Introduction to Atmosphere and Space Science

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Lecture – 17
Atmospheric Thermodynamics

Hello dear students. So, today we will start a different module in our discussions of Atmospheric and Space Physics. So, this module is called as the Atmospheric Thermodynamics. So, we will discuss various aspects of atmospheric and various aspects of thermodynamics, which will be relevant for our understanding of atmospheric science, right.

So, this is; today we will in particular we will talk about, we will talk various things about the basics of thermodynamics; how do we formulate the basic principles, how do we define the constants, how do we define the variables, and what are the general equations which are relevant for atmospheric physics, right.

So, to begin with, so let say what is thermodynamics?

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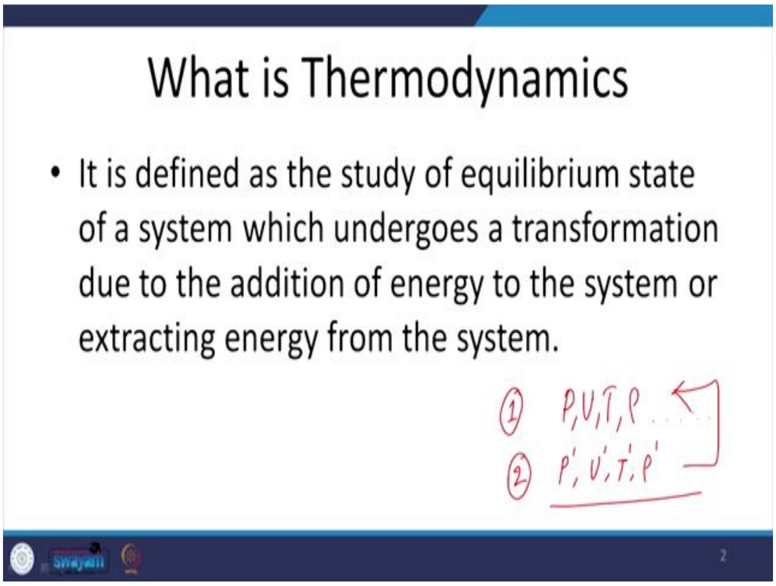

So, it is defined as the study of equilibrium state of a system which undergoes a transformation due to some addition of energy to the system or extraction of energy or extraction of work from the system. So, it is basically defining; how the system responds to addition of heat or removal of heat, how the system will transform from one state of equilibrium to another state of equilibrium, right.

So; that means, that every state of equilibrium is defined with the help of few variables which are generally called as the thermodynamically variables. So, we define a particular state of a system with the help of variables such as pressure, volume, temperature, density and so on, chemical potential so many other things. So, the point is thermodynamics deals with the understanding, thermodynamics will be able to tell you what will happen to a particular system and it is variables. If you add some energy to it under some conditions under certain conditions; what will happen to these variables, how will they transform with respect to time or with respect to changes in any other variables, right.

So, if so the initial state of equilibrium is defined as 1; if this transformation happens to another state which is equilibrium state 2, so these variables are to be defined as a different set of variables. We will the thermodynamics basically deals with the understanding of how these variables can be derived in terms of these variables, or how you can describe the new state of equilibrium with the help of your understanding of the process and the initial set of variables. So, this is the basic definition of thermodynamics, right.

Now, what do you call as a system? So, we are we are saying that system is something which undergoes a transformation from one state of equilibrium to another state of equilibrium. So, a system is simply defined as a simple or specific state of matter. So, you can take any defined state of matter which is obeying some physical laws as a particular system. Now this system can be of different types.

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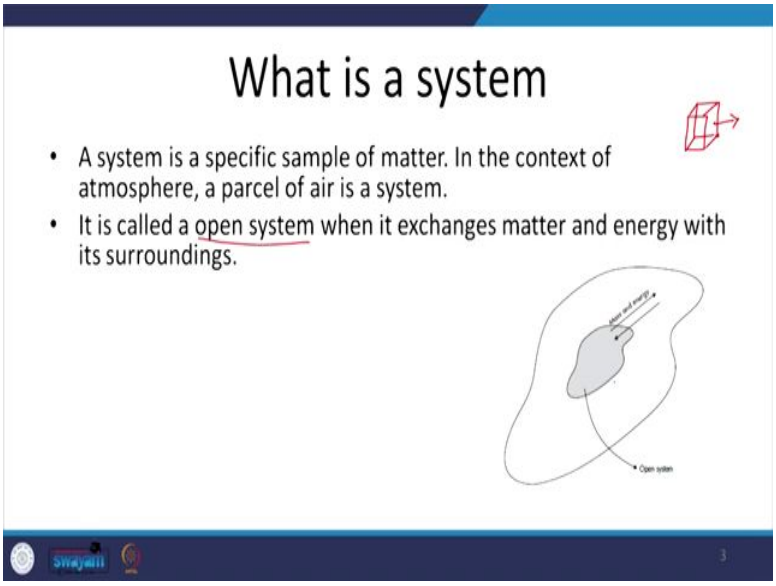

So, for example, in the context of atmospheric physics, we will be talking about something called as an air parcel; if small infinitesimal small volume of air which is suspended in the atmosphere is generally referred to as an air parcel.

So, now our discussions will be pertaining to the changes that will happen within this air parcel or the way this air parcel interacts with the surroundings, that is; with the atmosphere, right. Now what we will do is, we will define a set of parameters for this air parcel, and under certain circumstances we will allow certain type of energy transfer with the surroundings. And whatever it is; the basic identity on which your equations are written, or on which you are trying to focus is called as a system.

It is simply is a collection of matter, right. So, this can be so depending on the type of physical process that you want to understand, depending on the state of matter, your system can be different; it can be a liquid, it can be a solid, it can be a mixture or it can be anything.

So, basically system refers to the object which you are trying to understand. So, by the means of understanding you should be able to tell what will happen to the system; if it is subject to a certain change, how will the system behave. So, you cannot write how the system behaves; but you have to take help of few variables which will tell how the system is behaving. Let say for example, if the system is expanding; then the variables, the certain variables that are going to help you in describing this particular change are the pressure and volume. So, the pressure will decrease, if the system is expanding and the volume will increase.

So, this kind of quantitative behavior with the help of quantitative description; with the help of few variables will make the description of the system simple, right. So, now, the system can be of many at least two different types; one an open system or a closed system. Now system is a specific collection of matter, sample of matter that is it. Now this system can be open or closed; you call it as a open system, when it exchanges matter and energy with it is surroundings.

So, you define particular; let say in our case, we have seen that the air parcel which is freely suspended in air is just a small volume of air which is suspended in the atmosphere. So, this is your system and if the system is exchanging matter or energy with its surroundings, you call it as an open system; that means, through the walls of this air parcel, if matter is flowing in and out or if energy is flowing in and out or if the system is changing its temperatures due to its interaction with the surroundings, then you call that particular system as an open system simple, right.

Now, on the other side let say, if you have let says the inner contour that you see with a shaded region is an open system, which is able to extract, which is able to exchange mass and energy with the surroundings. If there are specific ways you define surroundings as well, but this kind of system which kind of allows this transfer of mass and energy is called as an open system, right.

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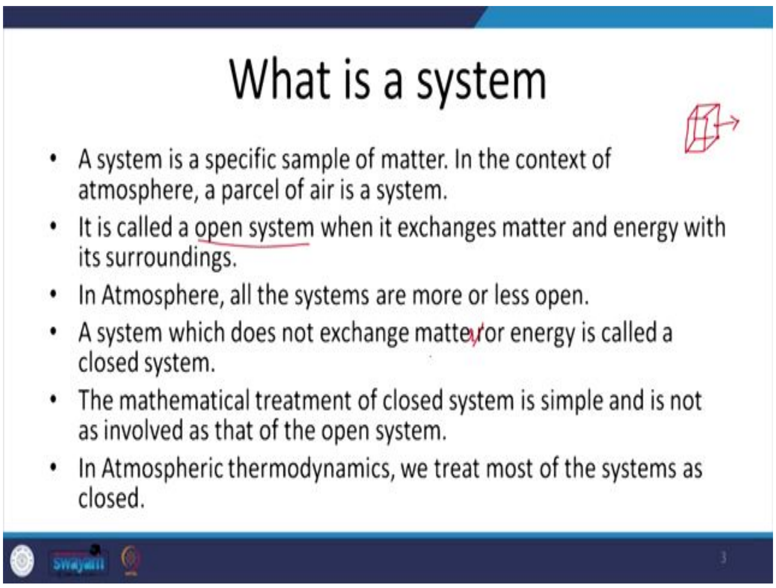

So, generally in atmosphere all the systems are more or less open. So, whenever you want to describe a certain physical phenomena in atmosphere and if it is thermodynamically in nature, if it is dealing with the exchange of energy or exchange of matter; then you consider a system, and generally the considerations are always such that the systems are always more or less open. So, you do not deal with closed systems many times. A system which does not exchange matter or energy is called as a closed system. The system which does not exchange matter or energy is called as a closed system. So, it is quite contrary to the definition of the open system, nothing else.

So, the mathematical treatment of closed system is simple and is not as involved as that of an open system. I mean as the definition goes itself, because you are not allowing any interaction; so, it is very easy for you to write equations of motion within the closed system, because there is no interaction term. But when you want to write an equation of motion or when you want to describe the time evolution of a open system, it is more difficult; because as the system allows matter and energy to be transferred, there is the first thing that will make it complicated. Then if the system is moving with respect to space or with respect to time; then these exchanges will also fall under certain rates, then the system will get even more complicated.

So, as a rule, so the mathematical treatment for closed system is simple and is not as involved as that of an open system. So, open system is more difficult to describe or to comprehend. So, in atmospheric thermodynamics, we treat most systems as closed systems. So, you understand the difference. So, generally in atmospheric thermodynamics, we treat most systems as the closed systems; but in atmosphere, in the broad description of atmosphere, we treat them more or less open, right. So, because we want a simple description to be given for in terms of thermo dynamical variables, so we treat it as a closed system.

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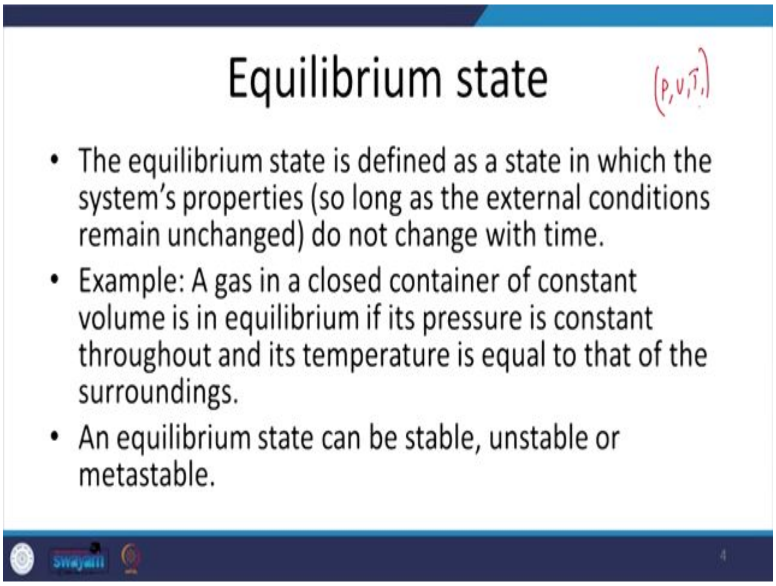

So, what is an equilibrium state? So, like I said, thermodynamics is the understanding is the is what gives description from one equilibrium state to another equilibrium state when something is exchanged ok; some work is done, some energy is given out, some energy is taken in something like that. So, the equilibrium state is defined as a state in which the system's properties, so long as the external conditions remain unchanged do not change with time, so simple, right.

So, equilibrium state is defined as something; let say if the system is not interacting with its surroundings or even if it is interacting with the surroundings, and the surroundings do not change so long. As long as the surroundings do not change; that means, you are limiting the kind of interaction, you are not allowing the interaction to change. There can be an interaction, but this interaction should not change with respect to time.

So, when it is not changing and if the system reaches a state, a particular state in which the variables which describe the system would not change with respect to time. So, let say for example, if you want to describe the equilibrium state of a thermodynamically system; you would naturally expect that the pressure volume let say temperature do not change with respect to time, then as long as these variables are held constant with respect to time, the duration of time is generally called as an equilibrium state. So, within this duration things are not changing much; but only if the external conditions also remain unchanged. I mean this goes without saying such that; if the external conditions change, in the system variables, the thermo dynamical variables; the dynamic variables are bound to change and you will have a different state that is not equilibrium state, right.

So, this is this equilibrium, let say for example, a gas in a closed system, gas in a closed container of constant volume in equilibrium; if it is pressure is constant throughout and the temperature is equal to the surroundings, right. So, what does it mean? So, if you have a closed volume affair, which will exhibit some pressure and this pressure is a function of the temperature of the gas of the container itself, right.

Now if the system is exchanging or energy with the surroundings, so the temperature; that means, there is a gradient in the temperature, if there is a gradient in the temperature, the temperature is bound to change. I mean it can go up or it can go down. When the temperature is changing, the pressure will change; because you have held the volume to be a constant, the pressure is bound to change, right.

So, if this exchange is not happening, if the temperature is the same inside and outside the system; so there is no reason for the pressure to increase or decrease. So, this state of equilibrium is generally referred to an equilibrium state, right. So, an equilibrium state can be stable, unstable, or metastable.

See; basically what do you call as an equilibrium; equilibrium is the state where the variables are not changing with respect to time. Generally, what happens is, over a limited period of duration the, with these variables do not change and this period of time is called as an equilibrium state over which things are not changing, right.

Now, this equilibrium state itself can be of three different types; one a stable equilibrium state, an unstable equilibrium state, or metastable equilibrium state. So, when we talk about the atmospheric stability or the formation of clouds and a convective processes in atmosphere, we will realize with more relevant examples of how this what is stability, what is stable, what is unstable, what is neutral or metastable, and what are the implications of this different kinds of stability in the formation of clouds.

So that means that, variables are not changing; does define what is an equilibrium state; but this in itself has three different types of equilibrium states, which are stable equilibrium state, unstable equilibrium state, and metastable equilibrium state.

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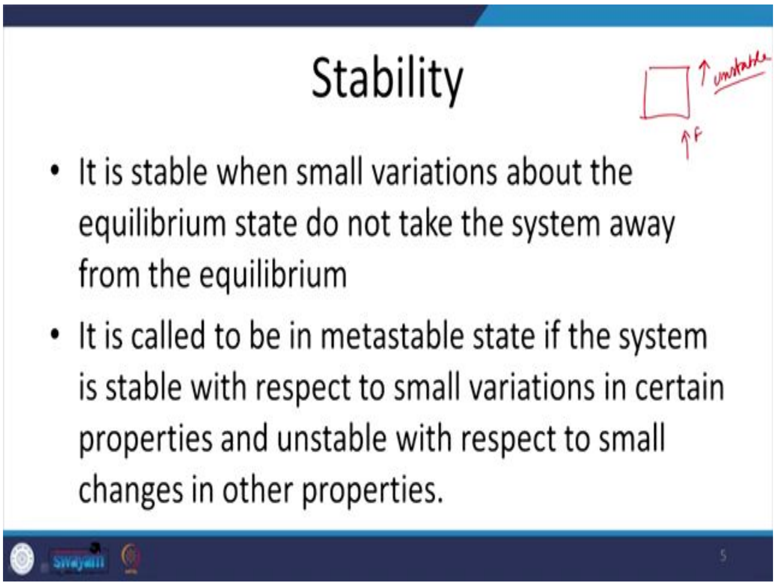

So, let say it is stable. So, the equilibrium state can be called as stable, when small variations about the equilibrium state do not take the system away from the equilibrium, right. So, what it means is that? When you induce small variations, you cause any physical force to act on it or you cause any small exchange of energy or heat into the system which is already in equilibrium.

But due to the small fluctuations, if the system deviates away it, does not deviate away from the equilibrium; if it comes back to the equilibrium state, then you call that particular equilibrium state has a stable equilibrium state. That means, the external influences are not making the system go away from the equilibrium. So, equilibrium is still maintained, subject to small fluctuations which you may induce, right. So, this is a stable equilibrium state.

So, when you talk about a metastable in equilibrium state; if it is if the system is stable with respect to small variations in certain parameters, and unstable with respect to small variations in some other parameters, right. So, like I said, any system has to be defined to be in equilibrium with respect to some variables, some set of variables. So, these variables are not changing with respect to time, even though you are change you are manipulating the external conditions; then it is stable. If they are not changing, you call it as equilibrium; if they are change if they are not changing, despite your external influence, it is called as a stable equilibrium. If the system is not deviating away from the equilibrium with respect to small variations in some parameters, but it deviates away from the equilibrium with respect to some other parameters.

So; that means, there are some parameters which can disturb the equilibrium and there are some parameters which will not disturb the equilibrium. So, this kind of stability is generally referred to as neutral or metastable equilibrium state. So, that goes without saying that, if the system is disturbed by a small influence and if the system deviates; if the this is your system, if you apply small force let say, the variables will change. But if it is not returning back to the equilibrium state, then you call it as unstable equilibrium state that is it. So that means that, if the system is deviating away from the equilibrium state subject to small variations outs from outside, then you call it as unstable equilibrium state, right.

So, we have seen what is the system, how would you describe the system, what is the reason for you to take something as a system, how many different types of system are there, open system and closed system, and when do you call this system to be in equilibrium state. And if it is an equilibrium state; how many different types of equilibrium states could be possible, and how do you define these different types of equilibrium states. Most importantly, the metastable state for example; the metastable state will remain stable with respect to some parameters, but not with respect to all parameters.

And these some parameters which will keep it stable are specific to a particular type of system; so not every system will have the same set of variables which will make it stable, right. So, that is something about the basic understanding of what is thermodynamics and what are the various principles, various beginning ideas of thermodynamics let say.

Now let say for example, in atmospheric science generally; we are dealing with a gas envelope offered, we are dealing with a mixture of gases which is surrounding the planet and the primary reason for these planets to be, for these gases to be surrounding to be near the planet is the gravity. So, gravity holds the holds the gases together or makes the gas stick to the planet, right. So, our thermo dynamical system by; you must have understood that, the thermo dynamical system that you are going to talk about is generally a gas, a fluid system which you have to describe with various specific laws. Let say for example, so the gas laws, I mean how do you let say; if you have a fluid system, mixture of gas, how do you represent this gas system, how do you write an equation of motion for this gas, what can be let say what can be the simplest expression by which you can derive various properties about this gas, ok. So, this and all will come under the gas laws.

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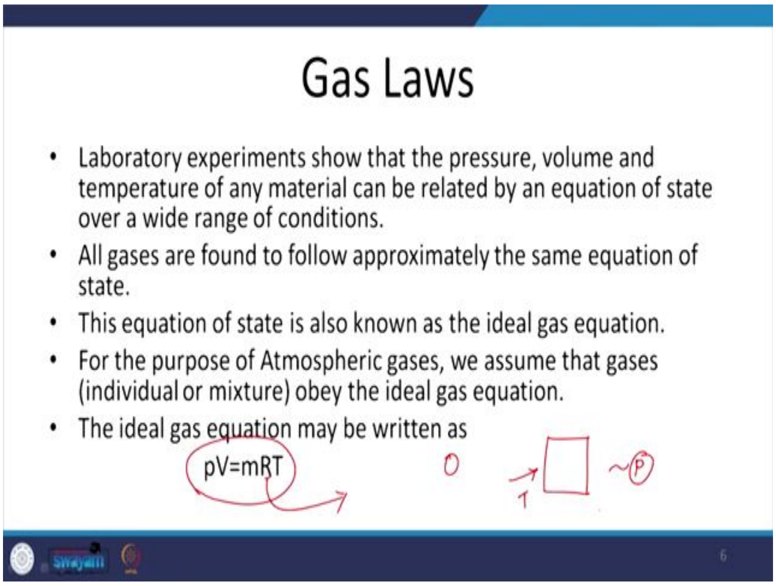

Let say laboratory experiments show that, the pressure volume and temperature of any material can be related by an equation of state over wide range of conditions. So, now, we have reduced ourselves to the understanding of gases. So, if it is the case. So, laboratory, I mean general experiments, I mean this is not something that we are discussing today; if this is this is kind of an established fact over several decades that, simple experiments have always demonstrated that if you take a gas, the way in which parameters thermo dynamical properties of the gas pressure volume and temperature vary, are simply connected by a simple equation of state. And this equation of state is valid over a wide range of conditions.

So, all gases are found to follow the approximately the same equation of state. So, no matter what; if it is a gas, if it is a mixture of gases, if it is oxygen, if it is nitrogen, any gas. You take the volume, you keep the you keep a particular value of temperature; you know what is the value of pressure by a simple gas flow, right. That means that, every gas under a wide range of circumstances; circumstances defined with the primarily with the help of temperature pressure and volume, will always obey a particular gas law.

So, this is this equation or this law is generally called as the ideal gas equation. So, for the purpose of atmospheric gases, we assumed that the gases obey the ideal gas equation. Let say for example; so individual gases or mixture of gases. So, the equation is generally written as p V is equal to m R T, right. So, this is the simplest form of the ideal gas equation and the point is, every gas will obey this ideal gas equation naturally, right. So, there is no specific condition over which this gas law is valid, naturally they will all obey this, right.

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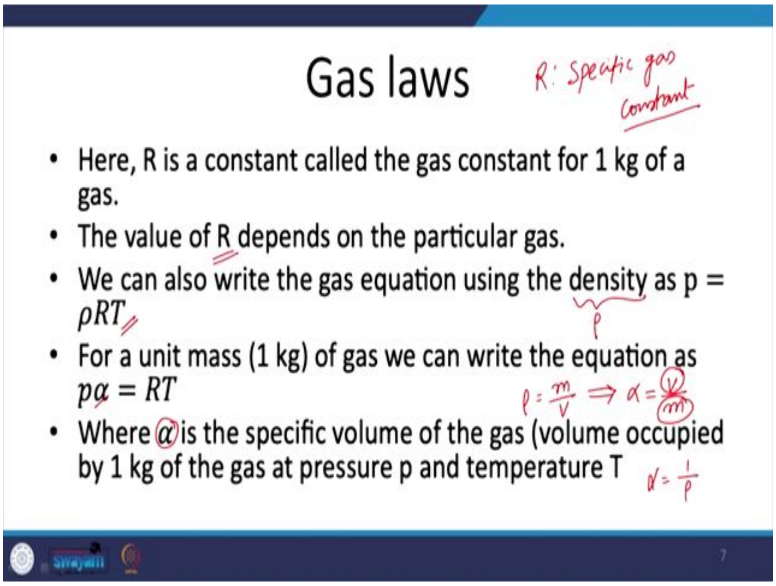

So, here if you see p V is equals to m R T. So, here this equation is a general equation, right. So, all the gases will obey it; but here very important thing is this R that you have seen is not a universal gas constant, it is a specific gas constant. Let see what it is, right. So, here R is called as a gas constant for 1 k g of a particular gas. So, what does it mean; it means that, if you are writing this equation for oxygen, let say for example; So, you have confined oxygen in a closed system, in a closed enclosure; you have kept the temperature of this enclosure to be at T degree Kelvin, then if you know the volume of this container you can derive the pressure of the gas. I mean pressure that is going to be exerted by this gas, right.

Now, for this you can use this equation, but only if you know the specific gas constant of oxygen to be used here. So that means that, every gas follows the same form of ideal gas equation; but it will take a different gas constant for each gas or for each gas mixture, right. So, the value of R now, let say this specific gas; I suppose you all of you must have learned these fundamental aspects in your earlier classes, but this will probably I mean this is serve as a refresher for your upcoming classes, right.

So, the value of R is depends on a particular gas. So, the value of R is different for each type of gas. So, simply speaking I mean. So, it is natural, is it follows naturally in the sense that, the pressure volume should, the pressure volume at a particular temperature should invariably depend on the type of gas; what is the gas, what is the size of atom, what is the size of molecule, how they interact and so many other things, right.

So, we can also write the gas equation using the density, as using the density rho as p is equals to rho R T. So, I have gotten rid of the mass term, now I have written in terms of rent density. Or for unit mass, for 1 kg of gas, we can write the equation as p alpha is equals to R T. Now where alpha is the specific volume of the gas; that means, volume occupied by 1 kg of a gas at a particular pressure at and at a particular temperature T. So, alpha is simply 1 by rho; alpha is 1 by rho. So, rho is defined as mass by volume; that means, alpha is defined as volume per mass.

So, the volume occupied by a gas of 1 kg, volume per unit mass, volume occupied per unit mass; that means, 1 kg is unit mass. And what is the volume that is occupied by this 1 kg unit 1 kg mass; is the specific volume. So, the specific volume is certainly different for different types of gases, right.

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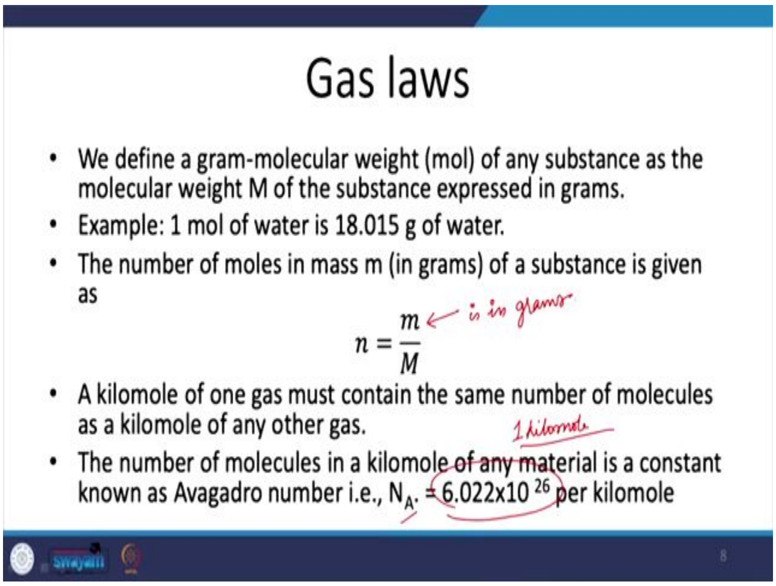

Now, we define what is called as the gram molecular weight of any substance as the molecular weight M of the substance expressed in grams, simple it is the same definition. One you define gram molecular weight as the molecular weight of a substance in grams.

So, 1 mole of water is 18.015 grams, right. So, what it means is that? If the molecular weight is 18.015 u; then 1 mole of water that is 18.015 grams of water of, let say this will contain 1 mol of water, right. So, like that for any given mass in grams; for any given mass of water in grams, you can always calculate the number of moles. So, the number of moles are defined as the weight defined by the molecular weight; but now m is in grams, right. A kilomole of one gas must contain the same number of molecules as a kilomole of any other gas, right.

Now, that is fine, but how much volume they occupy is the real question. A kilomole of oxygen will occupy the same volume as a kilomole of nitrogen, as a kilo mode of carbon dioxide; but eventually a kilo mole of any gas will contain the same number of molecules. Because you write the molecular weight in the units of u; that means, what is the total number of units of mass that it has, you take a certain grams of a particular substance, then you calculate how many number of moles are there in that particular weight, particular mass. Then any number of, same number of moles of any gas will contain the same number of molecules. But here the weight, I mean the mass has no meaning; we only talk about the number of molecules, we do not talk about what is the total cumulative mass that these equal kilomoles are have. They will have a different mass, but they will have same number of atoms or let say molecules, right

So, the number of molecules in a kilomole of any material is again a constant; which is generally known as the Avogadro number. Avogadro number is it 6.02 to 10 to the power of 26 per kilomole. So, you take Avogadro number 1 kilo mole; 1 kilo mole will contain this many atoms or molecules, this many atoms or molecules, right so simple. So, the Avogadro's hypothesis says, according to the Avogadro's hypothesis; gases containing the same number of molecules, occupy the same volume at the same temperature and pressure, mainly at the same temperature, right.

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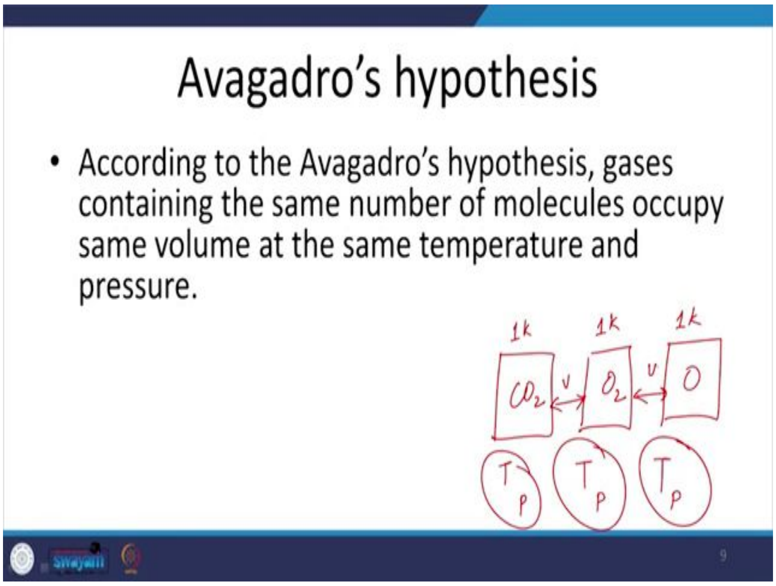

So; that means, you take different gases.

Let say you take a gas chamber of CO2, you take a gas chamber of O2, you take a gas chamber of O. Now if you maintain the same value of temperature T, the pressure will be different; of course, the pressure will be different. But if you maintain the same value of temperature and pressure over these different gases; then Avogadro's hypothesis says gases containing the same number of molecules of course, they are let say you take 1 kilomole of each gas, gases containing the same number of molecules occupy the same volume at the same temperature and pressure.

So, you keep these parameters same, then its natural that all these will have the same volume that is it. So, this is the basic idea of the Avogadro's hypothesis.

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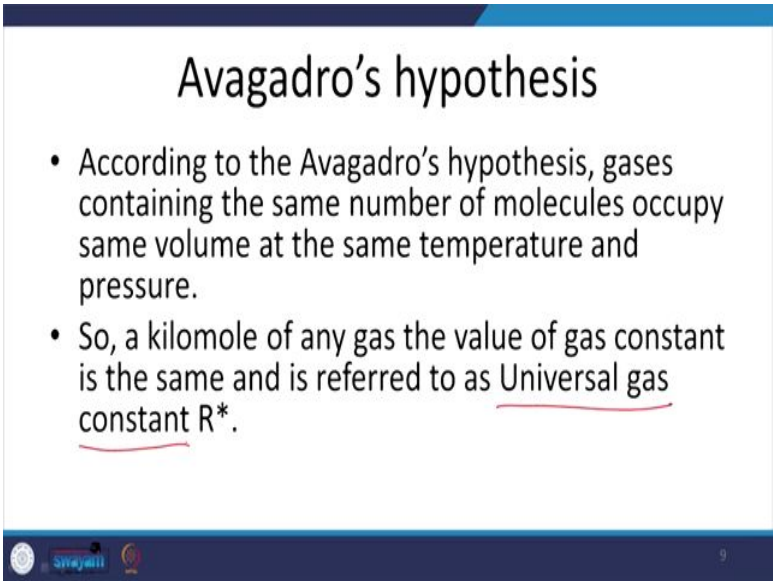

Then, so a kilomole of any gas, the value of gas constant is the same; a kilo mole of any gas, the value of gas constant is the same and this gas constant is referred to a universal gas constant. So, previously we defined R for 1 kg of a particular, specific type of gas. Now here we are saying we deviated away from 1 kg; if you take a lighter atom, 1 kg needs more number of atoms to be present. If you take a heavier atoms or heavier molecule; it is natural that, you will require less number of molecules to account for 1 kg, right.

When you get rid of this 1 kg, but rather you say in terms of number of molecules which are same over 1 kilomole. So, 1 kilomole of any gas, the value of gas constant is always the same and this gas constant is generally referred to as the universal gas constant. So, a kilomole of any gas, the value of gas constant is the same; because here it the definition of the gas constant relies on the number of molecules of a particular gas, but not on the mass of let say 1 kg, right. So, here 1 kilomole of any gas will have a same constant which is known as the universal gas constant. So, we will stop here, we will continue with our discussions in the next class.