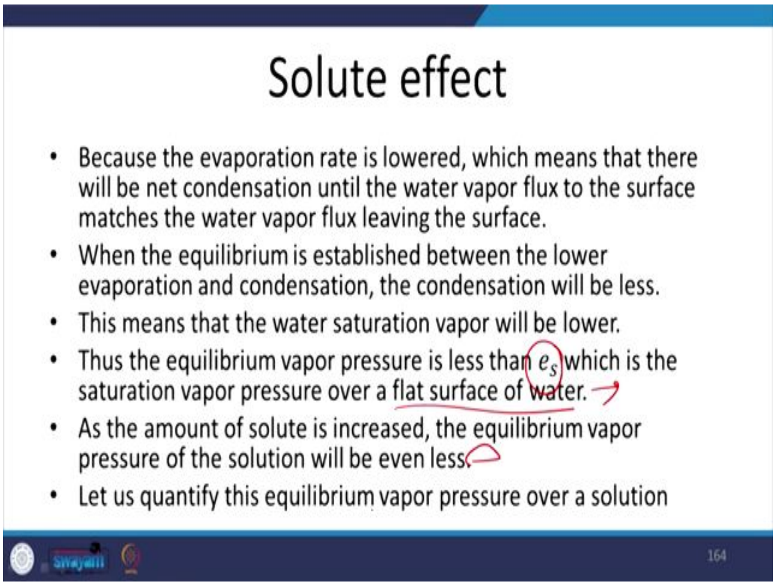

When the equilibrium is established any way between the lower evaporation rate and the lower condensation rate the condensation will also be less this means that saturation vapor pressure will be lower.

So, because of adding the impurities or any solvents what you have made is that you have brought down the level of saturation to a lower level. That is the equilibrium vapor pressure is less than e s, e s is the saturation vapor pressure in a pure atmosphere right which is the saturation over flat surface of pure water. So, as the amount of solute is increased the equilibrium vapor pressure of the solution becomes even less. Now let us quantify this equilibrium vapor pressure over a solution.

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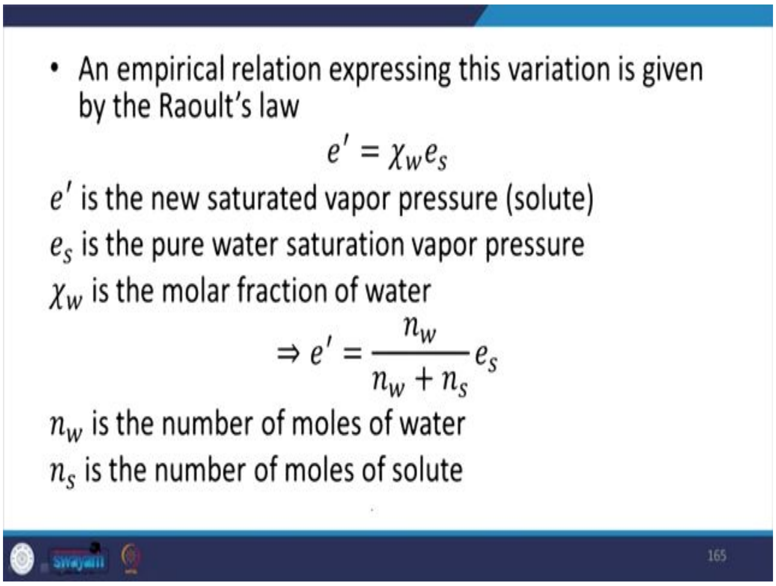

Let us say so we will take up this mathematical treatment in the next class. So, the basic idea of solute effect is that when you add solute to water the rate of evaporation will be lesser; proportionate to that the point of saturation will also be lower right. Now we will take up this solute effect and we will try to combine the solute effect and the curvature effect in a single picture. So, as to understand how these two inter competing processes will decide the rate of growth of a droplet by condensation.

So, we will stop this here we will try to see how solute effect and curvature effect which are kind of inter competing effects, how these two will contribute the overall growth of a droplet by condensation ok. So, we will continue this in the next lecture.