Introduction to Atmospheric Science

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Lecture-10
Atmospheric Thermodynamics- Introduction

Okay. Good morning, welcome back. We have completed two chapters in our course M.E. 5530 introduction to Atmospheric science.

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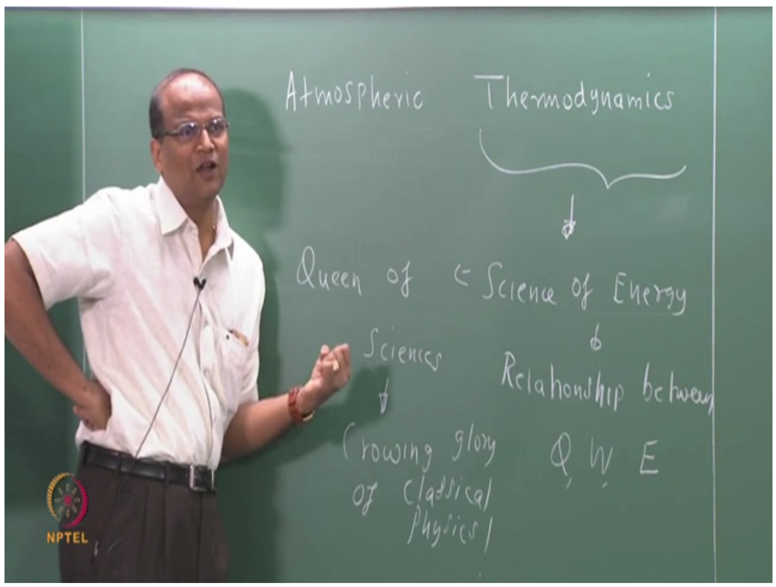

Now, we start off on a very important topic, if not the most important in this atmospheric science, which is atmospheric thermodynamics. So, we will be focusing on Thermo D as we frequently refer to thermodynamic system, Thermo D and the context is the atmosphere, the atmosphere of the earth. You can study atmospheric thermodynamics to Venus, Mars and so on, whatever context is atmosphere of the earth, okay. Thermodynamics is now I am very comfortable because thermodynamics to mechanical engineers is like playing cricket at the Lloyd's right.

So, we went through all this 1 month of descriptive type of lectures and all that. But I try to make it as interesting as possible by interspersing problems, whenever I feel whenever I felt there would be a sag in the interest every 15-20 minutes I will stop the PowerPoint and we have done problems, right. So, thermodynamics there is no need for that. You can just go on and on. So, we will have to take a call and where we want to stop, okay.

Wait, okay first we start with gas laws. Then, we look at virtual temperature but basically we are looking at moisture thermodynamics which is different from the thermodynamic which is studied a little bit. The science is not different but the context is different and the focus is different, okay. Mechanical engineering students must have already studied the psychometric chart and all that. But since most of your non-mechanical students, it would not be a repetition for you.

It, it may, it may bring in that much needed alacritic freshness which you are looking forward to any course. They, so, he will start with gas laws then we go to the first law then, you go to the second law and apply to the atmosphere. Anyway here the piston and cylinder will be there so we come without piston and cylinder we cannot study, hope to study thermodynamics. But we will restrict the piston and cylinder to a minimum. We are not going to solve problems and four-stroke engine two stroke engine and so on.

So, thermodynamics is the science of energy, relationship between heat, work done and the energy, okay. The transformations okay it is take place work to heat, heat to work and if they are not equal there is something which changes which is called the energy. This energy can be made more specific by calling it as internal energy + other energies and so on. This internal energy is a property of the system and all that.

We will really flesh out all this terminology as we go along. So, thermodynamics is refer to as the queen of Sciences always you say, queen of Sciences not, King because some queen is most, most the same the queen is far more important she is the queen of Sciences. Some people have said that if all knowledge is burnt if all of human or whatever human beings have acquired is burnt, the thermodynamics is left behind; we can pre-select the whole knowledge with thermodynamics.

Do not say sir, you will say like this because here from a M.E. of but a little bit that will be there. But still by and large this is true. So, thermodynamics is basically the queen of Sciences. And I am not saying this Wallace and Hobbs, we are referring to that book pretty I mean quite a bit Wallace and Hobbs, okay very respected atmospheric science professor. Professor says that thermodynamics is the crowning glory of classical physics, okay.

It is a crowning glory and 1 of the cornerstones of classical physics. It is not only the cornerstone of classical physics; it is also the cornerstone of mechanical engineering because we would like to convert heat to work through the heat engine. Though there are other ways of producing work directly without the heat engine name namely the solar photovoltaic, wind energy and so on, right.

But if you look at the automobile plane airplane and all these and engines producing power. In most of these cases we are able to convert heat to work which reduces human toil and makes human life more comfortable and productive you can go on and on. I can talk because it is my domain, I can keep on talking about this will restrict our will just close the discussion here that it is very important.

And it has got applications not only in mechanical engineering, it has got applications in physics, it has got applications in chemistry, it has got applications in metallurgy. You have got metallurgical thermodynamics, we got chemical engineering thermodynamics. Even thermodynamics and in entropy; entropy is the amount of disorder, right. So, there is something called information entropy and all this which is heavily used in computer science, ok.

We want to minimize the entropy and write. Information, more information is less entropy and less information is more entropy. The Shannon's entropy principle and there are so many things where thermodynamic concepts are used, okay. So, thermodynamics is basically a very important subject and in atmospheric science is very much used we can we can solve a lot of problems we can gain we can get a considerable handle on the way they atmosphere we get behaves if you take recourse to thermodynamics, right. So, where do we start? Gas laws, ok.

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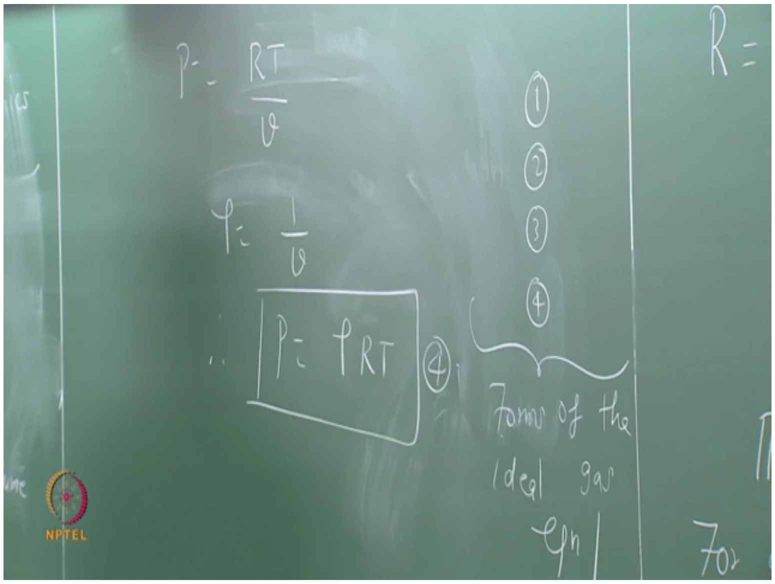

So, the ideal gas equation is PV = m RT, okay, Pressure, Volume, Mass, the gas constant, okay. Please forget that PV = NRT and moles and all that, okay. Sometimes it may be useful in the thermodynamic in chemistry and all that. But as an engineer I hate PV = I am sorry to say hate that PV = NRT, right. Mole cannot 1 kg is easy to comprehend, okay. So, your teachers have taught PV is = NRT, please remember that if you want. There is no problem. R is the gas constant what is, what is this R?

R divided by R, is the universal gas constant and M is the molecular weight of the gas. For air sorry, 28.97, what we can normally it is accepted 28.97, okay. You call it as kg per kilo mole. That is what we say. But some of the kilo mole is has not gained currency is it or what? Anyway, 28.97 so that will be joules per kilo mole, is it not, you do please remember your basic stuff meant joules per kilo mole. I want these, air to be 28.97. If you do not get that we will keep on working in reworking till we get that. Now you just 8314 divided by 28.97 you please do it, very good.

Joules per kilogram per Kelvin, you got the same units as specific heat, correct. But now I will have to say that this is the MD, molecular weight of dry air. So, this is the gas constant of dry air. That means later on I am going to talk about gas constant of moist air, okay. So, where whatever we come into the picture and so on. Now PV = mRT. RT, what is V by M Rho, what is V by M. Specific volume. What is 1 by Rho? PV = RT meter cube per kilogram.

All these are various forms of the ideal gas equation PV = m RT, ok; PV = RT for 1kg. PV by M = RT. So, this is specific volume. Yes, engineers hate density so, we prefer specifically chemists are so hung up with density. All this is Lie man and so can we let it a little later. You are not hung up on density, right. Our steam table is all specific volume: v F V g; H F H G S F S G. How many of you use the steam table? Yes all of you have used the first year. So, it is all specific volume, no density okay.

Now, now whatever you wanted to say now, you say that P = 1 by V = Rho P = Rho RT is a very good equation number 4. So, 1,2,3,4 they are all forms of the ideal gas equation, okay. How did this come into play? Be how did you figure out this play? Boyle's law and Charles law, okay. There are so, two guys who just first figured out these two. So, we look at the historical development quickly.

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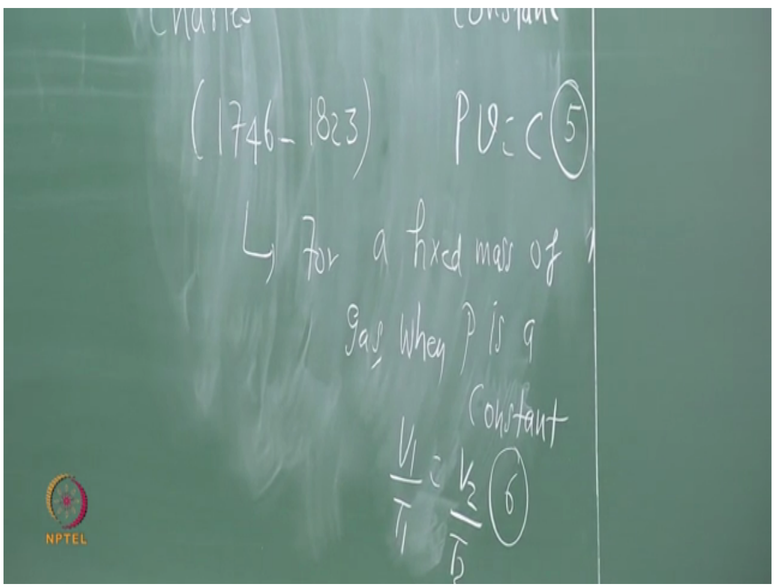

I will use the notes to give the year in which they gave us born and so he is British both physicists and chemists Boyle. So, it is okay if he makes call him Sir Boyle, right as he was Sir Boyle. So, 1691; so, for a fixed mass of gas when T is a constant you figured out that PV is a constant, okay. This is very important. T is constant; you want to use small v or we will use small v, it is some 5.

For a fix at mass of gas so, some silly questions will come balloon is a being inflated, volume is also increasing, pressure is also increasing, Boyle's law is violated. What a silly question, it is not a fixed mass of gas this is a trick question. You do not know this tricky question. You inflate a balloon, is the pressure increasing? Yes, is the volume increasing? Yes. Then, how is PV = constant, is it violated?

Silly question because it is not for a constant mass of a gas. And also when we say Hookes law what define Hookes law? Stress is proportional to strain. What a silly answer? Within the elastic limit, stress is proportional to strain outside the elastic limit it is not valid. You have to be careful, okay. Precision is very important, all right. So, next is this Charles, okay. What is this? What should be his nationality? Charles in Germany, you ask him no way, no. They do not like, French, okay.

So, they like William, Williams, Swen, Yen's, Marius, ok. 1746 okay. So, what did this guy say? Again, for a fixed mass of gas, right; what did he say? When P is a constant correct know? There are various forms. When P is a constant V1 by T1 is = V2 by T2. Somebody taught you V is a constant P1 by D1 is also constant and that is also correct. You cannot contact him now and find out version is correct.

But both that we can derive 1 from the other, okay. What is this now? V1 by then it is possible for you to combine the Boyle's law and Charles and say that PV by T is a constant and then somebody did a lot of experiments and then, they figured out the universal gas constant all the story, you must have studied earlier, okay. So, let us go past that apparent mixed is, okay. Now, I have to say number of moles anyway though I do not like it for the sake of completeness, we have to define, what is the n the number of moles, okay?

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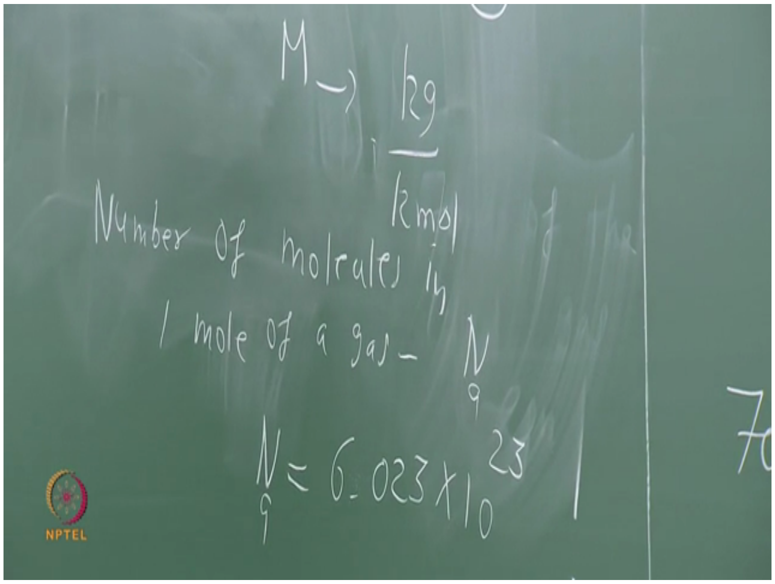

Is given by, okay so, what is this one, 7. So, this is also helpful in those cases where you know the molecular weight and for some strange reason somebody gave does not give you the mass but this gives the number of moles. Then using number of moles and molecule weight, you converted it to mass. And then use it in PV = mRT is it okay? What is the number of molecules in 1 mole of a gas? That is the Avogadro number, right. N, n is the number ah Capital n it is always capital n. Na is it? I forgot all this long back.

So, Na is 6.023 into 10 to the power of 23 is that ok? So, if you feel by some strange me means you know the number of molecules, it is possible for you to find the number of moles if you know the molecular weight, you can get the mass, once you have the mass then PV is = mRT. If two are known the third can be found out. That is a silly application of plug and play you know formula, okay. A + B = C + D. ABC are given find D, alright.

But we will do much more than that? What is the apparent molecular weight in the mixture? We have already seen this in the first chapter itself; we solve problems where we figured out, the molecular weight of air. But we will just formalize this with an expression for the apparent molecular weight.

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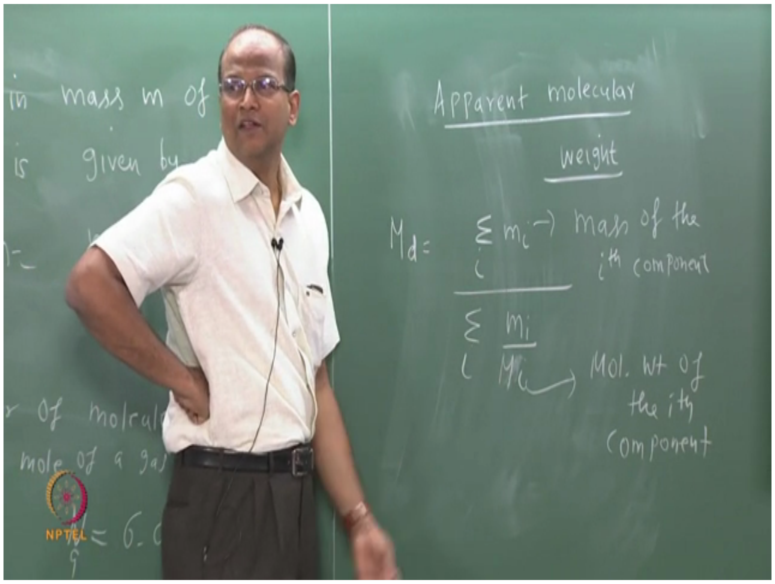

Where mi is a mass of the ith component, this is Mi know, okay molecular weight of the ith component. So, shall we check for the asymptotic correctness of this? If there is only 1 component it is M 1, M 1 divided by M 1 by M 1; there is no Sigma. small m1, small m1 will get canceled. MD = M 1 the molecular weight of the single component therefore, this formula appears to be correct, alright.

Next, okay what is the equation number 8, very good? Keep all these things in your notes. So, when we solve problems all these will be useful.

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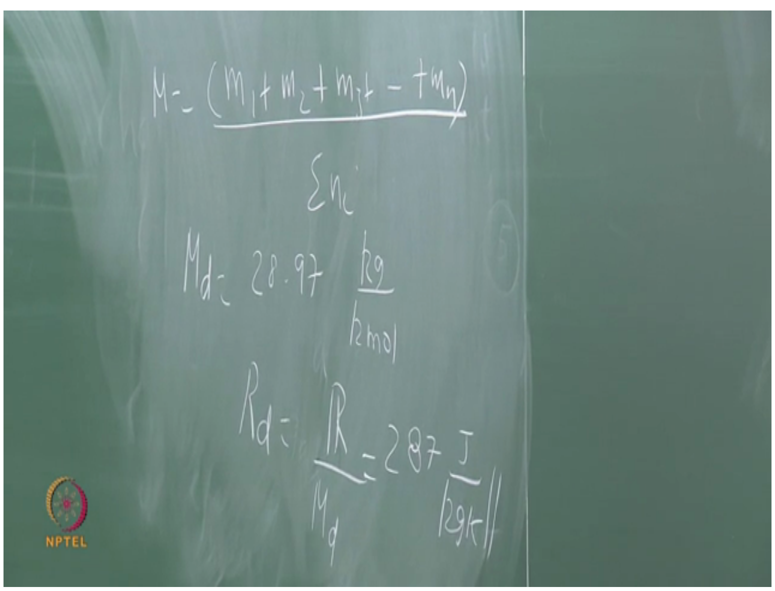

So, we can also call it as M = m by total number of molecules. So, we already did this, right. Numerator will give you kg, denominator will give you kilo mole. kg per kilo mole, fine. So, Rd there is no substitute for this. This is a universal gas constant again we turn around and write the 287 again, okay. So, this is basically a 20-minute course on gas laws. So, this is the ideal gas equation, okay.

The ideal gas equation is also applicable for individual species in air. So, the ideal gas equation should also be applicable for the water vapor present in the atmosphere, okay. So, let us write the ideal gas equation for the water vapor.

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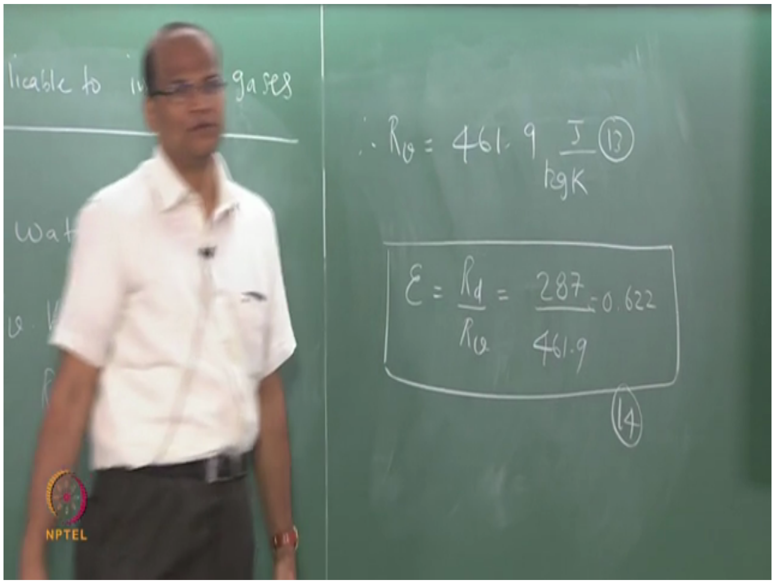

So, water vapor, okay equation number 9, we will put it as, we call this 9, 10, 11what is RV, 461.9, very good RV. RV by MV 18 kg per kilo gram, very good. Joules per kg, all right. So, you can apply this to the individual Rd by RV = 287, 461.9, 0.622, very important value in atmospheric thermodynamics, right. 0.622, we call it as epsilon. The ratio of the gas constant for dry air to the gas constant of water vapor is 0.622.

So, we will develop the concepts in moisture thermodynamics or psychometry in mechanical engineering based on this epsilon of 0.622, all right. Now, we are shifting gears from dry air, Boyle's law, Charles, Rd = RV. From dry air we are now getting into moist air. In moist air, this water vapor is also there. So, who is having a or which is having Ro of 461.9 which is quite different from 287. How to handle this moist air? You should have a framework for handling this, correct? Before that, if several gases are occupying a container, 1 first law which is very important has to be applicable. What is it?

Dalton's law of partial, partial pressures: So, you have to get a handle on this. Only then, you will be able to work out. Without this Dalton’s law will not be able to proceed further.

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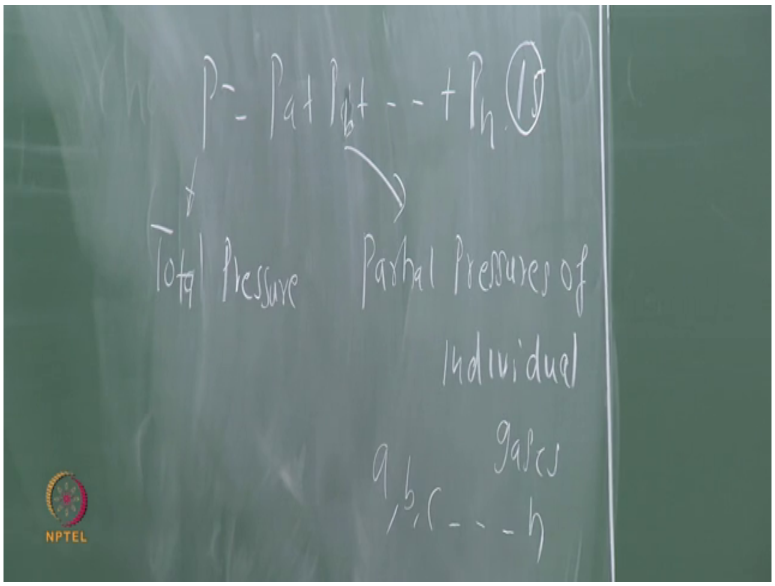

If you are looking at mixture of gases, okay. So, please take down the Dalton's law of partial pressures. It appears that he is a Brit know, okay. 1766, 1766 to 1844. 1844 is also important here, Ludwig Boltzmann was born in 1844. Boltzmann is 1844 to 1906, okay. So, you have got the Boltzmann constant and this thing and distributions, right. Boltzmann has got Stefan Boltzmann constant and radiation will spend start gaming, okay. Just like Max Planck and others, all right.

Dalton's law of partial pressures: the total pressure exerted. Please take down the total pressure exerted by a mixture of gases that do not interact chemically, okay; is = the sum the total pressure exerted the mixture of gases that do not interact chemically is = the sum of the partial pressures of the gases. This is a bad chalk okay.

Equation number 15. We have not done yet because we need to know what is partial pressure maybe okay. Once you know the definition of partial pressure you can use that Dalton's law of partial pressure and then I am going to introduce a construct. The construct I am going to introduce this I want to retain the gas constant for dry air itself. I want to stay, I want to stay with 287 joules per kilogram per Kelvin. I know the total volume V and so on but I but I know that I cannot proceed further without recording for the water vapor.

Therefore I am introducing a constraint called the virtual temperature. The virtual temperature will correct for the water vapor present in the atmosphere. So, once I have a virtual temperature then I go ahead and use the ideal gas equation as though all other things will correspond to dry air and then, I will make this virtual temperature correction and do all the calculations, okay. So we are heading towards that. So, the first step was the Dalton's law of partial pressure.

Then, partial pressure: Please take down the definition of partial pressure. The pressure a gas would exert at the same temperature, as the mixture, the pressure a gas would exert at the same temperature as the mixture, if it alone occupied; pressure a gas would exert at the same temperature as the mixture if it alone occupied all of the volume.

Pressure a gas would exert at the same temperature as the mixture if it alone occupied all of the volume that the mixture occupies, okay. So, that volume problem is not there because for everything it is a total volume V, okay. Now, we have to go into this very important concept of virtual temperature I do not think you have studied this elsewhere is it not ok? So, virtual temperature is an important concept in atmospheric thermodynamics.

Finally in some problems we will tell pit we will say that virtual temperature is same as temperature but first we should know what virtual temperature is, all right.

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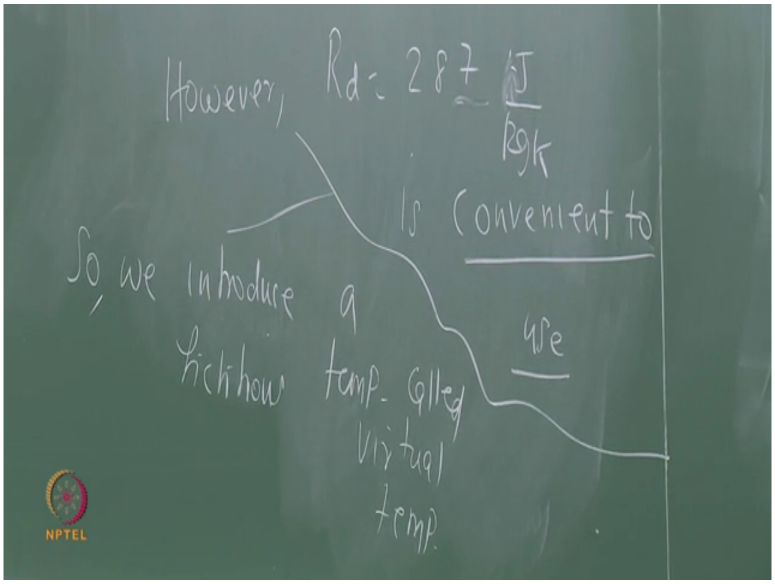

Virtual temperate this good, they are good. They call it temperate tua, German okay. Virtual temperature TV small v whatever you want, where is the need for introducing this virtual temperature because M of moist air is not = Md, okay. Joules, however R is = 287 joules per kilogram per Kelvin. It is convenient to use. So, we introduce a fictitious temperature called virtual temperature. Now, how do you derive this virtual temperature okay? Shall we derive this now?

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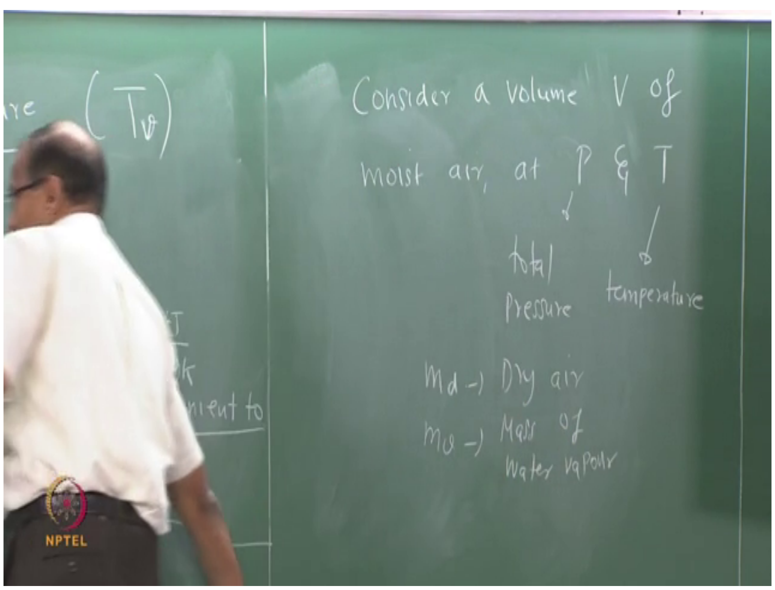

Consider, a volume of capital V of moist air and pressure total pressure P and okay P is not good. So, Md is the mass. What is the Rho of air?

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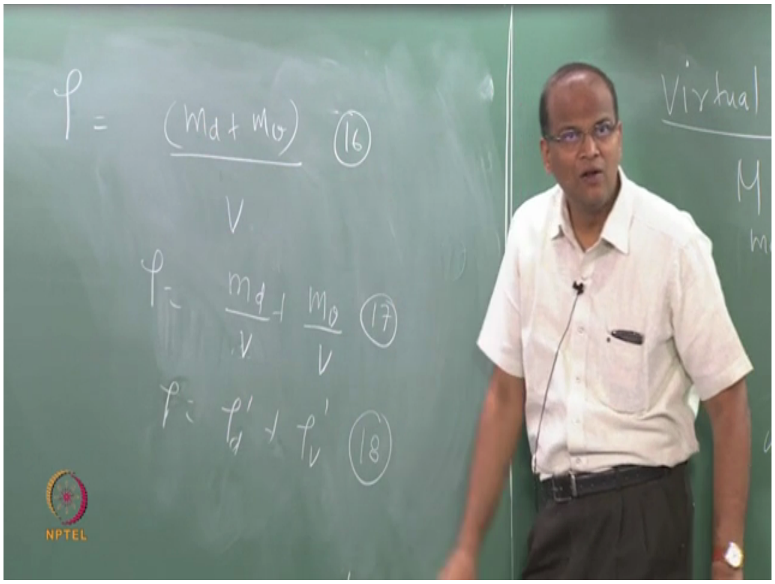

From the data given, what is Rho? It is Md + Mv by v, as simple as that. Why do you take such a long time? Yes or no. Of course it is correct, right. 16? I am introducing something called a partial density, okay somebody, some teacher taught me, that densities cannot be added. So, it is partial density it is some other hypothetical concept, okay. Volume can be added; density cannot be added. All those principles are correct? What is this partial density?

Please take down this definition. I have some definition, okay. Rho d dash density Rho d dash is the density Md kg of air, okay Rho d dash, the partial density of dry air is the density Md kg of air would have had, if it alone occupied all of the volume V, correct. The density Md kg of air would have had, if it alone occupied all of the volume Capital V, okay. Rho V dash, dash, dash, dash, Mv kg of water vapor and complete the sentence, okay.

The partial density of water vapor is the density Mv kg of water vapor would have had, if it alone occupied or of the volume, okay.

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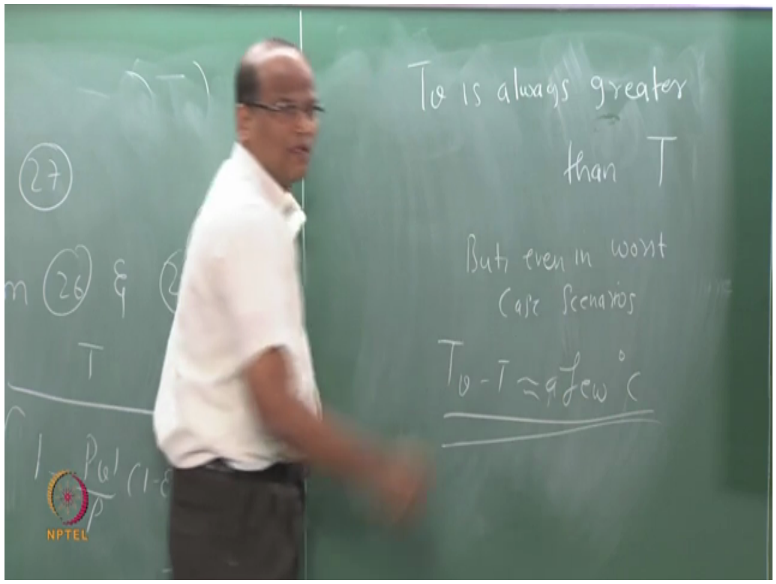

So, what is P, what is PV dash? Very good, good, 19. Pd dash, Rho Rd T, correct, now, the key funda is P =, who is responsible for this? Dalton's, okay. So, this is Dalton's Law, okay. So, what is the funda now? all right. Correct, all right, Can you complete this? 1-, this is correct I think it is correct. What is Rd by Rv, epsilon. That is also 0.622 substitute for that. So, this is now 25. Why all these struggle in life? Sir, what are you doing sir? That question comes why, and then you have to introduce that.

I want this. That is what I want, okay. Therefore, correct. So, TV is the virtual temperature. See, if you are doing atmospheric thermodynamics calculations if you know what is the partial pressure of water vapor, or if you know what is the concentration of water vapor in the total, I will tell you in terms of volume, okay, volume and pressure is the same. You know to 1%, 2%, 3% you can put that point naught 2 into 1.62 so this will be a small number okay and then since this is the denominator Tv is always;

But even in worse case scenarios, Tv - T is only a few degrees C. We will demonstrate it with a help of two problems in tomorrow's class. The first problem I will give an arbitrary concentration of water vapor is 1% or 2%. You will find out the virtual temperature correction, in the second case we will refer to an old table where the atmospheric concentration of water vapor is there the lower limit and upper limit, you will apply the upper limit of the atmospheric concentration of water.

It is the worst case, okay. In that case we will see that TV-T will not be 10's of degrees centigrade. It will be only a few degrees centigrade. Sometimes, you can ignore or I mean sometimes ignore or you make this correction and use it in your calculations. So, this is the way you correct for water vapor in the, instead of working on the gas constant this thing you know that you just correct the temperature, there is a virtual temperature.

Therefore, you still have 1 minute. Please take down the formal definition of virtual temperature. Virtual temperature is the temperature that dry air would need, sorry, correct, but the way I said it is not correct virtual temperature is the temperature that dry air would need to attain in order to have the same density, okay. Virtual temperature is the temperature that dry air would need to attain in order to have the same density as moist air. In order to have the same density as moist air at the same pressure, correct.

As it gets heated it becomes lighter therefore the temperature from T has to go up from Tv so that it density is lighter so that it matches with the density of moist air. The density of moist air is less than the density of dry air, consequent upon the fact the gas constant of for water vapor is 461.9 and this is 287, if some few percentage points are there, you will get a gas, you will get a composite gas constant which is more than 287, consequent upon which the density will be lower. So, this air has to be heated up by a few degrees from T to Tv in order that its densities are matched, okay.