Refrigeration and Air Conditioning

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Lecture No. # 34

Psychrometry

Welcome back in today's lecture. I shall take up the subject of air conditioning and we begin this subject with the topic called psychrometry okay.

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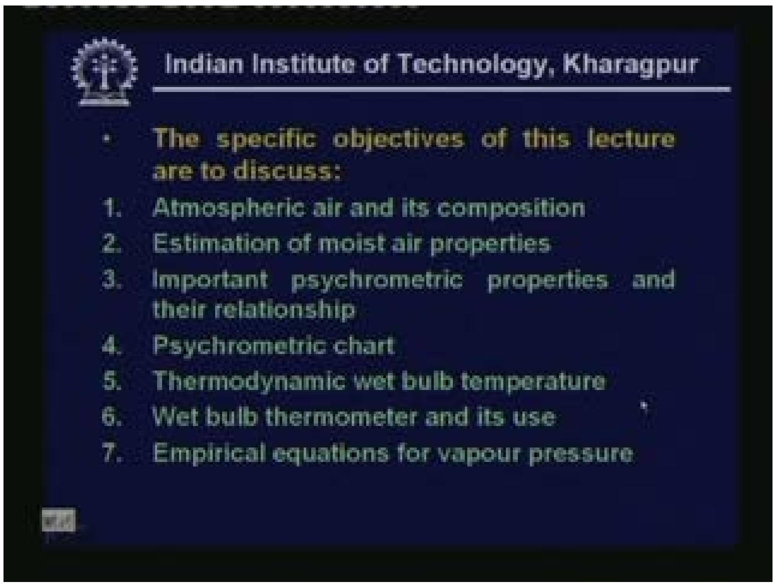

So the specific objectives of this particular lecture are to discuss atmospheric air and its composition, estimation of moist air properties important psychrometric properties and their relationship psychrometric chart thermodynamic wet bulb temperature wet bulb thermometer and its use and finally some empirical equations for vapour pressure.

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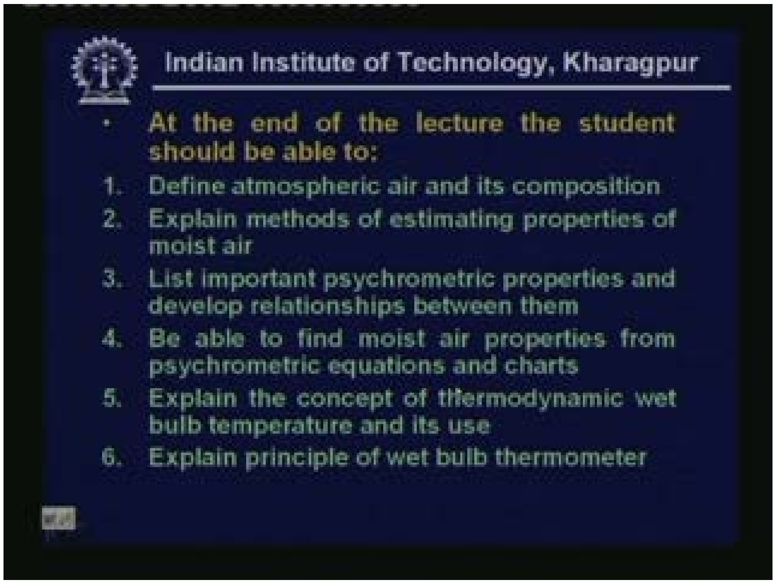

So at the end of the lesson you should be able to define atmospheric air and its composition, explain methods of estimating properties of moist air, list important psychrometric properties and develop relationships between them be able to find moist air properties from psychrometric equations. And psychrometric charts explain the concept of thermodynamic wet bulb temperature and its use and explain the principle of wet bulb thermometer.

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So we begin psychrometry with a small introduction atmospheric air makes up the environment in almost every type of air conditioning system a thorough understanding of the properties of atmospheric air and the ability to analyze various processes involving air is fundamental to air conditioning design Psychrometry is the study of the properties of mixtures of air and water vapour. This is very important topic and you must understand this topic thoroughly.

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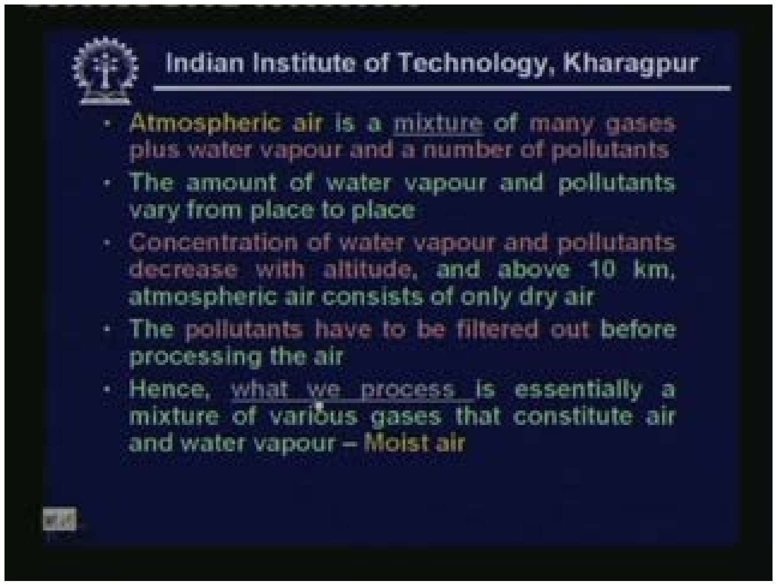

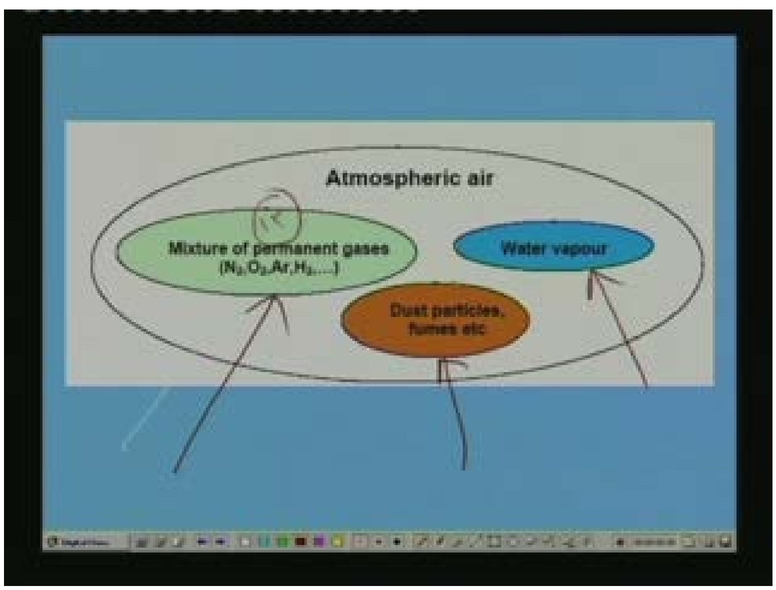

So first of all let us look at atmospheric air what is atmospheric air atmospheric air as you know is a mixture of many gases plus water vapour and a number of pollutants okay. That means you have a mixture of permanent gases okay. Like nitrogen oxygen argon hydrogen etc, there are almost about fifteen gases, it is said there are about fifteen gases okay. And you also have water vapour and you also have dust particles dirt particles fuels fumes vapors etc okay. So all these are taken together is what we call it as atmospheric air. The amount of water vapour and pollutants vary from place to place. However concentration of water vapour and pollutants decrease with altitude. And above ten kilometer atmospheric air consist of only dry air the pollutants have to be filtered out before processing the air hence what we process is essentially a mixture of various gases that constitute dry air and water vapour this mixture. That means the mixture of various permanent gases plus water vapour is called as moist air.

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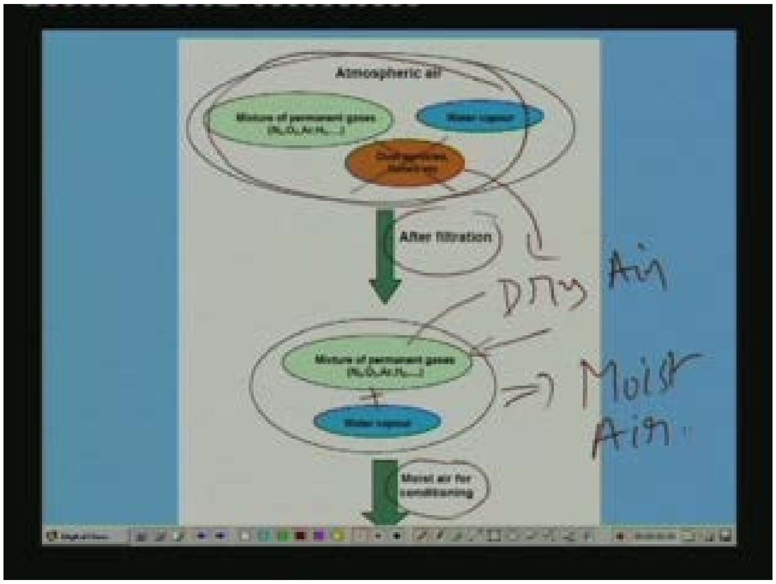

So as I said this entire thing is your atmospheric air but in a typical air conditioning plant what is done is first of all we filter this air okay. When you are filtering this air you remove the dust particles fumes etcetera okay. So once you removed dust particles fumes etcetera you are left with a mixture of permanent gases. And you call this portion that means the mixture of permanent gases as dry air okay, plus water vapour okay. So this is what is actually processed or conditioned in a air conditioning plant okay. So this mixture of dry air plus water vapour is send to an air conditioning plant for conditioning okay. So this mixture is called as moist air.

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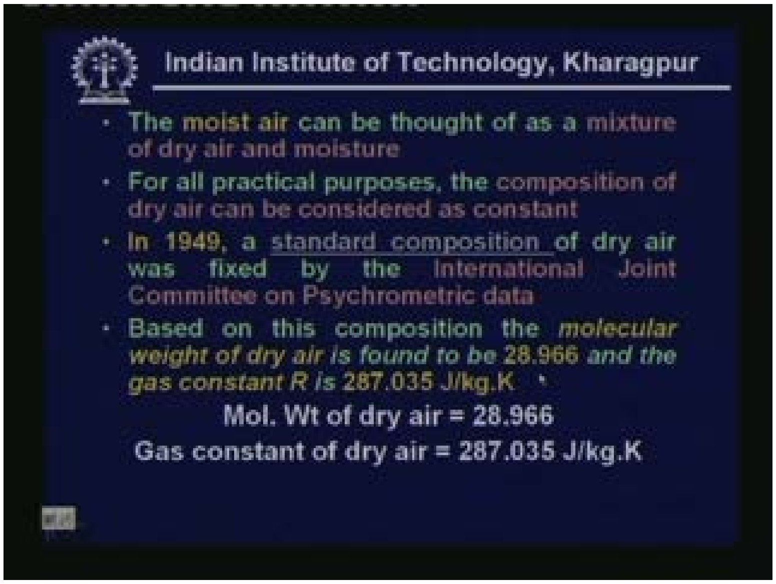

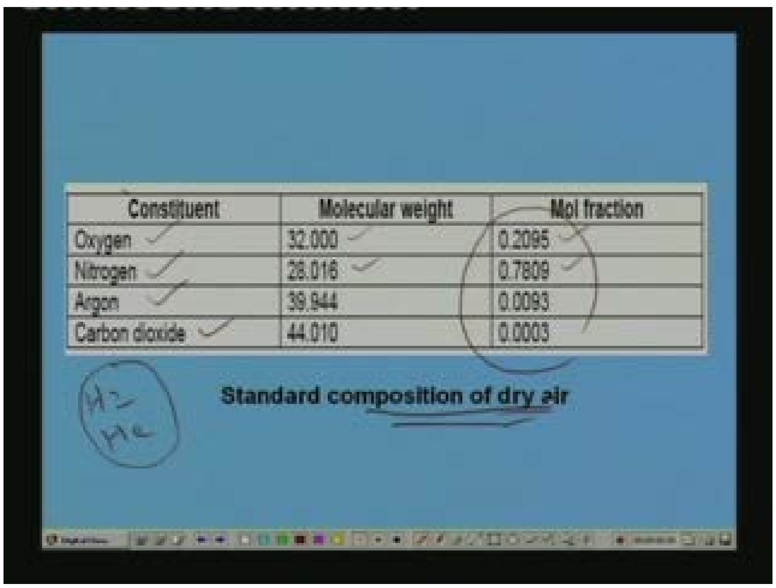

The moist air can be thought of as a mixture of dry air and a moisture. Moisture means water vapour for all practical purposes the composition of dry air can be considered as constant. It is observed that the composition of dry air remains almost constant. Wherever you go, that means it does not really vary with place to place or from altitude to altitude okay. So it remains more or less constant okay. So in nineteen forty-nine a committee was formed to find the, or to fix the composition of this particular dry air for calculation purposes okay.

So as I said a standard composition of dry air was fixed by the international joint committee on Psychrometric data okay. So what is this standard composition?

This according to this committee this is the standard composition of dry air okay. So it consists of oxygen it consist of nitrogen, it consist of argon and it consist of carbon dioxide. Of course it also consists of many other gases. Such as hydrogen helium etc but these gases the concentration of these gases are very small okay. So as a result it was decided by the committee that dry air means essentially these four components okay. And the properties of these components are as you know oxygen molecular weight is thirty-two and it is mole fraction in dry air is found to be point two zero nine five.

And nitrogen molecular weight is twenty-eight point zero one six. And it is mole fraction is point seven eight zero nine okay. And argon the molecular weight is thirty-nine point nine four four. It is mole fraction in dry air is point zero zero nine three and finally carbon dioxide molecular weight is forty-four point zero one. And it is concentration or mole fraction is point zero zero zero three in dry air okay. So this is the mole fraction of various gases in dry air okay.

So based on this composition the molecular weight of dry air is found to be twenty-eight point nine six six and the gas constant R is two eighty-seven point zero three five Joule per kg Kelvin. It is important to remember these values because we, I will be using these values in calculations okay. So molecular weight of dry air is twenty-eight point nine six six gas constant of dry air is two eighty-seven point zero three five Joule per kg Kelvin.

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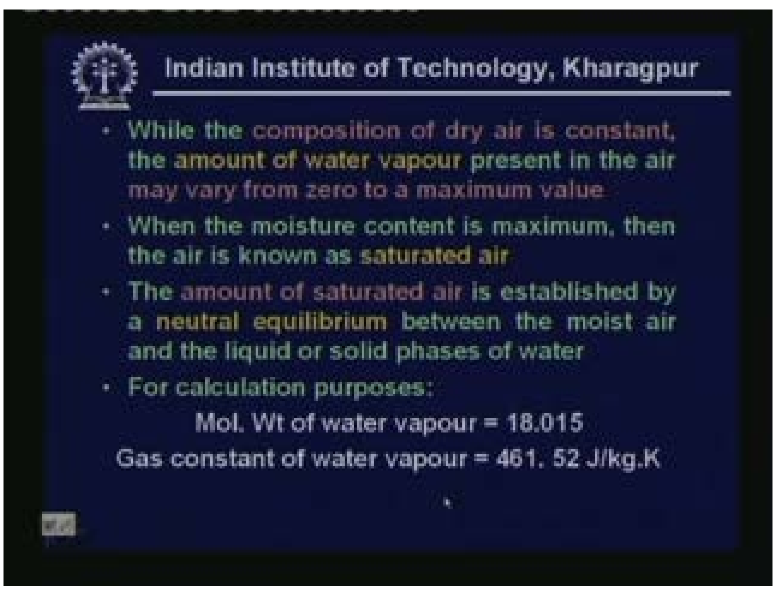

While the, as I said while the composition of dry air is constant the amount of water vapour present in the air may vary from zero to a maximum value. That means you can have a perfectly dry air okay. That means there is no moisture at all or you can also have a saturated air. That means air having a maximum amount of moisture. That means it can hold at a given pressure and temperature a certain maximum amount of moisture or water vapour okay. So this is the maximum that the air can contain okay. So the in a general the amount of water vapour in air can vary between zero to this maximum amount okay. When the moisture content is maximum then the air is known as saturated air. The amount of saturated air is established by neutral equilibrium between the moist air and the liquid or solid phases of water okay.

So when you say that air is saturated. That mean, the essentially, there is an neutral equilibrium between the moist air containing water vapour and water liquid or solids okay. That means equilibrium between liquid water and moist air or between ice and moist air. For calculatin purposes we can use take the molecular weight of water as eighteen point zero one five and the gas constant of water vapour as four sixty-one point five two Joule per kg Kelvin.

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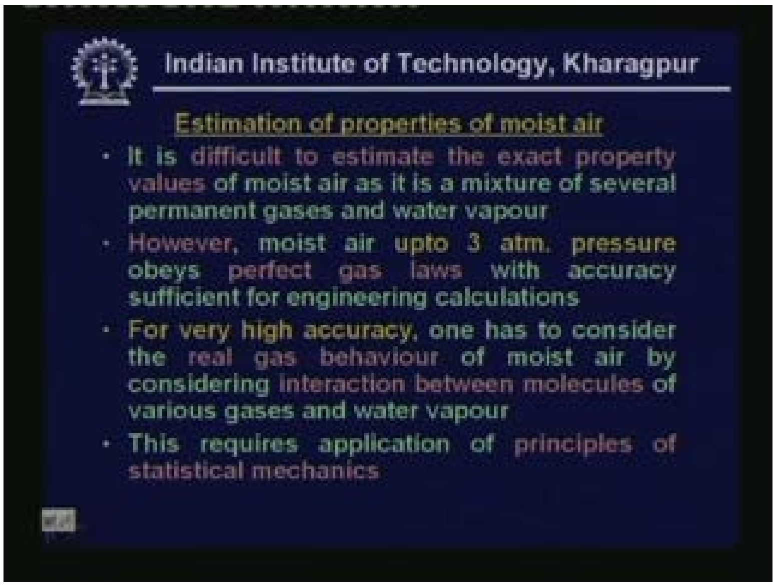

Now let us look at the estimation of properties of moist air. As I said in most of the time in air conditioning you will be dealing with air okay. So in most of the calculations for example if you want calculate what is the energy required for cooling air what is the energy required for heating the air. You, I will have to know the properties of air okay.

What is the density of air what is the specific volume? What is its specific heat? What is its enthalpy? Right, so you we have to find out various properties of air right. Air is not a pure fluid just, now we have seen that it is a mixture of several gases plus water vapour okay.

So by some means we must be able to find the, or estimate the properties of moist air for further calculation and design of air conditioning systems okay. It is difficult to estimate the exact property values of moist air. As it is a mixture of several permanent gases and water vapour if you want a hundred percent accurate or exact value. It is very difficult because it is a mixture of several gases and water vapour okay. However moist air it is found that moist air up to three atmosphere pressure obeys perfect gas laws with accuracy sufficient for engineering calculation. That means we assume that moist air behaves like an ideal gas or a perfect gas. So that you can apply the perfect gas laws and it is observed that this does not really give arise to a huge error.

For very high accuracy of course one has to consider the real gas behavior of moist air by considering interaction between molecules of various gases and water vapour this requires application of a principles of statistical mechanics. So for most of the time we need not really bother about the real gas behavior of various gases and water vapour okay for our engineering purposes. If you treat it as a mixture of ideal gases that means you treat dry air as an ideal gas. And also take up treat moist air that is water vapour also as an ideal gas and take moist air as a mixture of ideal gases okay. This will give you reasonably good accurate values but in some cases you may require much higher accuracy okay. In such cases you have to consider the actual real gas behavior of various gases okay.

So when you consider the real gas behavior of various gases and all you must consider the interaction. This way between the molecules of various gases and between the molecules of the same gas okay. Because in a real gas the molecular interaction is very much present okay. So one must consider the interactions and one must evaluate the properties by taking all these interactions by taking the volume of the volume occupied by the molecules etcetera into account okay.

So this requires the application of the fundamental principles of statistical mechanics okay. So using this method and gaf and grace have formulated tables for psychrometric properties okay. So these tables are based on the real gas behavior of moist air okay. So that will give you very good very accurate properties. However unfortunately the gaf and grace charts or tables are valid for one atmosphere barometric pressure okay. So if you want the psychrometric values at different barometric pressures then again you have to do the calculations okay. So generally the calculations are found to be very complex okay. Because of the number of gases involved okay.

So what we I will do is and what is generally done is assumed that it is a mixture of ideal gases and apply the ideal gas laws and evaluate the properties that is what is done in this lecture okay.

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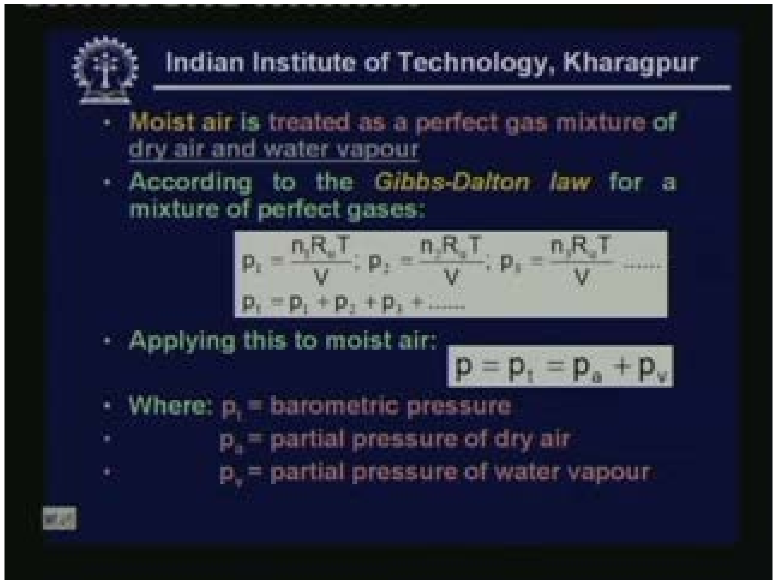

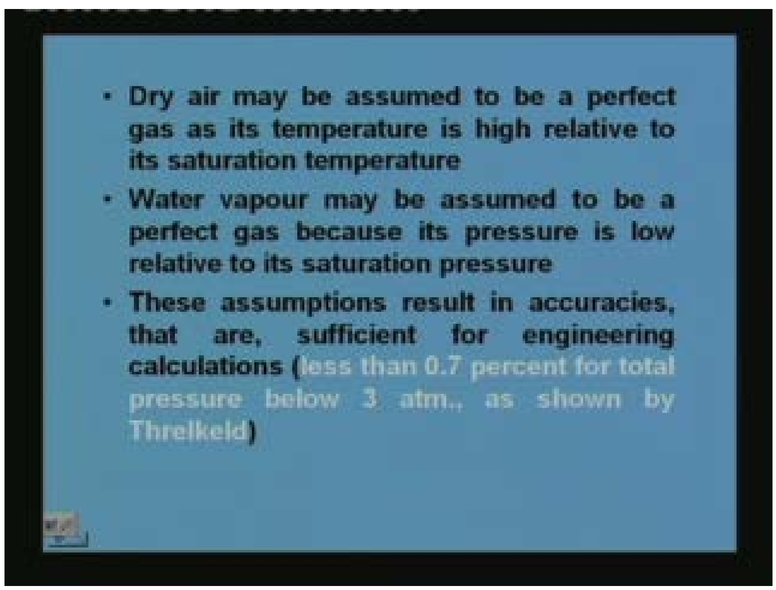

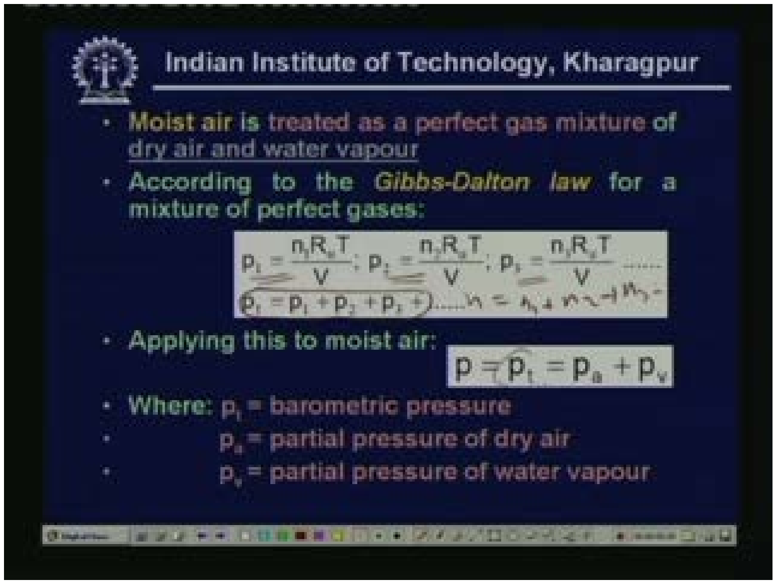

So as I said moist air is treated as a perfect gas mixture of dry air and water vapour. What is the justification, how do you justify this assumption that dry air behaves as an ideal gas and water vapour behaves as an ideal gas this is justified. Because dry air may be assumed to be a perfect gas as it is temperature is high relative to it is saturation temperature okay. The saturation temperature of dry air is very low. So the actual temperature at which the air conditioning systems operate are much higher compared to the saturation temperature okay. So under these circumstances dry air behaves more or less like a an ideal gas okay, so the assumption is justified.

When it comes to water vapour water vapour may be assumed to be a perfect gas. Because its pressure is low relative to it's saturation pressure okay. So normally in air the amount of water vapour that that is there in air is very low. So it exits very low small partial pressure okay. So this pressure is much lower than the saturation pressure. So we can treat this as an ideal gas. And these assumptions result in accuracies that are sufficient for engineering calculations. And it is shown that the errors because of these assumptions is less than point seven percent for total pressure below three atmosphere and this is shown by Threlkeld .

Okay, so since we are treating moisture as a mixture of perfect gases. That means moisture itself behaves as an ideal gas or a perfect gas. So we can apply the Gibb's-Dalton law and you know that Gibbs-Dalton law for a mixture of perfect gases is given like this. According to Gibbs Dalton law each perfect gas behaves as though it is occupying the whole volume right. And there will not be any interaction between the molecules of different gases right. So these are the assumptions. So since each gas is behaving as though it is occupying the whole volume when you apply the ideal gas equation the volume occupied by each gas is the total volume okay. And since you are talking about the equilibrium the temperature of the all the gases have will be same okay. Since then we get this equation.

For example, let us say the gap for gas. One ideal gas equation is this P one V is n one Ru T where Ru is universal gas constant and one is the number of moles of P one. I mean number of moles of one and T is the absolute temperature. Similarly for gas two P two V is n two Ru T similarly for gas three P three V is n three R u T like that okay. And when you apply this one and the conservation of number of molecules. That means n is n one plus n two plus n three etcetera. You finally find that the total pressure okay Pt is nothing but the summation of the individual pressure. That means Pt is equal to P one plus P two plus P three etcetera okay where P one P two P three etcetera are the partial pressures exhibited by the individual gases.

So when you apply this Gibbs Dalto law to moist air in our case we have only two gases that is dry air and water vapour okay. Both as I said are assumed to behave as perfect gases okay. So if you apply this to moist air you find that total pressure or the barometric pressure Pt is equal to Pa plus Pv where Pa is the partial pressure of dry air and Pv is the partial pressure of water vapour.

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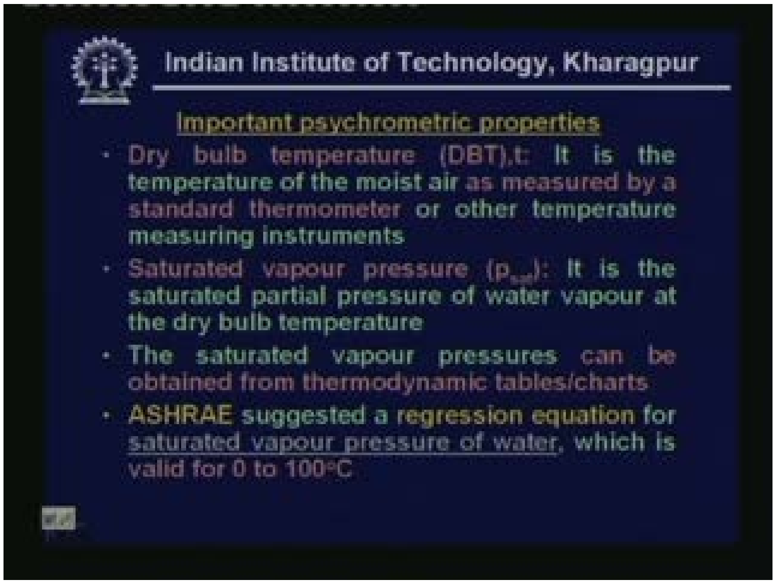

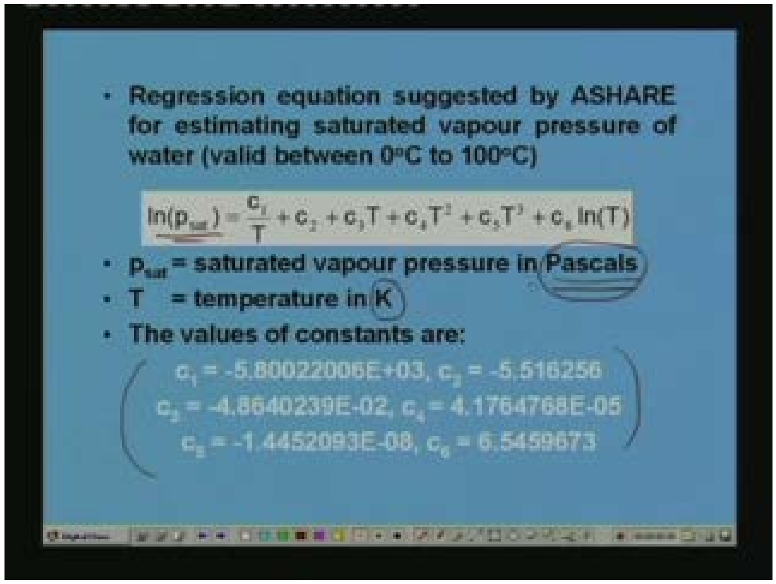

Now let us look at important psychrometric properties these psychrometric properties what I will do is define the psychrometric properties and give equations for the psychrometric properties. And these equations are derived based on the assumptions made earlier that means the based on the perfect gas model okay. The first and the most important property of course is the dry bulb temperature in short form DBT and it is denoted by small t and it is as you know this is DFT is the temperature of the moist air as measured by a standard thermometer or other temperature measuring instruments. So I actually dry bulb temperature is nothing but the temperature okay. So we call it as we add the term dry bulb. Because we also have another temperature called as wet bulb temperature okay.

So to distinguish between these two we call this temperature as dry bulb temperature okay. So dry bulb temperature is nothing but the normal temperature measured by a standard or normal temperature measuring instruments such as the thermometer okay. Next important property is the saturated vapour pressure P sat this is the saturated partial pressure of water vapour at the dry bulb temperature. The saturated vapour pressures can be obtained from thermodynamic tables and charts. We have seen the thermodynamic tables and charts. And we have used these saturated vapour pressures of refrigerants while doing calculations. So for water also you can use similar tables and charts and you can get the saturated vapour pressure value if you know the temperature. So ASHRAE suggested a regression equation for saturated vapour pressure of water which is valid for zero to hundred degree centigrade.

That means I, if you have the thermodynamic tables or charts. Then straight away you can get the values of saturated vapour pressure of water if you know the temperature okay. If you want to computerize this and if you want to do the calculation from the computer. Then you need these kinds of form of an equation okay. So ASHRAE suggested very accurate regression equation for the saturated vapour pressure of water okay this equation is like this lnPsat okay, is equal to, you can see that C one by T plus C two plus C three T plus C four T square plus C five T cube plus C six natural log of T. Where Psat is saturated vapour pressure in Pascals it's very important to note the units okay. Because you must use the same units to get thesame values okay. Otherwise it, I will give wrong results and T is the temperature and it is in degrees Kelvin okay. So these correlation is the valid for these units.

That means pressure in Pascals temperature in Kelvin okay. Of course because you have to use these constant values okay. So these constants values are valid for these units okay. And the values of constants C one to C six are given here C one C two C three C four C five and C six. So you substitute these values then P sat is a function of temperature only. Of course you know the temperature you can calculate the saturation pressure of water vapour. And as I said this is valid for zero degrees to hundred degrees centigrade.

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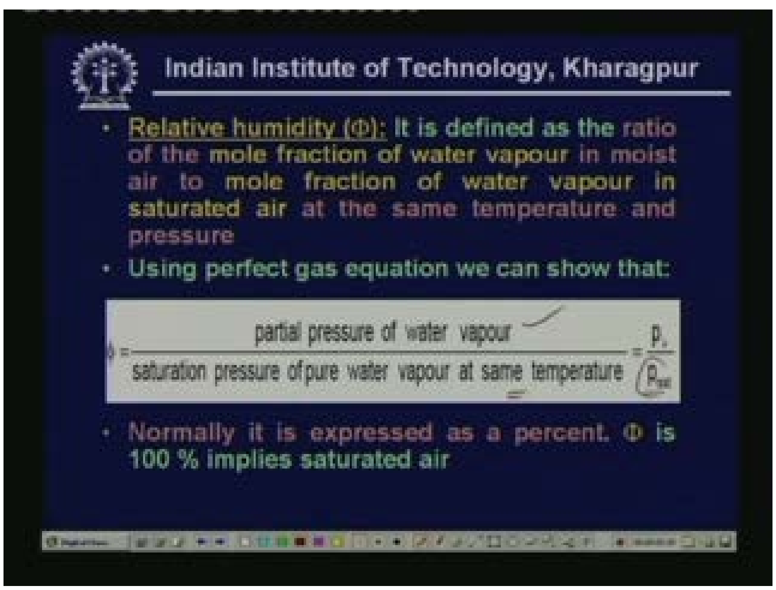

Next important property's relative humidity, it is, symbol is phi. But sometimes RH is also used it is defined as the ratio of the mole fraction of water vapour in moist air to mole fraction of water vapour in saturated air at the same temperature and pressure okay. So it is a ratio of, first of all it is a ratio of mole fractions of, what mole fractions of water vapour. That means actual mole fraction of water vapour to mole fraction of water vapour in saturated air okay, at the same temperature and pressure. Here, pressure means barometric pressure and temperature means dry bulb temperature. Now using perfect gas equation the mole fraction ratio can be replaced with partial pressure ratio okay. So the, you can replace mole fraction by partial pressures.

So you can write finally relative humidity as partial pressure of water vapour divided by saturation pressure of pure water vapour at same temperature. That means Pv divided by P sat P sat can be obtained from the equation given just now or from the thermodynamic tables and charts. Normally the relative humidity is expressed as the percentage and if it, if you say that phi is hundred percent. That means relative humidity is hundred percent. That means the air is saturated because Pv is equal to P sat so the air is saturated.

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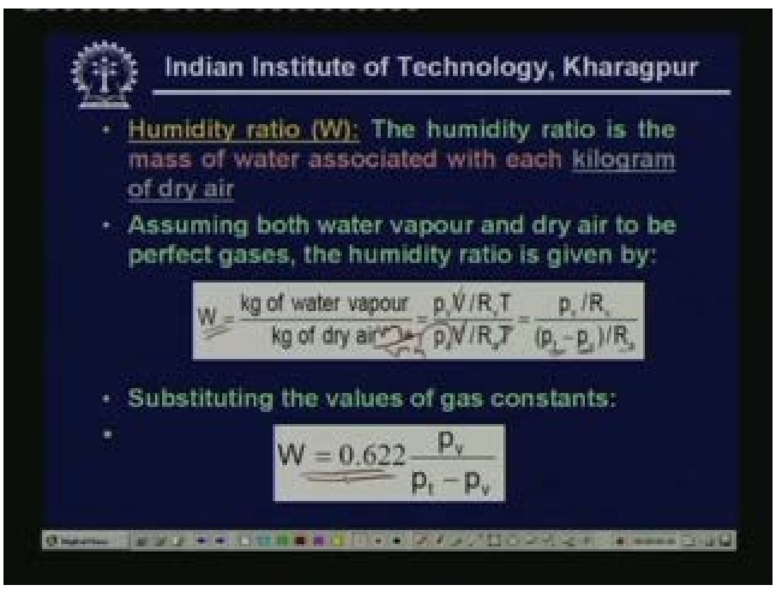

Next important property is called as humidity ratio and the symbol is capital W and it is defined as the mass of water vapour associated with each kilogram of dry air okay. So it is important to note that this is the mass of water vapour associated with each kilogram of dry air. And we can get an expression for this assuming both water vapour and dry air to be perfect gases the humidity ratio is given by this expression humidity ratio W is kg of water vapour divided by kg of dry air k. That means mass of water vapour okay, ma I mean mv divided by ma and mv and ma are written in terms of pressures volumes and temperature using the perfect gas equation. Because we know that pv is MRT as the as well as the perfect gas equation is concerned.

So we replace the mass is by these quantities okay. So ma mv by ma that means mass of water vapour by mass of dry air is written as pv into V by Rv T divided by pa into V by Ra T okay. Where pv and pa are the partial pressures of water vapour and dry air Rv and Ra are the gas constants not universal gas constants. These are the actual gas constants and V for the volumes and T's are the temperatures. Since temperatures are same volumes are same. These things gets cancelled then we write pa in terms of total pressure pt and vapour pressure of water Pv using the Dalton's law of partial pressures okay. So pa is replaced by pt minus pv.

So finally you find that W is equal to pv by Rv divided by pt minus pv by Ra where Rv and Ra are the gas constants. And if you substitute the values of Rv and Ra i have given the values of gas constants you finally find that humidity ratio W is given by point six two two pv by pt minus pv. Let me repeat ones again pv is the vapour pressure of water vapour and pt is the total pressure or the barometric pressure. So you can see that the humidity ratio depends on the vapour pressure of water as well as the barometric pressure okay.

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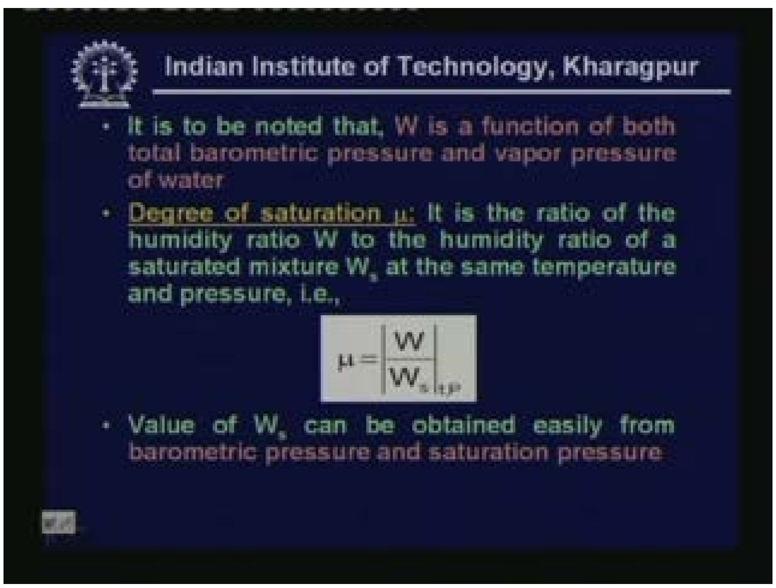

Next property is called as the degree of saturation the symbol is mew this is defined as the ratio of humidity ratio W to the humidity ratio of a saturated mixture Ws at the same temperature and pressure okay. So mew is given by W by Ws where Ws is the saturated humidity ratio at the same derival temperature and the total pressure and of course value of Ws can be obtained easily from barometric pressure and saturation pressure.

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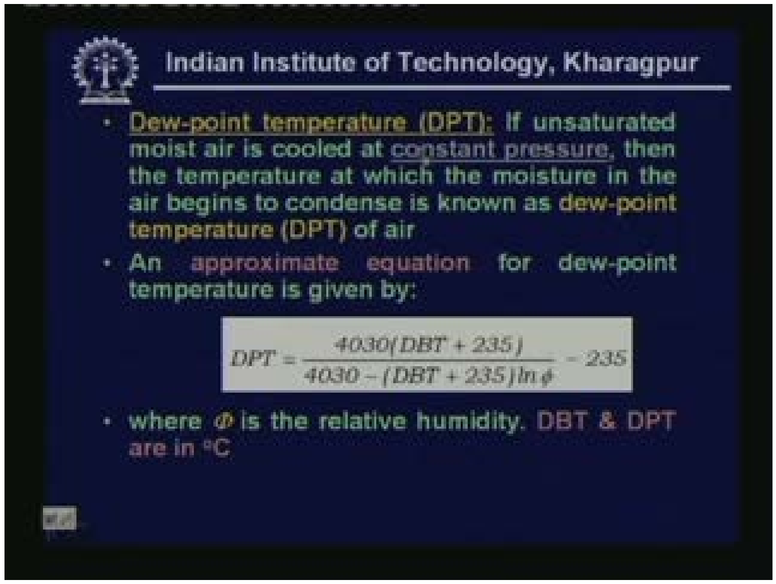

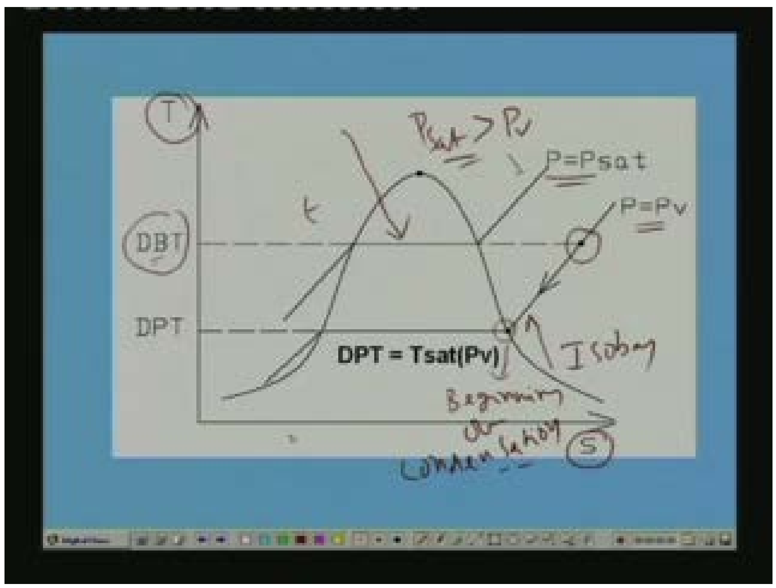

Next comes the property called Dew-point temperature or DPT if let me explain this. If unsaturated moist air is cooled at constant pressure. Then the temperature at which the moisture in the air begins to condense is known as dew point temperature of air okay. I am sure that you know what is dew point temperature. But let me explain this with the help of a TS diagram. This is the TS diagram of water vapour okay. Let us say that this is your pressure okay total pressure this is the saturate pressure at the dry bulb temperature T okay so P is P sat.

Now let us say that the water vapour exists at this point okay. That means it is in a super heated condition right. So at this point the temperature of the water vapour is same as the dry bulb temperature t. But it is, partial pressure is lower than the saturated hm pressure of water vapour okay. You can see that this is the saturated pressure and this is the actual partial pressure that means Psat is greater than Pv. Now if you cool this water vapour isobarically so that means along the constant pressure line. So this is an isobar okay. So if you cool the water vapour along the constant pressure line. It is pressure reduces, I mean it is, pressure remains constant sorry, its temperature reduces. And you find that at a particular point the water vapour begins to condense okay. So this is the point where beginning of condensation occurs okay.

And you call this temperature at which the first drop of water forms is called as the Dew-point temperature okay. And actually if you look at the TS diagram what is Dew-point temperature Dew-point temperature is nothing but the saturated temperature corresponding to the partial pressure of water vapour okay. So if you have the equation for partial pressure of water vapour. Then you can easily solve that equation and find the dew point temperature okay. Of course when the air is saturated then Dew-point temperature is same as diry bulb temperature. In that case your condition is somewhere here okay.

It s an approximate but very useful equation for Dew-point temperature is given by this. DPT is Dew-point temperature that is equal to four zero three zero into DBT plus two thirty-five divided by four zero three zero minus DBT plus two thirty-five into natural log of phi where this phi is the relative humidity expressed as a fraction okay. Not as a percentage and here DBT and DPT are in degree centigrade. So using this equation you can find out the dew point temperature if you know the dry bulb temperature and relative humidity.

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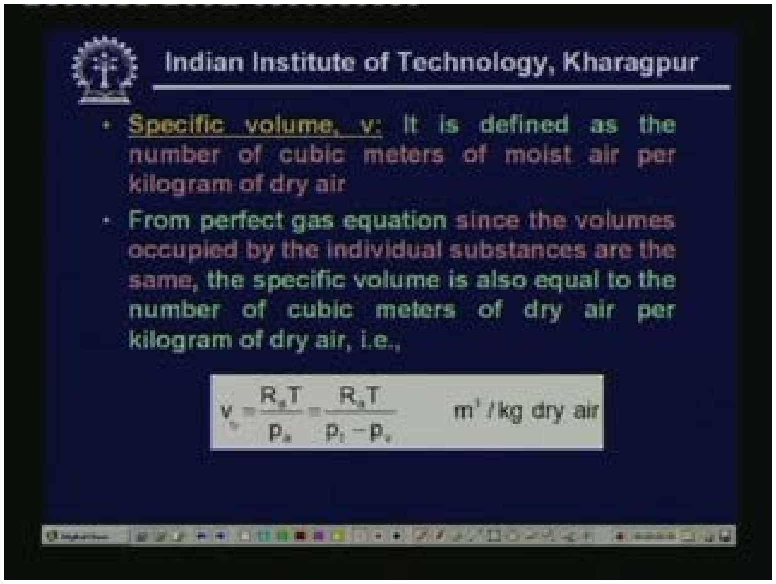

Next is the specific volume small v this as you know is defined as the number of cubic meters of moist air per kilogram of dry air. All these properties are moist air properties okay. Please keep that in mind. So when I say specific volume that is the, that means specific volume of moist air right. So from perfect gas equation since the volumes occupied by the individual substances are the same the specific volume is also equal to the number of cubic meters of dry air per kilogram of dry air okay. Since each gas behaves as though it is occupying the whole volume you can write the specific volumes of moist air in terms of the volume and in terms of the mass of the dry air using this equation okay.

This is the specific volume using the perfect gas equation for dry air pa into v is equal to Ra into T where pa is the partial pressure of dry air v is the specific volume. And Ra is the gas constant and T is the derival temperature and pa from Gibb's-Dalton law is nothing but pt minus pv okay. So v is equal to Ra T by pt minus pv and the units are meter cube per kg dry air okay. Before we go to next properties I just want to bring if your notice that, so far humidity ratio and specific volumes etcetera. These are all intensive properties. They are defined on basis of one kg of dry air okay. That means in denominator you have kg of dry air okay. So this may look a little surprising because we are talking about the properties of moist air. So if it is a specific or intensive property then it should have been the mass of dry air. That means kg of moist air sorry it should have been the kg of moist air but we are writing this in terms of kg of dry air. What is the reason behind this?

The reason is like this okay. So okay, so there is a small problem anyway. Let me explain why we take the mass or the denominator as kg of dry air. That means why all the intensive properties are based on the mass of dry air. This is a because of the fact that the amount of dry air in any air-conditioning process always remains constant. Whereas the amount of water vapour may get reduced or may increase okay. For example if you are demodifying the moist air. Then the amount of water vapour reduces. On the other hand if you are demodifying the air then the amount of water vapour increases. That means the mass of that moist, total mass of the moist air may change okay. During a given process. But the mass of the dry air always remains constant okay. For if you write all the intensive properties in terms of the mass of dry air then the calculations become very easy okay. This is the reason why all the intensive properties of moist air are based on the mass of dry air okay.

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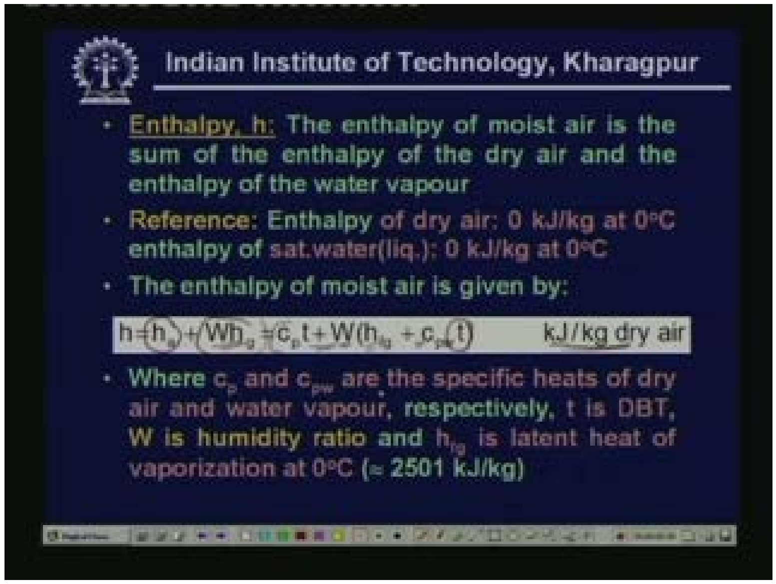

Next important property for the calculations is the enthalpy the enthalpy of moist air is the sum of the enthalpy of the dry air and the enthalpy of the water vapour okay. Because moist air consist of dry air as well as water vapour. So the total enthalpy of the moist air is because of the contributions of the dry air part plus contribution of the moist air okay. And for enthalpies we know that we have to define you cannot have an absolute value of enthalpy. So you have to have a difference values so here the differences are like this for dry air. The enthalpy of dry air is taken as zero kilo Joule per kg at zero degree centigrade. This is the difference value for dry air whereas for water the enthalpy of saturated liquid water is taken as zero kilo Joule per kg at zero degree centigrade. So these are the difference enthalpy values based on which we define the enthalpy of moist air.

So the enthalpy of moist air is given by ha plus W into hg okay. So where ha this is an intensive property. So the unit is kilo Joule per kg of dry air right so everything is in terms of kg of dry air. So ha is nothing but the contribution of the dry air part and it is nothing but the enthalpy of the dry air okay. And W into hg is the contribution of the water vapour in this hg is the enthalpy of the water vapour and W is the humidity ratio okay. So the first term takes care of the contribution of the dry air and the second term takes care of the contribution of water vapour okay.

And if you assume or if you use an average value of specific heat cp and if you take these reference values and then you can write ha plus W hg in terms of specific heats and temperatures like this. That means finally enthalpy of moist air is written as Cp into t where Cp is the specific heat of the dry air specific heat at constant pressure of the dry air t is the dry bulb temperature. W is the humidity ratio h fg is the latent heat of vaporization of water Cpw is the specific heat of water vapour at constant pressure. And t is the dry bulb temperature okay. And h fg is actually the latent heat of vaporization at zero degree centigrade. Because the difference is the zero degree centigrade. So you can take an approximate value of two thousand five hundred and one kilo Joule per kg okay. So remember that when you are writing this enthalpy in terms of in terms of specific heat that when you are writing the delta h as Cp into delta t. That means we are using a average value of specific heat okay.

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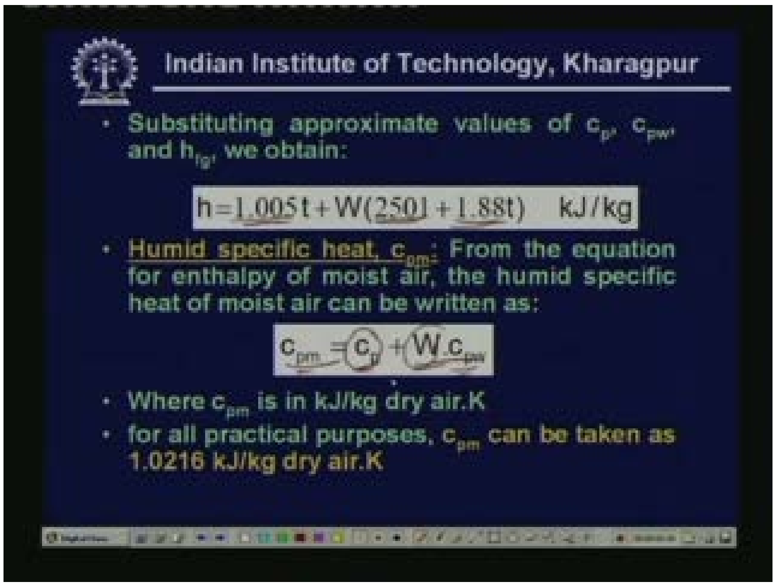

So substituting approximate values of Cp Cpw and h fg we obtain this expression h is one point zero zero five t plus W into two thousand five hundred and one plus one point eight eight t okay. This is obtained by taking specific heat value of one point zero zero five kilo Joule per kg Kelvin for dry air okay. So this is the Cp of dry air and this is the latent heat of vaporization at zero degree centigrade and this is the Cp of water vapour okay. So if you remember these things or these simple equation. Then it is very easy to calculate the various properties okay.

For example enthalpy it is all if you know other properties right. Next property is the humid specific heat that is nothing but the specific heat of the moist air the symbol is C subscript pm from the equation of for enthalpy of moist air the humid specific heat of moist air can be written as Cpm is Cp plus W into C pw. Where Cp is the specific heat of the dry air W is the humidity ratio and Cpw is the specific heat of the water vapour at constant pressure. And of course the units of Cpm are in kilo Joule per kg dry air per Kelvin okay. And for all practical purposes you can take you can use the mean value of humidity ratio and you can take the value of Cpm as one point zero two one six kilo Joule per kg dry air Kelvin okay.

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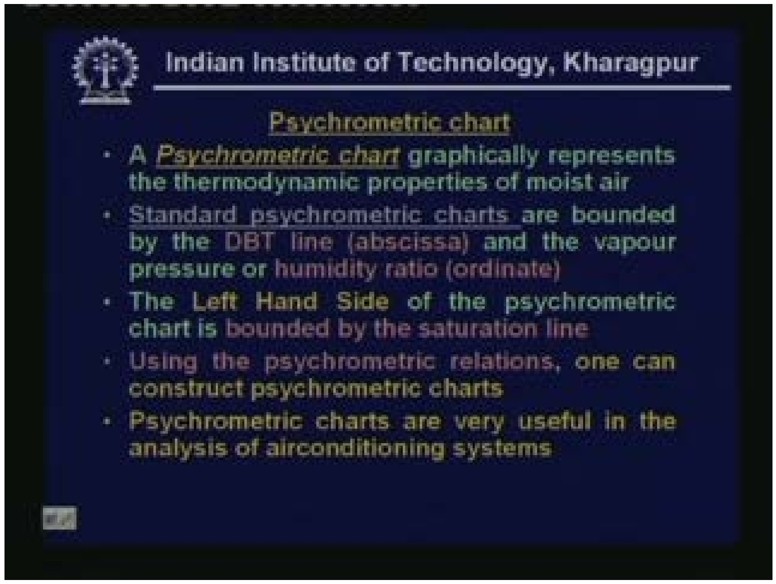

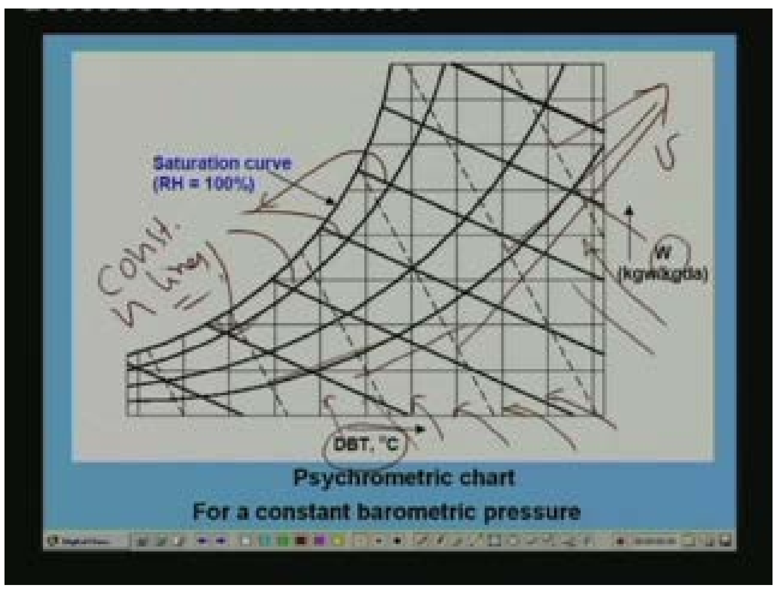

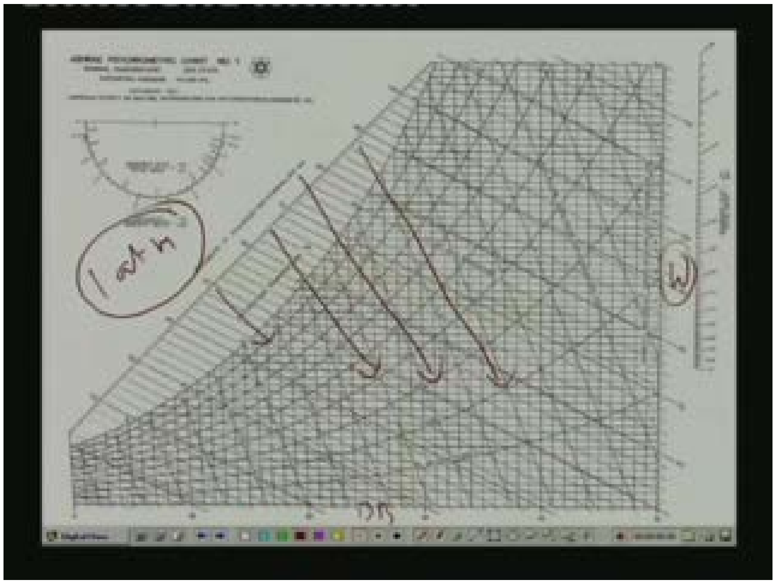

Next let us look at psychrometric chart what is a psychrometric chart. So far we have seen the psychrometric equation then let us look at the psychrometric chart. A psychrometric chart graphically represents the thermodynamic properties of moist air it is nothing but a graphical representation of moist air. Standard psychrometric charts are bounded by the dry bulb temperature line and the abscissa. And the vapour pressure or humidity ratio as an ordinate and the left hand side of the psychrometric chart is bounded by the saturation line okay. Let me show the psychrometric chart now. Okay, so this is the skeleton of a psychrometric chart.

As I said you have the dry bulb temperature DBT on the X-axis and here you have the humidity ratio W on the Y axis. Of course you can also have in place of W you can also have vapour pressure of water okay. Because these are related okay. And very important thing is that the in order to find the way we will come to that in order to fix the status moisture. We need to know three independent properties okay. So that means the degree of freedom are three. Because we are talking about a binary mixture okay. But the psychrometric chart is a two dimensional representation of the properties. So how is it possible this is made possible by giving the psychrometric charts for standard barometric pressures okay. That is how a three dimensional figure has been reduced to a two dimensional chart okay. That means any psychrometric chart is valid for that particular barometric pressure. And if you look at any psychrometric chart they always mentioned the barometric pressure at which the chart has been obtained okay.

So we always say the P values for example if it is standard atmosphere they said P is zero hundred one point three two five kilo Pascal okay. That means it is one atmospheric pressure like that psychrometric charts are of course available for different barometric pressures okay. So you must whenever you are using psychrometric chart you have to be careful and first of all you have to see for what barometric pressure that particular chart is valid okay. So you cannot use the same chart at all altitudes okay. Now coming back to psychrometric chart the psychrometric chart as I said is a graphical representation of psychrometric properties. And using the psychrometric chart you can find the properties of all psychrometric properties okay. And this as I said is a saturation curve in the left hand side .

Saturation curve means relative humidity is hundred percent and on the same chart you find constant relative humidity lines. These are the constant relative humidity lines okay. For example this could be the seventy-five percent relative humidity line this could be for the fifty percent relative humidity line this could be twenty five percent relative humidity line like that okay. So that is those are the constant relative humidity lines. Of course since the dry bulb temperature is the X axis and humidity ratio is the Y axis obviously these lines are the constant dry bulb temperature lines okay. There not exactly vertical but for all practical purposes. They are almost vertical okay. So the vertical lines are dry bulb temperature all the horizontal lines these lines are the constant humidity ratio lines okay. And as I said these curve lines are here the relative humidity lines and these dash lines okay.

These are the specific volume lines okay. All these dash lines are specific volume lines and finally you have these thick inclined lines okay. All these thick inclined lines are constant enthalpy lines okay. So you can see that all the required properties are specified on the psychrometric chart okay. So if you know any two properties any two psychrometric properties you can find the rest of the properties. For example if you know the dry bulb temperature and relative humidity. Let us say this is your dry bulb temperature. This is your dry bulb temperature. Let us say and this is your relative humidity okay. That means this is the straight of the air this point then you can find out their humidity ratio like this you can find out the specific volume like this you can find out the enthalpy value by reading this line like that okay.

So remember again that this is for a given pressure okay. So you if you need to know the properties you need to know the barometric pressure plus any other two properties okay. So once you have these three properties you can find the rest of the properties using the psychrometric chart okay. This actually shows this picture is not very clear but this is the psychrometric chart given by ASHRAE and ASHRAE’s provided psychrometric chart which can be used for different elevations and this particular chart is valid for one atmospheric pressure okay, barometric pressure.

They have also given similar charts for different elevations. For example for fifteen hundred meter elevation for thousand meter elevation like that. That means for different charts for different elevations and different conditions and again. As I said you have the dry bulb temperature here and you have the saturation humidity ratio as the ordinate and all these curved lines okay, are your relative humidity lines and these slant lines are specific volume lines and enthalpy lines okay. So using the psychrometric relations one can construct a psychrometric charts this is the usefulness of having a psychometrical relations. You can construct your own psychrometric chart using the simple relations okay.

This is very easy all that you have to do is, you have to take the dry bulb temperature in the x axis and take the humidity ratio on the y axis and you have to have the steam table or the steam charts or the regression equation for the saturation pressure of water vapour. So if you have these three then using the psychrometric relation you can construct the psychrometric chart. The advantage of constructing your own psychrometric chart is you can construct the psychrometric chart for any barometric pressure okay. There is no limitation but of course remember that all these relations are based on the assumptions of ideal gas okay. Psychrometric charts are extremely useful in the analysis of air conditioning systems we will be using these charts again and again for showing the psychrometric processer for estimating psychrometric properties etcetera.

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Now measurement of psychrometric properties based on Gibb's phase rule thermodynamic state for moist air is uniquely fixed if the barometric pressure and two other independent properties are known as I have already mentioned. If you apply the Gibb's phase rule that is number of p plus V C plus two where p is the number of phases present and V is the degree of freedom and C is the number of components. You find that the degrees of freedom or number of independent components to be specified are three for moist air okay, when you treat it as a mixture of two components right. So minimum number of three parameters have to be three independent parameters have to be specified to fix the state of the moist air okay. So what are those three parameters unless you fix these three unless you specify these three you cannot find the properties of moist air okay.

Normally barometric pressure is specified because we know the barometric pressure. So at a given barometric pressure the state of moist air can be determined by measuring any two independent properties okay. So given the barometric pressure we need still two more properties. One of them could be the dry bulb temperature as the measurement of temperature is fairly simple and accurate okay. So if the, if you need three independent properties one of them is barometric pressure because it is known to us okay. So if we need to fix it other one could be dry bulb temperature right what is the third property okay. What is the third property which can be specified and which can be measured easily so that you can fix the state of air okay.

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Third property could be theoretically third property could be anything for example the third property could be relative humidity third property could be humidity ratio. It could be for example enthalpy of course enthalpy cannot be measured. So there is no point in taking that as an independent variable but theorotically speaking it can be any intensive property right. But there are some problems it solve the independent in the intensive properties. For example if you want to specify humidity ratio as an independent propertyit's not very convenient. Because accurate measurement of humidity ratio is very difficult in practice.

Since measurement of temperature is easier it would be convenient if the other independent parameter is also a temperature. So one of the independent parameter is this dry bulb temperature if the other independent parameter is also a temperature then it will be very convenient to us. Because it can be measured very easily right. So temperature measurement are easier right but could it be the dew point temperature. Accurate measurements of dew point temperature is difficult. So even though dew point temperature is also a temperature spaces taking that as an independent parameter is difficult in practice because measurement of dew point temperature is very difficult okay, just like humidity ratio okay.

Hence a new independent temperature parameter the wet bulb temperature is conceptualized okay.Because of this difficulty that means because of the difficulty of measuring other properties such as the humidity ratio or relative humidity or dew point temperature people have come out with a new concept of wet bulb temperature okay. So this concept is very useful because we shall see that measurement of wet bulb temperature is relatively easy compared to dew point temperature okay. So compared to as I said compared to dew point temperature it is easier to measure the wet bulb temperature of moist air.

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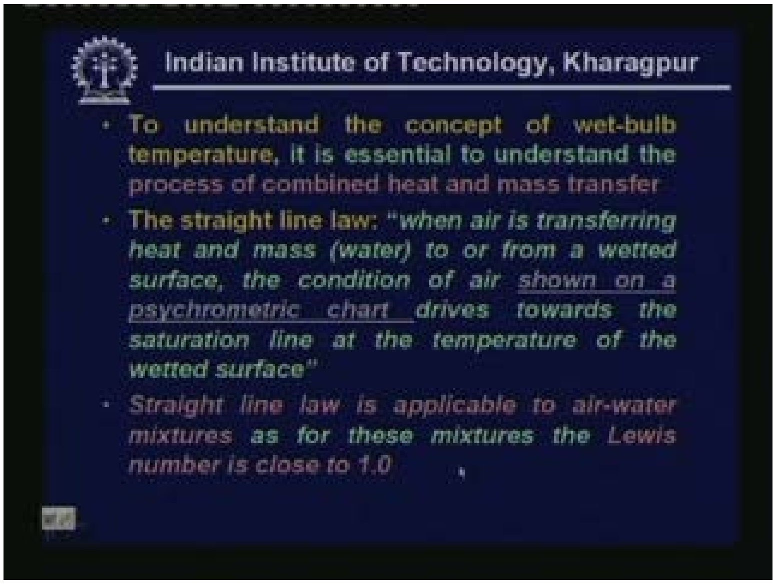

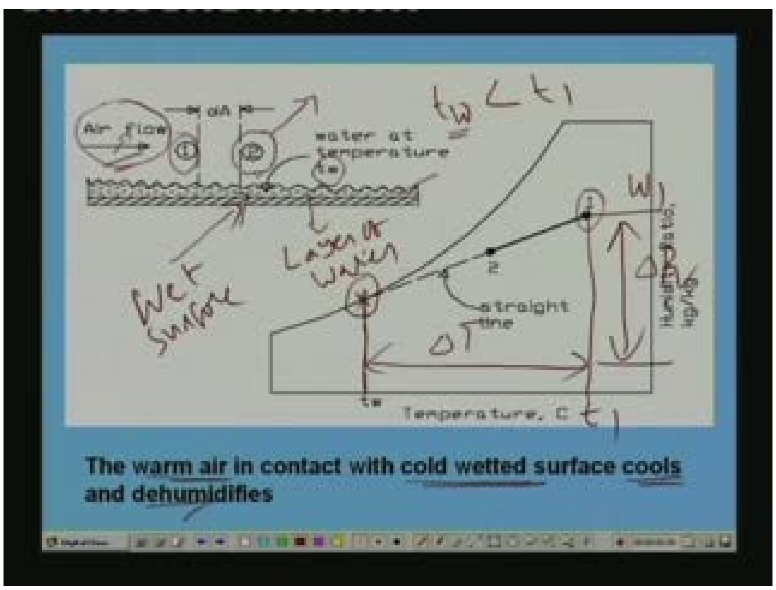

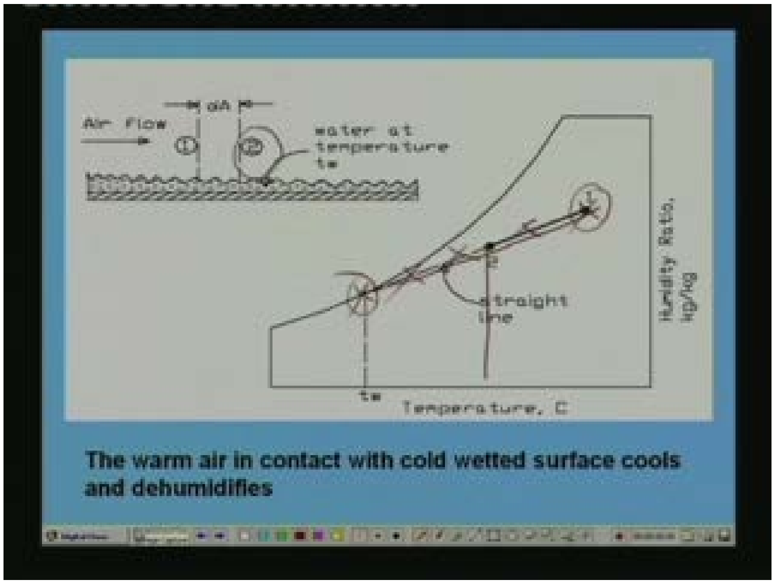

To understand the concept of wet bulb temperature it is essential to understand the process of combined heat and mass transfer. So we have to have combined heat and mass transfer when we discuss combined heat and mass transfer with reference to a mixture of air and water vapour. Then we have to talk about a law called as straight line law what is a straight line law. Straight line law states that when air is transferring heat and mass. Here mass means water vapour to or from a wetted surface the condition of air shown on a psychrometric chart drives towards the saturation line at the temperature of the wetted surface okay.

So this is the straight line law let me explain this. Let us say that we have moist air okay. For the time being let us assume that this is unsaturated okay. That means its relative humidity is less than hundred percent and let us say that we have a moist surface okay.

So this is the wet surface that means on this surface we have a layer of water let us say okay. And for argument saying let us assume that this water is at different temperature compared to this air or for the time being let us say that this water temperature is tw. tw is less than the air temperature t one okay. And on the psychrometric chart let us say this is the condition of the air at this point at point one. It is at some tribal temperature t one okay. And at some humidity ratio W one so air at this condition is coming in contact with a wet surface at which is at temperature tw.

When you have a wet surface at a temperature tw a concentration boundary layer develops near the wet surface. And air in the mediate vicinity of the wet surface will be saturated. That means in the immediate vicinity of this wet layer you have a saturated water vapour layer and since this temperature is also same as tw the condition of that layer will be represented by this point okay. So this is the condition of the saturated water vapour next to the wet layer okay.

So air is coming in contact with this. Now you can see that there is a temperature difference between this saturated air and this air okay. That at this temperature difference is there similarly there is a vapour pressure difference or humidity ratio difference okay. Humidity ratio difference means vapour pressure difference is also there okay. Since the vapour pressure and temperature of this air are greater than the water vapour. Saturated water vapour heat transfer will take place sensible heat transfer will take place from air to the water. And latent heat transfer will also take place from air to the water. That means this warm air when it comes in contact to the cold wetted surface it gets cool and dehumidifies okay.

So what you are getting outside that means what you get at point two is a cold and dehumidified air. Now the question is what will be the condition of this air okay. How do you determine this condition of this air or where does this point lie okay. This is where the straight line law is useful okay. The straight line law says that the condition of this point okay, lies on a straight line joining these two points okay. That means joining the points of the saturated water vapour condition and the inlet air condition okay. The straight line joins these two points is this and that means this exit condition must lie on this straight line okay. For example on this point so this is what is known as straight line law. So straight line law is applicable to air water mixture as for these mixtures the lewis number is close to one.

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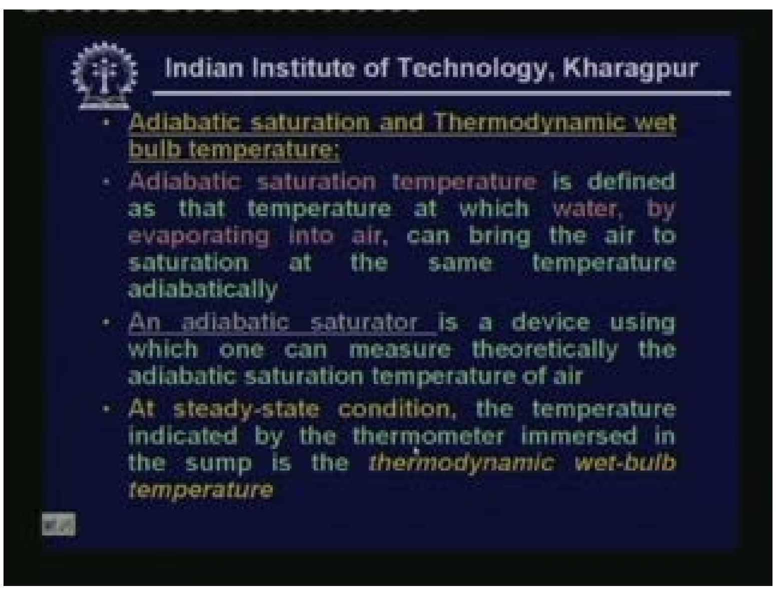

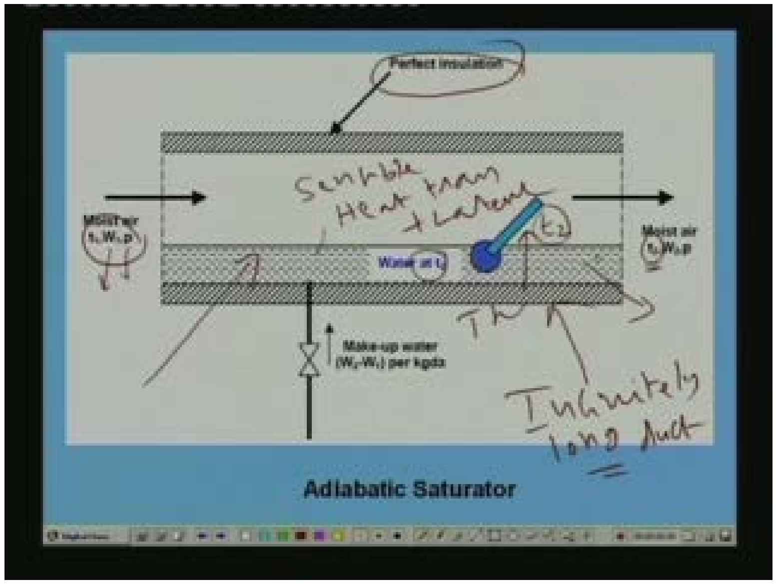

Now let us look at another concept that is thermodynamic wet bulb temperature and the process of adiabatic saturation. Adiabatic saturation temperature is defined as that temperature at which water by evaporating into air can bring the air to saturation at the same temperature adiabatically okay. An adiabatic saturator is a device using which one can measure theoretically the adiabatic saturation temperature of air okay, let may describe this okay. So this is an adiabatic schematic of a adiabatic saturator. So what we have is an infinitely long infinitely long duct let us say okay. And this duct is perfectly insulated right and it consist of water okay.

Now moist air at this condition dry bulb temperature t one humidity ratio W one and total pressure p flows through this insulated infinitely long duct okay. And as it flows through this it comes in contact with this water okay. So as a result you have sensible as well as latent heat transfers takes place, sensible heat transfer plus latent heat transfer takes place okay. And if the, if you are measuring let us say using this thermometer. We are measuring the temperature of this water and if this duct is infinitely long and if the system reaches the steady state you find that at steady state for an infinitely long duct the exit temperature of the moist air will be same as the temperature indicated by this thermometer.

That means the exit temperature of water moist air will be same as the steady state temperature of the water okay. Both will indicate the same temperature of course during this process water vapour evaporates to take care of that we have to continuously supply some make up water okay. So this kind of a device is called as an adiabatic saturator at steady-state condition the temperature indicated by the thermometer immersed in this sump is the thermodynamic wet bulb temperature okay. That means thermodynamic wet bulb temperature is nothing but the temperature indicated by thermometer which measures the water kept in the sump of this infinitely long duct okay.

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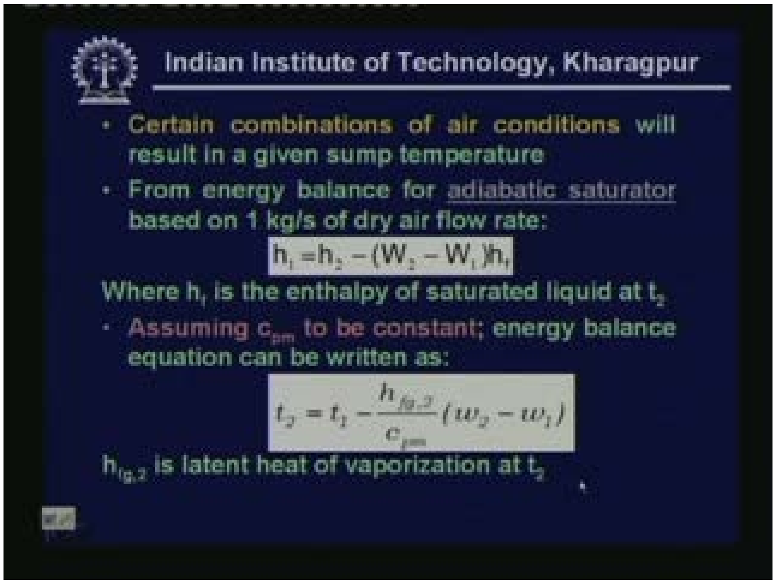

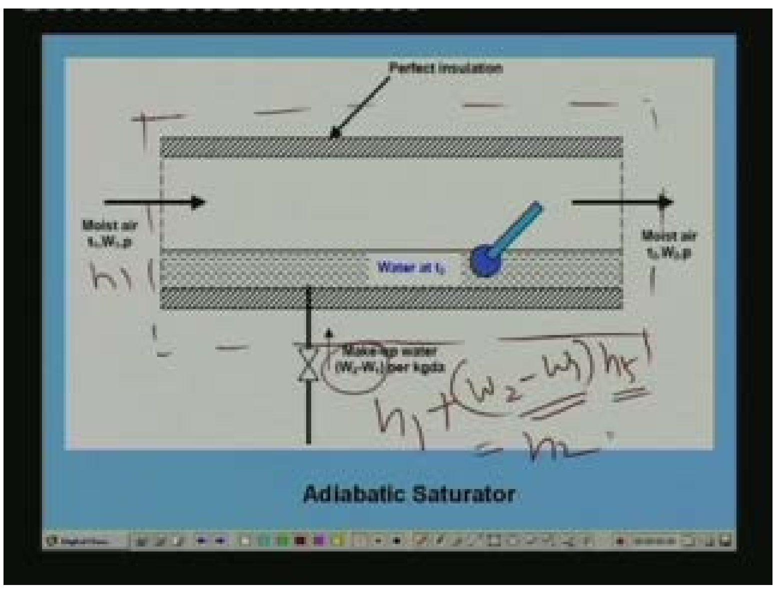

Now certain combinations of air conditions will result in a given sump temperature okay. From energy balance for adiabatic saturator based on one kg per second of dry air flow rate we can derive this energy balance equation okay. So if you take this as a control volume take this as a control volume and apply energy balance equation you find that energy coming in is energy going out and energy coming in everything is on based of one kg of dry air. So energy coming in is nothing but h one plus this energy this is nothing but W two minus W one into h f where W two minus W one is nothing but the amount of water evaporated in the adiabatic saturator. And h f is the saturated liquid water enthalpy at this temperature t two okay.

So this is the energy entering and what is the energy leaving energy leaving is nothing but h two okay. So assuming the moist air specific heat Cpm to be constant energy balance equation can be written in this form okay. So we can write the energy balance equation like this where t two is the exit or thermodynamic wet bulb temperature t one is the inlet dry bulb temperature h fg two is the latent heat of vaporization at temperature t two Cpm is the moist specific heat W two and W one are the exit and inlet humidity ratios.

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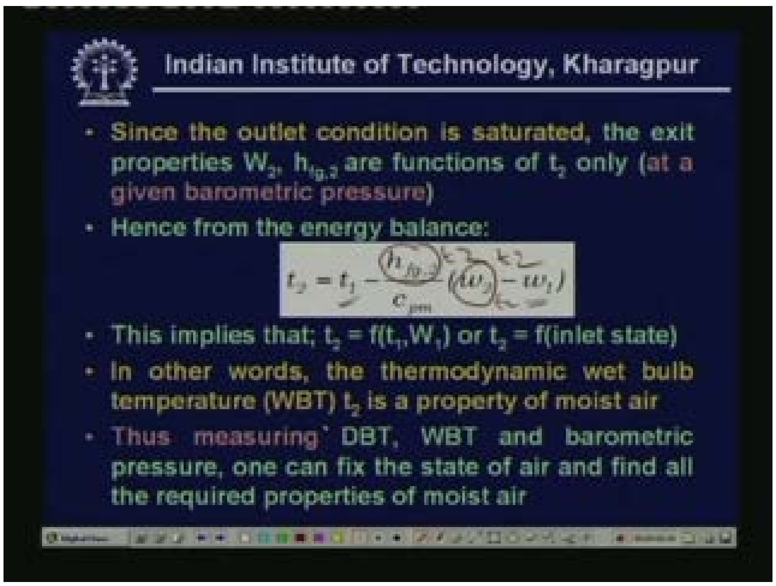

Since the outlet condition is saturated thus the exit properties W two h fg two are functions of temperature t two only okay. Because the outlet condition is saturated of course this is at a given barometric pressure. Hence from the energy balance t two is equal to t one minus h fg two by Cpm into W two minus W one okay. So what I am saying here is W two this is the function of temperature only. And this is also a function of temperature t two only okay. So from this implies that t two, that means the exit temperature is the function of t one and W one only right. Because you have temperature t two on this side apart from t two you have only t one and W one. That means t two is a function of t one and W one t one and W one are the properties of the inlet state. So finally what we are saying is the temperature measured by the thermometer is nothing but the function of inlet state okay.

In other words the thermodynamic wet bulb temperature t two is the property of moist air thus measuring dry bulb temperature wet bulb temperature and barometric pressure one can fix the state of air and find all the required properties of moist air okay. So what we are saying finally is that if you can have an adiabatic saturator and if you can measure the temperature of the water in the adiabatic saturator at steady state then you have another property of moist air okay. So one property is dry bulb temperature and the other property is thermodynamic wet bulb temperature okay. So from these two temperature values and the barometric pressure you can find out the rest of the psychrometric properties okay.

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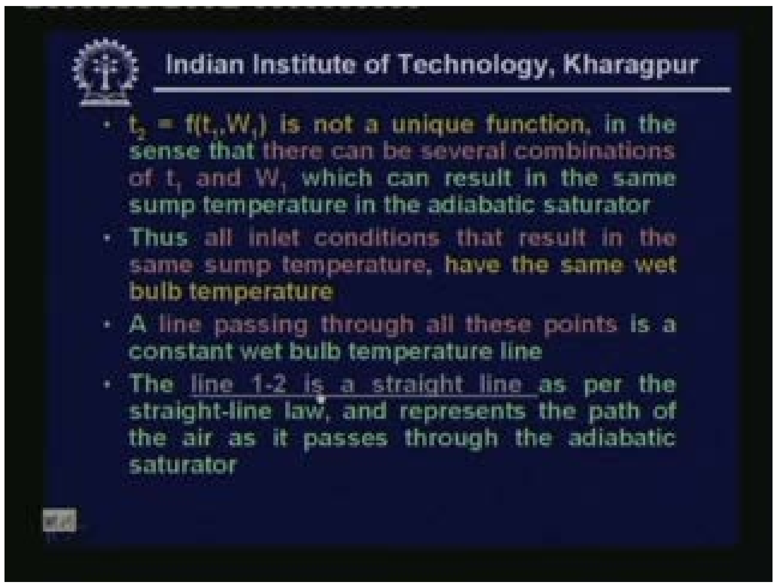

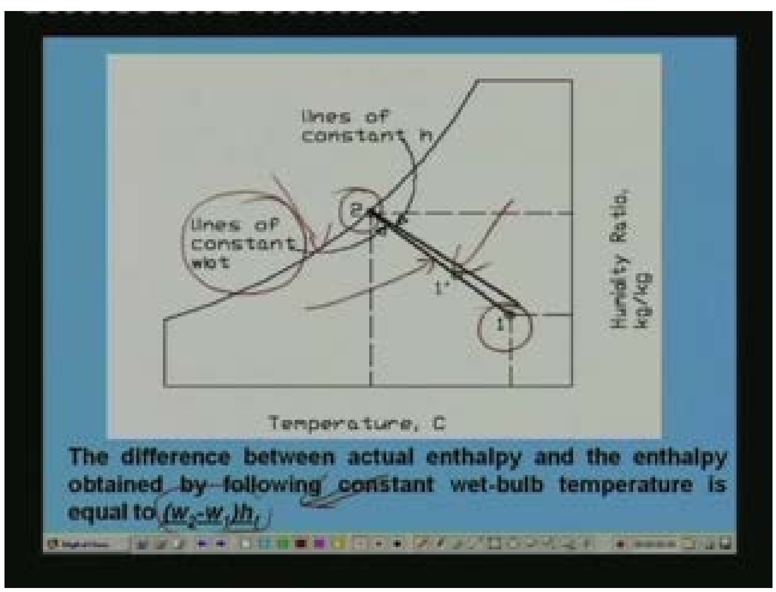

Now t two is a function of t one and W one this is not a unique function. Because in the sense that there can be several combinations of t one and W one which can result in the same sump temperature in the adiabatic saturator okay. That means several inlet conditions can result in this same sump temperature. That means they can they all have same thermodynamic wet bulb temperature. Thus all inlet conditions that result in the same sump temperature have the same wet bulb temperature. A line passing through all these points is a constant wet bulb temperature line because all these points have a same wet bulb temperature line.

Obviously line passing through all these points is a constant wet bulb temperature line the line one-two is a straight line as per the straight line law and represents the path of the air as it passes through the adiabatic saturator okay. That means let us say that this is our inlet condition to the adiabatic saturator and the outlet condition is the saturated air. So it is lies on the saturated line okay. And the process follows the straight line joining one to two according to the straight line law.

That means the line joining one to two is a constant wet bulb temperature line okay, where as this line what is shown here is a constant enthalpy line. So that there is a difference between constant enthalpy line and constant wet bulb line and what is the difference from energy balance you can show that the difference is nothing but W two minus W one into h f.

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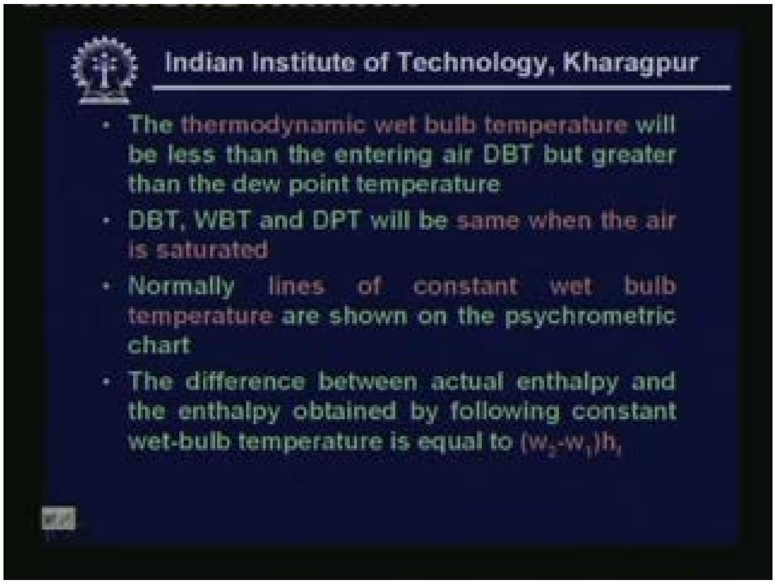

The thermodynamic wet bulb temperature will be less than the entering air dry bulb temperature. But greater than the dew point temperature obviously dry bulb temperature wet bulb temperature and dew point temperature will be same when the air is saturated. Normally lines of constant wet bulb temperature are shown on the psychrometric chart. So psychrometric chart also has lines of constant wet bulb temperature the difference between actual enthalpy. And the enthalpy obtained by following constant wet bulb temperature is equal to W two minus W one into hf this is from the energy balance for the adiabatic saturator okay.

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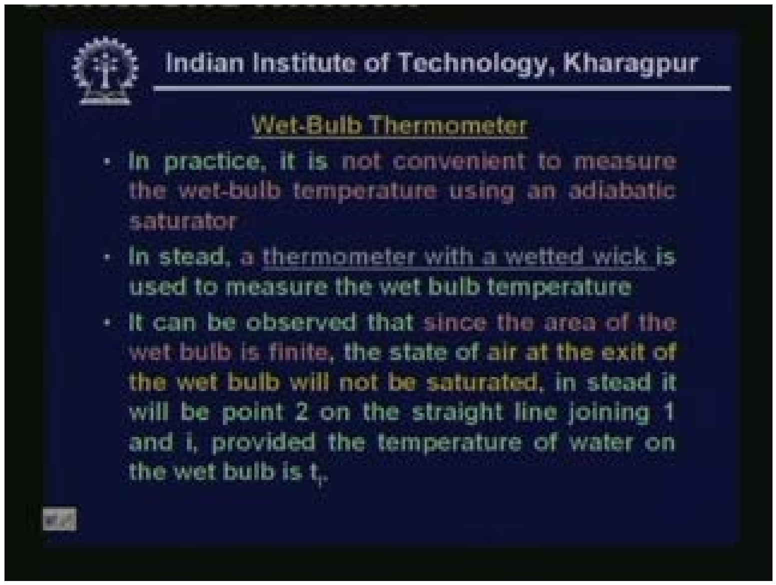

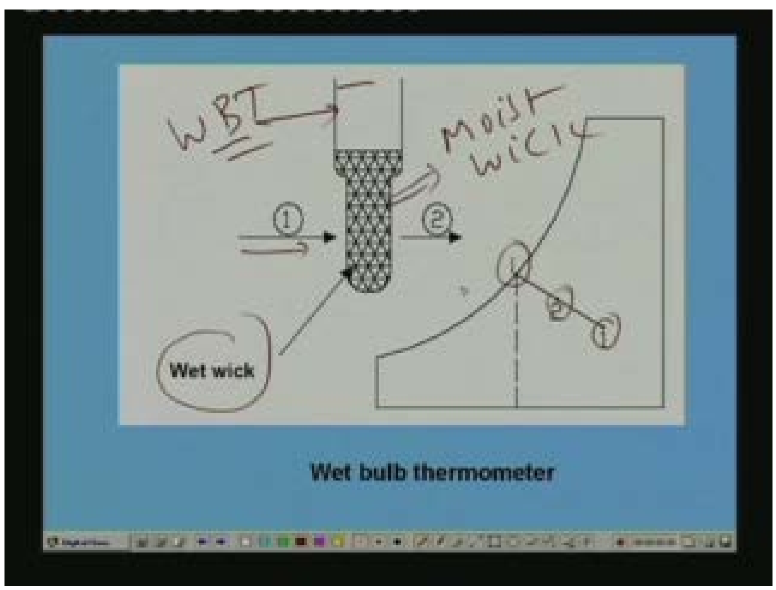

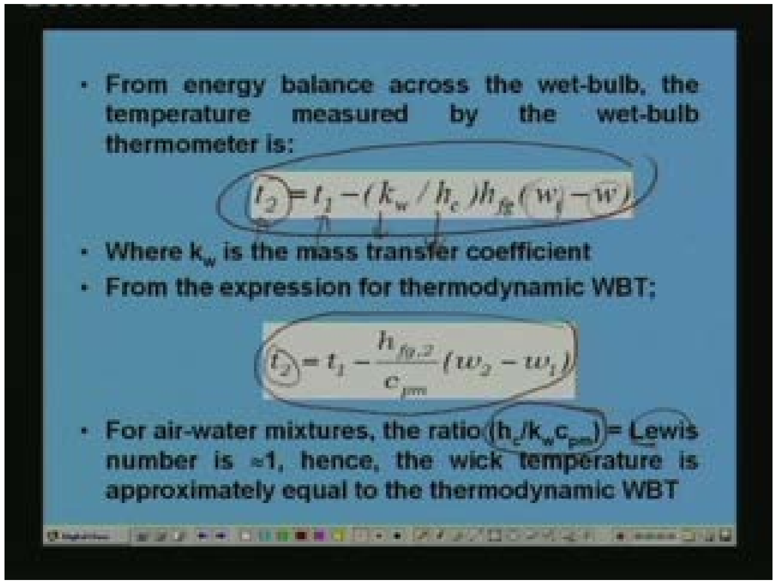

Now let us quickly look at what is known as the wet bulb thermometer in practice. It is not convenient to measure the wet bulb temperature using an adiabatic saturator instead a thermometer with a wetted wick is used to measure the wet bulb temperature okay. We cannot find the in practice you cannot have a infinitely long and perfectly insulated duct and wait for its steady state and measure its temperature okay. It s not convenient it is not practically feasible okay. So in practice what we use is what is known as the wet bulb thermometer okay what is a wet bulb thermometer? A wet bulb thermometer is nothing but an ordinary thermometer. But it is bulb sensing bulb is covered with a wet wick okay. So this is covered with wet wick that means you have a moist wick okay. And air flows over this one right and the temperature measured by this is your, we call it as wet bulb temperature or WBT okay.

And if you are applying the straight line law you find that if this is the inlet condition to the wet bulb wet bulb thermometer and if this is the of the moist air on the bulb okay. Then you find that outlet the condition lies on this here okay. And it is called the Lewis number. So when lewi number becomes one then the temperature measured by the wet bulb thermometer is same as the thermodynamic wet bulb temperature okay. So this is the principle.

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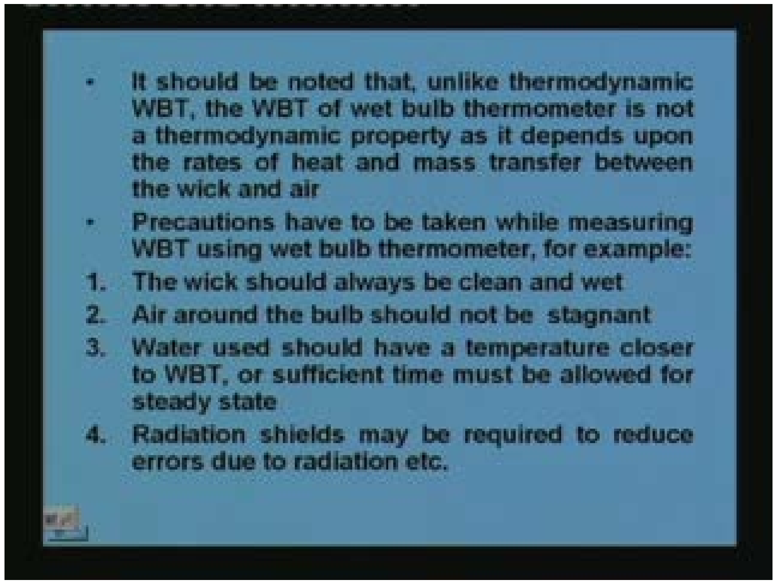

Of course it should be noted that unlike thermodynamic wet bulb temperature the wet bulb temperature of wet bulb thermometer is not a thermodynamic property. As it depends upon the rate of heat and mass transfer between the wick and air. So precautions have to be taken while measuring WBT using wet bulb thermometer. For example when you are using the wet bulb thermometer you should make sure that the wick is always clean and wet air around the bulb should not be stagnant water used should have a temperature closer to wet bulb temperature or sufficient time must be allowed for steady state. And radiation shields must be required to reduce errors due to radiation etcetera.

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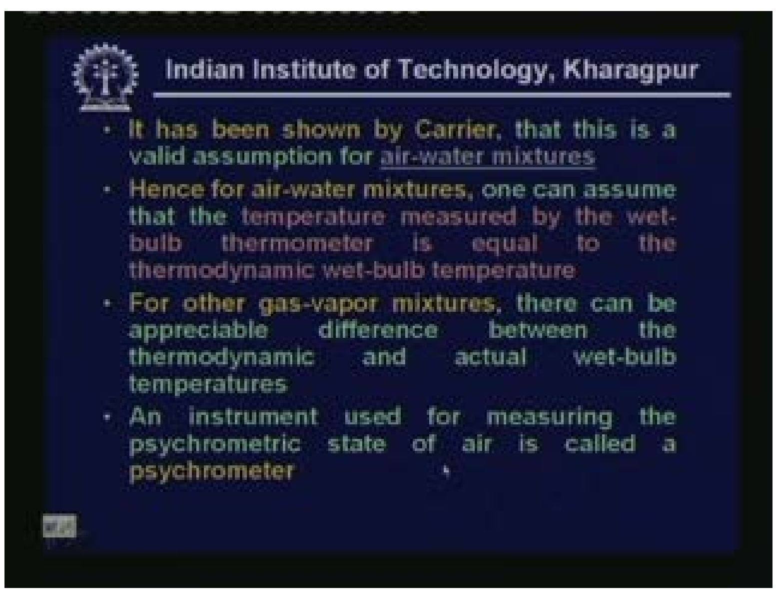

Okay, so for air water mixtures we assume that the temperature measured by wet bulb thermometer is equal to the thermodynamic wet bulb temperature. But this may not be valid for other gas vapour mixtures okay. There can be appreciable differences when you are talking about other gas vapour mixture and an instrument used for measuring the psychrometric state of air is called as a psychrometer okay. There are different types of psychrometer. So at this point I stop this lecture okay.

Thank you.