Molecules in Motion
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Lecture – 01
Kinetic theory of gases

Welcome, to the course on Molecules of Motion. In molecules in motion, it is a important part of the physical chemistry syllabus, since we deal with the motion of molecules or particles either in the gas phase or liquid phase. So, kinetic theory of gases is one of the most important sections when we are dealing with gases. And kinetic theory of gases is one of the most fundamental theories based on which we have a model generated and this model actually relates the macroscopic properties of gas like pressure, volume, temperature.

These are the macroscopic properties to some of the microscopic interpretations and these microscopic interpretation is based on the principle or based on certain assumptions based on which we develop a model and that we model we call as the molecular kinetic theory model. For to begin with this section, let us briefly view the equations ideal gas law equations, we will not look into the details of it, we will just mention and recapitulate what are the different laws.

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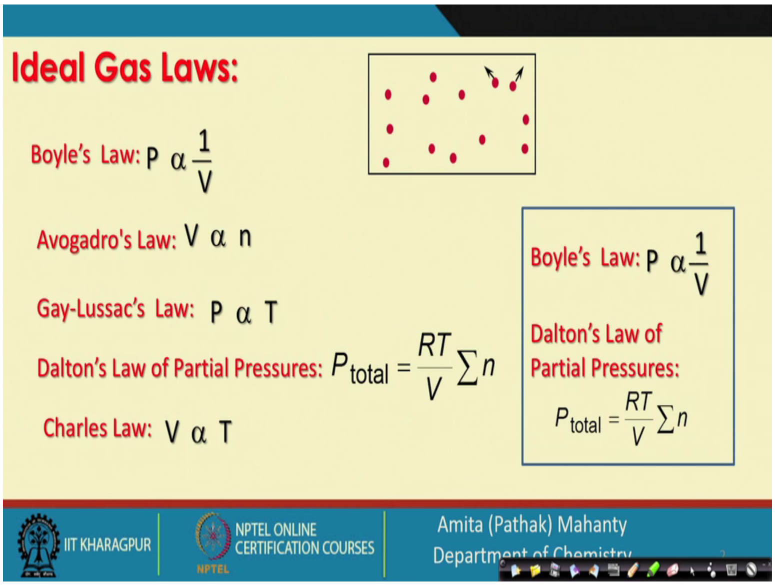

We have the Charles law, we have the Boyle's law, we have the Avogadro's law, we have the Charles we have the Dalton's law of partial pressure. What we are going to be looking into these are something which we are not going to dwell in, but these all these equations as we know are based on certain observations. What we see here is a macroscopic observation of a gas where we see say that when the temperature of the gas is held constant, the pressure of the gas is inversely proportional to the volume.

Similarly, we have this Charles law where you say that we have the observation that when we increase the volume or decrease the volume of the gas, when the pressure is held constant then increase in volume is going to be proportional to the increase in temperature. Similarly, we have the Avogadro's law and the partial law of partial pressures, Dalton's law of partial pressure where we are equating the total pressure of the gas is the as equal to the sum of the partial pressures of the individual gas with this is considering when we have a mixture of non reacting gases in a system.

So, all these pressure terms which we have pressure here, pressure here are these quantities are macroscopic properties of the gas. What we will look through the model the kinetic theory model or molecular kinetic theory of model is how we interpret the macroscopic observation in terms of certain outputs or certain results which we derive from the law.

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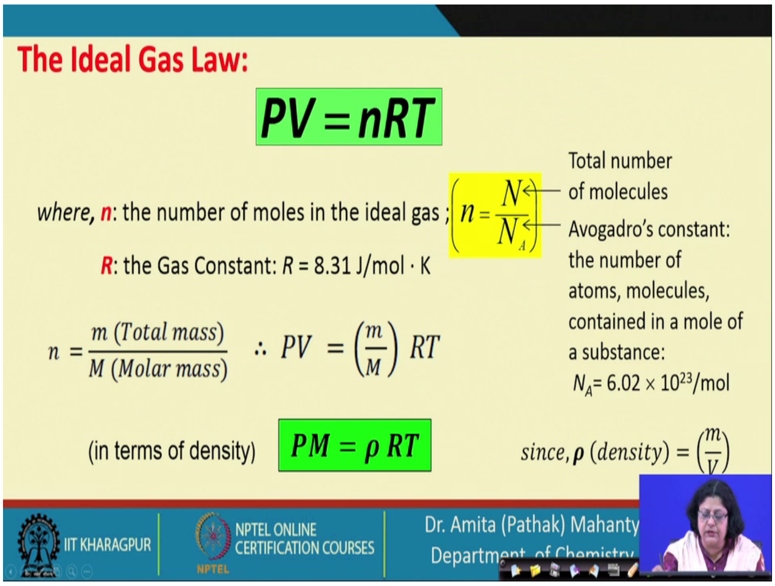

So, to begin with we will start with the mention of these laws and come up to the ideal gas law equation which is obtained from the ideal gas laws PV equal to nRT. What is n here? The number of moles of the gas which we are looking in and we are dealing with the ideal gases. So, the number of moles is nothing, but the total number of molecules of that gas divided by the Avogadro number and Avogadro number is given by 6.023 into 10 to power 23 per mole.

So, each of these parameters are microscopic macroscopic observable parameters which we can measure pressure, volume, temperature and this is the gas constant and that gas constant if we express the other parameters according to the joules then we have 6.3 6 8.314 joules per mole Kelvin. So, these are the this is one of the fundamental things which we will be visiting again when we had developed the kinetic theory model.

Before that we can have another expression for the ideal gas law where we are talking about the number of moles in terms of the mass. Total mass of the gas divided by the molar mass gives you this and what is this is the total mass divided, if I look into the volume term if I can get the volume here then I have the mass by volume mass by volume is defined as density. So, I can rewrite this equation in terms of the density when I take the V out here and I can put the M out here.

So, I have this expression where I have PM the pressure of the gas into the molar mass of the gas equal to the density of the gas into gas constant into the temperature, this temperature is in Kelvin an absolute temperature scale. So, based on these observe these are equations derived on observation. Based on this we are going to generate our theory which is actually a model based on certain simple assumption.

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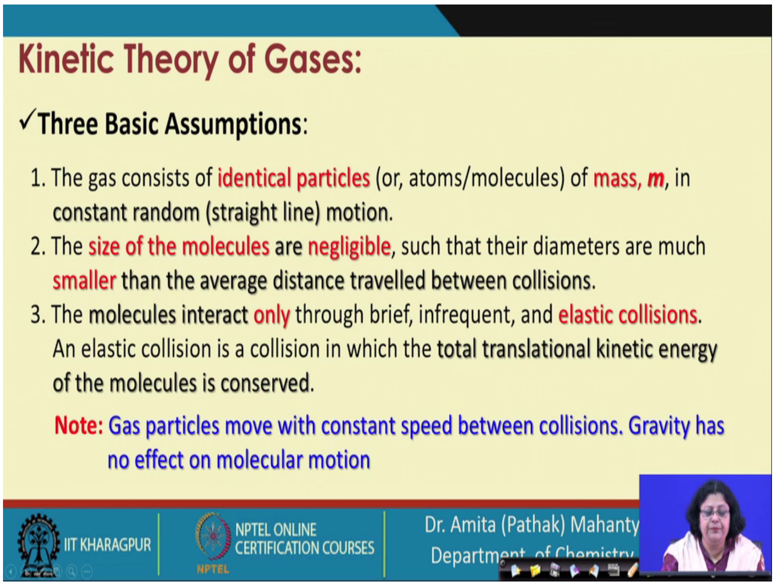

The beauty of this kinetic theory is whatever assumptions we are going to be looking into is from what whatever we observe about a gas; like the gas laws there were these equations were developed based on the observations man made. Similarly, based on certain assumptions very simple assumptions we come up with powerful conclusions we deduce powerful conclusions using the kinetic theory of gases.

So, kinetic theory gives us a model on which we are going to develop something which is going to be having giving rise to molecular interpretation to whatever we see in the macro scale in terms of the pressure temperature volume as expressed in the gas laws. So, essentially what are the simple assumptions we are going to go into is the gas is consisting of ideal particles, they are all identical particles of say mass m and they are in random motion. They are continuously moving and they are all the movement is in straight line the motion is continuous and in straight line.

And, the next one which is another important assumption is the size of the molecules. Here we are talking about molecules we can sometimes we will talk about a term the molecules as atoms, we can call them as particles. So, whenever I mention molecules or atoms or particles they what I mean is they are all the same. The size of the molecule or the atom or the particles whichever we want to mention is going to be negligible compared to the total volume it occupies; like size of one molecule which we are looking into is going to be much much smaller compared to the total volume of the gas which it occupies that means, it is a volume of the container which occupies. Also, it is also much less than the average distance they travel between two collisions.

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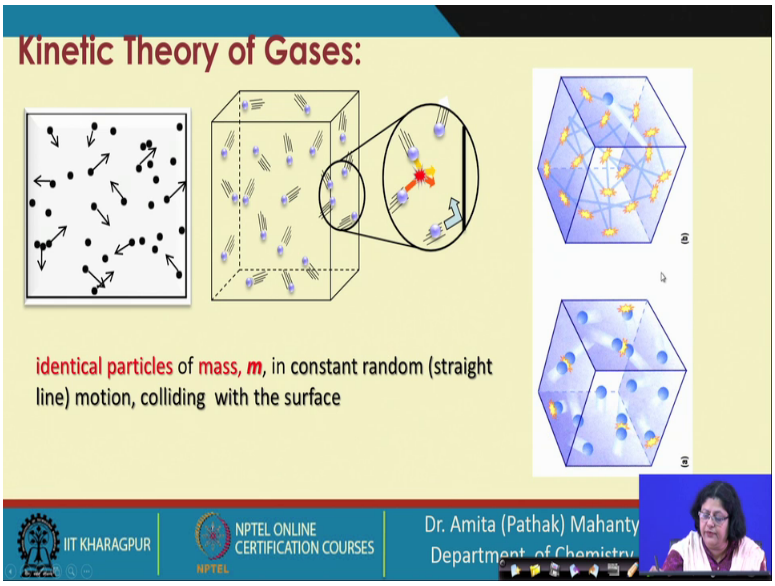

When we have number of gas molecules, what happens let us see the picture what it looks like. It is something like this a number of gas molecules are there and they are randomly moving some are moving this side, some are moving that side. So, they are in random motion, but you remember there all in the straight line motion. So, when they are in straight line not only they collide with the wall; this is the wall if this is the container, then this is the wall of the container not only they collide with the wall of the container, they collide with each other as well, right. If there this is moving this side and this is moving this side then they are supposed to be colliding.

So, there collisions which is taking place, but we are looking also into the collisions of the particles, these are the particles or the molecules or the atoms of the gas when they collide with the surface of the container. So, this is one thing which we need to understand about the collision. So, this is the container which we are looking into. So, this is the container we are specifying, these are the molecules these are the collisions between the atoms which is occurring. So, these are all identical particles moving in random straight line motion and colliding with each other and also colliding with the surface.

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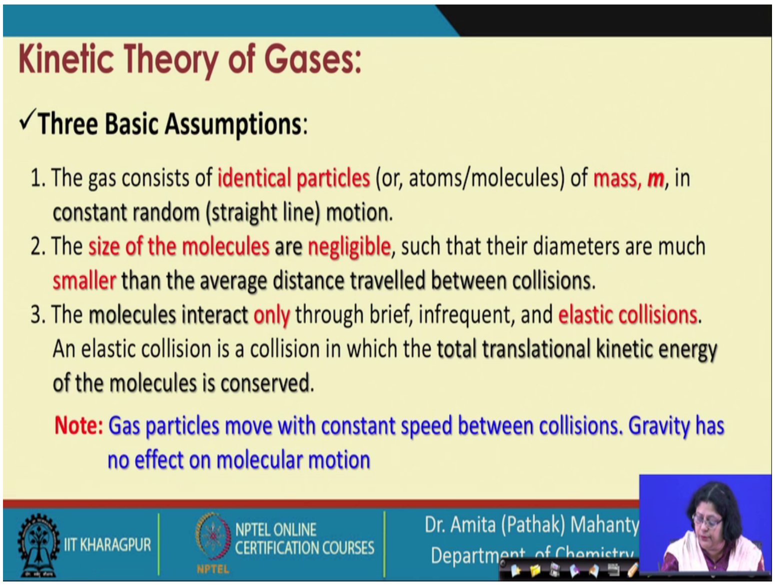

The next one which we are going to look into is the next assumption. We are talking about three major assumptions and one of them is being identical particles next one being the size of the individual particles. And then is the assumption that they are they do not interact, they do not have any intermolecular forces which is existing; that means, we are essentially talking about the ideal gas and when whenever they are colliding they undergo elastic collision; elastic collision with each other and elastic collision also with the walls of the container.

So, the this in elastic collision what we assume the total translation energy kinetic energy of the molecules is going to be conserved, ok. So, the gas molecules are continuously moving randomly and they are colliding with each other and also with the walls of the container and we assume the gravity has no effect on the motion of the molecules, ok. So, these based on these three assumptions we are going to derive a model which is going to be interpreting certain things we already know.

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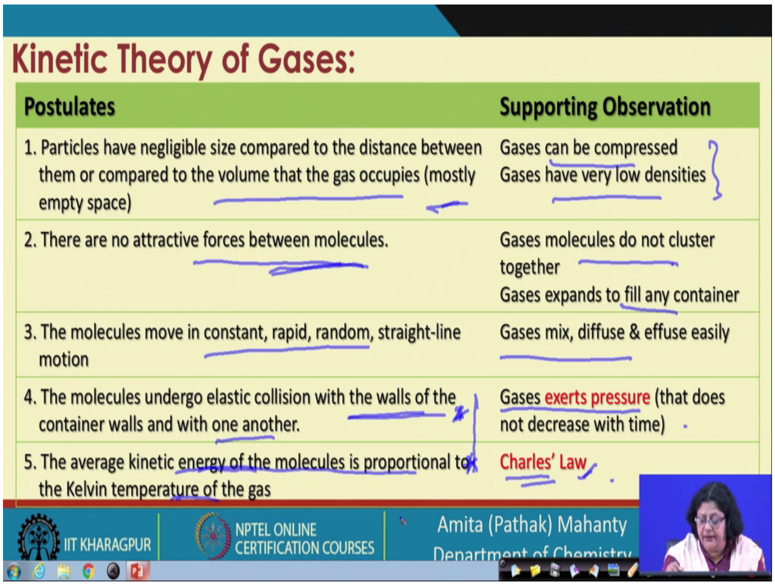

Suppose, why do I say the gas why do I assume the gas particles have negligible size compared to the distance between the two collisions or compared to the total volume of the gas it occupies in a container. We know that gases are compressible, they are of low density the number of particles in a in a certain volume is very low. So, based on these two we have assumed this assumption when in our model.

There are no attractive forces. The molecules do not interact, they only collide and these only collisions are elastic collisions or perfect collisions. So, what is there what do what do I have this assumption based on the no attractive forces then gas molecules never cluster and they fill the entire container. So, based on this observation we have say we can say that they do not have any attractive forces or intermolecular forces or inter particular forces.

Then we have taken that the gases are continuously moving in a straight line, what reflection do we have in a in day to day observation? The gases can easily diffuse mix if use from a container. So, these molecules undergo elastic collisions with the wall and with one another, what is the observation which we have? The gas exerts pressure, we do not have any microscopic interpretation of the pressure, but we know that the gas exert pressure.

The kinetic energy of the gas molecules are proportional to the Kelvin temperature of the gas this is again based on observation which is postulated in the Charles law, where you have the kinetic here we are these two are points. In fact, these two points will be more elaborately discussed when we are talking about the kinetic model the how the average kinetic energy of the molecules is proportional to the Kelvin temperature and how the gas when they collide with the surface of the walls of the container give rise to pressure.

These two things these two points are the ones which we have observed this is from Dalton's pressure law. And this is from the Charles law based on this to two observations we will try to have a molecular level interpretation of pressure and the temperature in the kinetic model.

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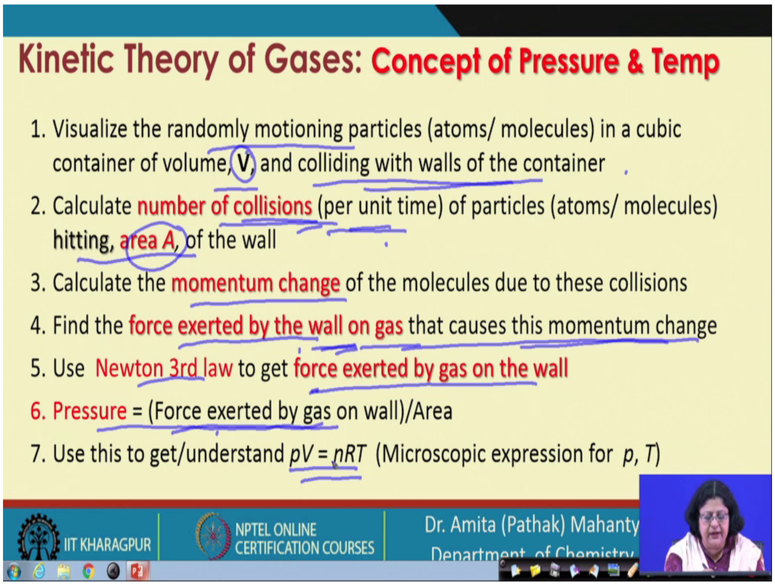

So, you can understand that since we are getting two very important concepts generated from the kinetic theory of gases one is the pressure and other is the temperature. So, how important it can be for general for us when we are talking about a gas system or any molecule which is under motion.

So, what do we have? We have to for developing the model we need to have some strategy. What are the things which we will be looking into we will visualize the random movement of the particles in a cube, a volume which is cubic having a volume of total volume of V and the particles of the gas are continuously colluding with the colliding with the surface walls of the container.

Based on that what we do we can find out the total number of collisions that is happening per unit time and that is in fact, which is colliding the area A of the volume total V in unit time; that means, we have we have specifying that we have a when definite volume of the container

V. And we have a number of molecules which are moving randomly in this cubic container and these molecules which are moving in straight line are continuously colliding. And these collisions we are now going to note, how many number of collisions are occurring on a given area of the wall of the container at unit time.

Then what do we do? We find out what is the change in momentum of the molecules after the collision. So, first we are interpreting the size we are defining the size then we are coming to the number of collisions the particles are moving on the surface of the wall at a given area per unit time then we are going to calculate the force it exerts. What is force? Force we are going to be using the Newton's laws of motion to interpret force. A force is going to be mass into acceleration.

So, we will be first find out what is the force exerted by the molecules on the wall on collision and that from that we calculate the total change in momentum using the third law of motion we will Newton's third law, we will find that the pressure exerted by the gas on the wall will be equal to the force exerted by the gas on the wall, by the wall on the gas.

So, what we are going to be generating then? We are going to find out because we as we have already said we are going to get a molecular interpretation of pressure from the kinetic model. So, we are going to define what is pressure from the Newton's law of motion force exerted by the gas on the wall divided by the area and using this we will apply or compare our equation to the macroscopic relation we have of pV equal to nRT for ideal gas.

So, let us summarize what we are looking into we are going to define the volume of the container, we are going to define the number of molecules contained in this container and then we are going to number and find out what is the number of collisions which is taking place on a unit area of this volume per unit time. Then we calculate the change in momentum and from the change in momentum during the collision with the wall, we find out the force exerted and from the force we find out the pressure and which is exerted by the gas on the wall by divided by the area on which it is hitting. So, from this we get the pressure. So, these are the strategies which we have going to employ to develop the model which we are going to have.

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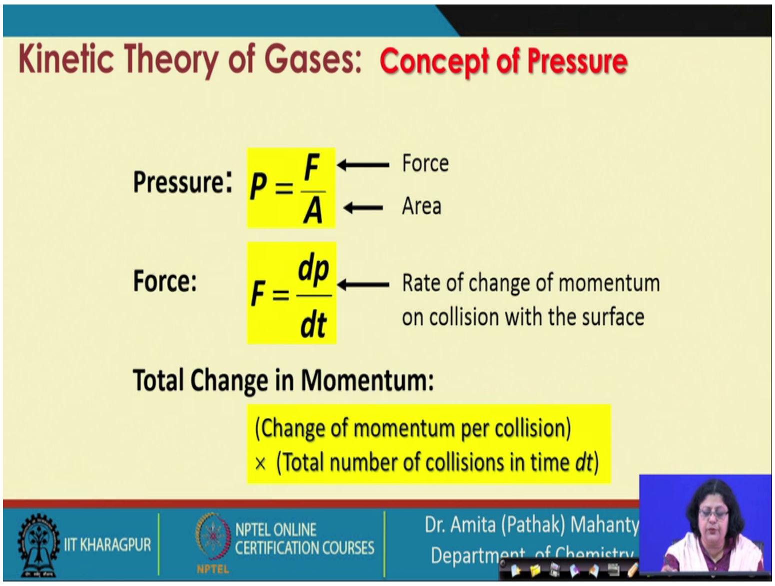

So, here we have already discussed this that pressure is equal to force by unit area. What is force? Rate of change of momentum, rate of change of momentum on collision with the surface or the wall of the container; So, total change in total change in momentum when with the particles are colliding, what is going to be the total change in momentum? Change in momentum per one collision multiplied by the total number of collision that is separate happening in a given time t or delta t ok.

So, we are interested in total number of change in total change in momentum that will be equal to the change in momentum per collision multiplied by the total number of collisions that is taking place in a given time delta t. So, based on this if we have to now find out what is going to be the total change in momentum per one collision, then we have to find out how many collisions are happening in a unit time delta t.

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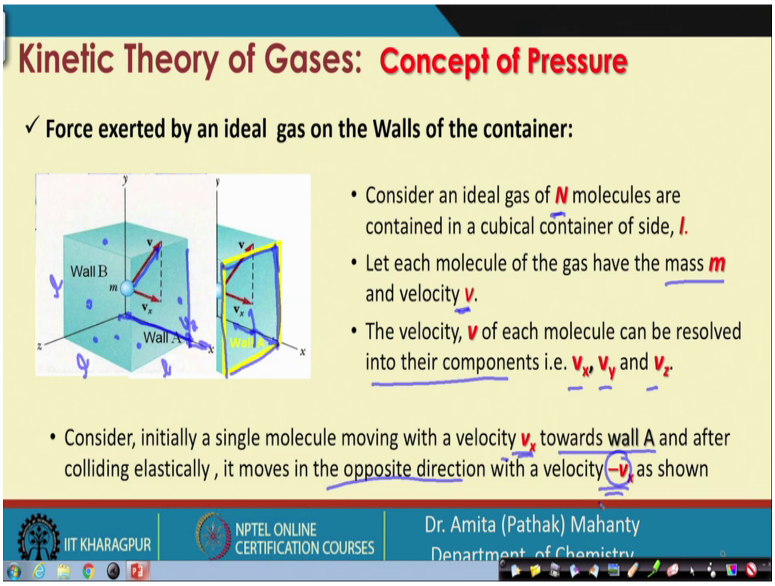

So, let us visualize this we have N number of molecules contained in a cubic container like this which is length l, since it is a cubic container all sides have length l and each of the gas molecule there are number of gas molecules contained in this. And each of this gas molecule has a mass m they are moving with the velocity v velocity as you know is a vector. So, velocity has can be resolved in three components the x, y and z. So, we have the three components of velocity x, y and z .

What we are going to be looking into is the velocity resultant velocity after we have resolved the component into three parts and this is the resultant one. But, let us not go into the resultant one just now let us only look into concentrate only the movement of the molecules and x direction. So, this is the x direction which we have. We are looking into the movement of the molecules or particles or atoms only in the x direction and all are moving towards the wall; this is the wall or this is the wall which you can look into.

So, all particles which are moving towards the wall x will have the velocity v x, that is how we are going to interpret and when they come and most of the molecules which is with the velocity v x is moving towards the wall a and after collision it moves back in the opposite direction with the velocity minus v x.

So, if I have any reference point here if it is hitting here with a velocity v x, then after collision it is going to be reverted back reflected back with the velocity minus v x. If this is my difference similarly if I this is my reference then after collision with the wall with velocity v x, it is going to be deflected back whenever we have a reflection back in the opposite direction we denote it by the minus sign this minus sign indicates that the it is a bounce back particle.

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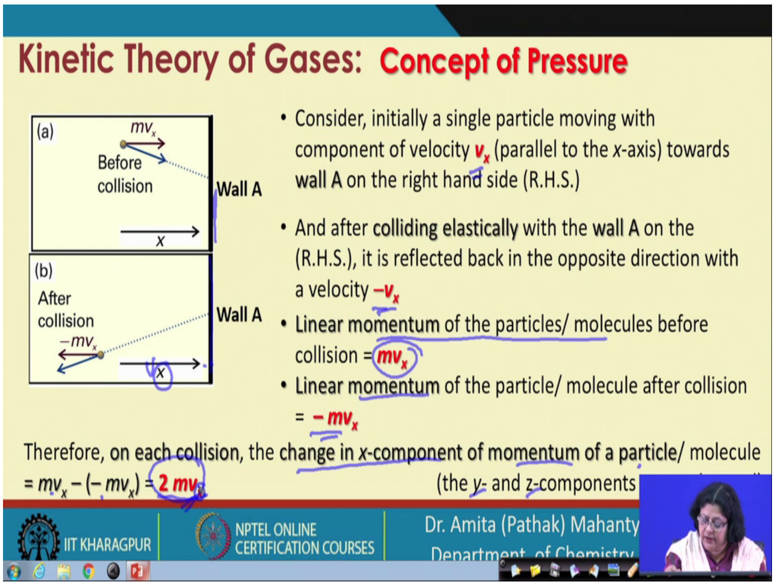

So, what we have let us consider a single particle moving with the velocity v x which is parallel to the x axis and move it towards the wall, say A that is in the right hand side. After collision with the wall A in the right hand side it is reflected back in the opposite direction with the velocity minus v x.

So, what will be the change in momentum linear momentum is nothing, but mass into the velocity. So, the linear change in momentum of the particles that are moving in the x direction, hitting the wall at the right hand side will be the linear momentum will be on the forward direction will be mv x and the linear momentum of the particle that is bouncing back after collision will have minus mv x. So, for each collision so, this is only for one particular mass molecule we are talking, for each collision what was going to happen the change in x component of the momentum of the particles or molecules is going to be what this is the forward and this is the backward and this difference is going to be minus.

So, what is the total momentum a change in momentum which we have in the x direction, this is the change in momentum after collision with the wall in the right hand side. So, the total change in momentum is going to be 2 mv and x represent the direction we are considering.

And, we are assuming the y and z components are unchanged. So, what we are looking here we are you looking at the wall, we are having the particles which is colliding with, the wall with in the x direction parallel to the x direction move wall is on the right hand side, they are moving with the velocity v x; And when after collision they are going to be reverted back with the velocity minus v x. So, total change in momentum for one particle will be equal to 2 mv an x direction in the x direction, it represents the velocity v x, am I clear?

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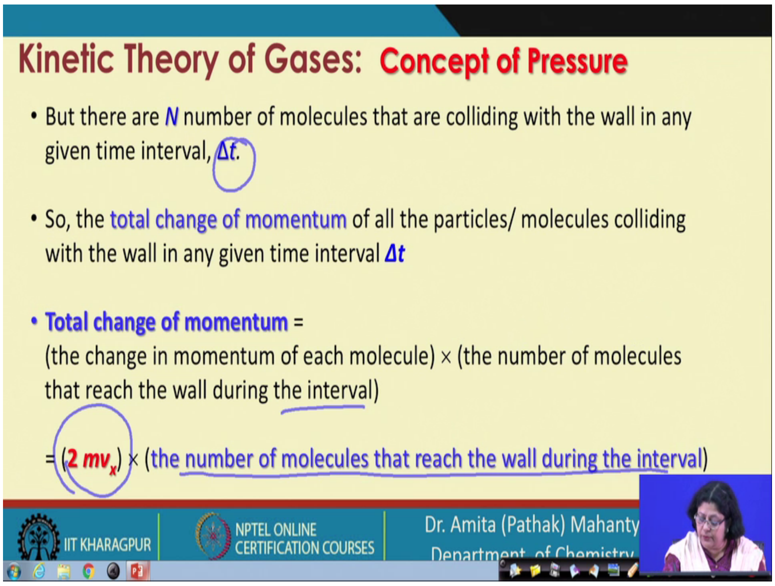

So, the total number of molecules we have in the in the collision with the wall in delta time t is needs to be found out. So, how do we find out the total number of collisions which is happening? So, what we are looking into? We are looking into the total number of there are n number of molecules that are colliding with that in time delta t.

So, here we have the time interval delta t, the total change of momentum of the particles or molecules colliding with the wall in delta t will be what? The total change is in the momentum for one molecule in the total number into the total number of molecules that reach the wall of the container at delta t time. So, what we have this is the change in the momentum of one particle after collision. Now we need to know the total number of molecules that reach the interval the wall in the interval delta t. So, how do we find that out?

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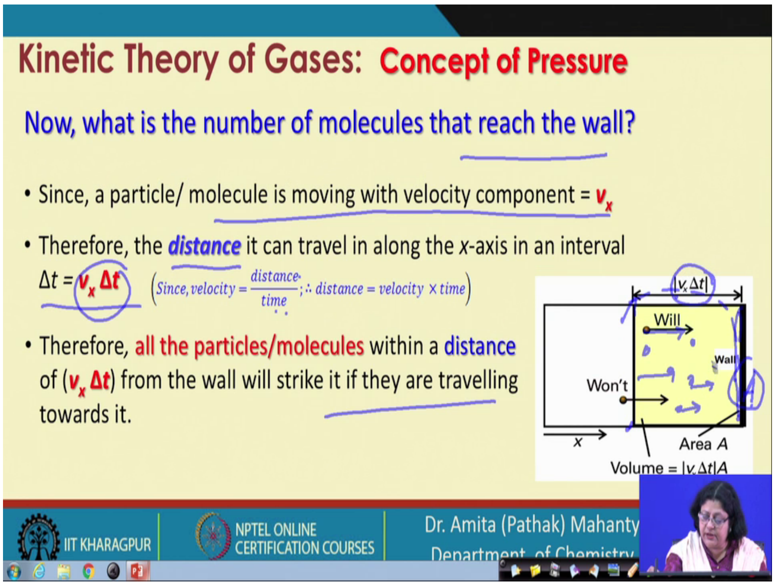

For that we need to consider a section of the container. This is the wall it is colliding and this is the area which we are looking into one collision. Now, if I imagine a container of a portion of this container where only this part particles are moving only going to all these particles which are contained in this section of the volume which we have considered are reaching the surface or the walls, then the rest of it is going to be not included in this within the container which is going to reach the wall. So, what is the total number of molecules that reach the wall?

Since particles are moving with the velocity v x then how do we find out? Whatever the number of molecules are existing within the distance, what is the distance? This is the distance which we are looking into. distance is velocity is distance by time. So, for finding out distance we know it is going to be velocity into time. So, my time is delta t; so, with within moving with the velocity of v x.

So, this is the distance I am going to have within which we are going to have observe the molecules which are coming towards the wall A. Then total number of particles that reach within the distance and strikes the wall A is going to be all the particles which are contained in this, right.

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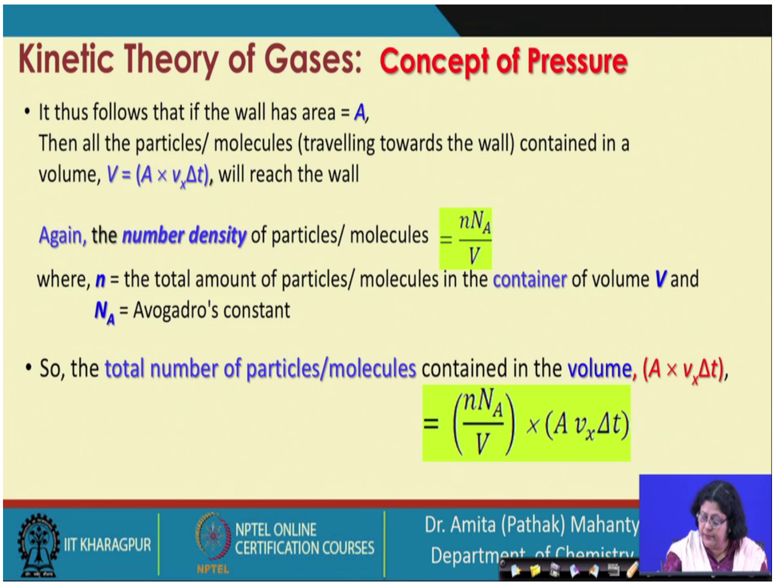

So, as it follows the area is A, the number of molecules traveling towards the container in the volume V the volume element we going to have is this is the distance and this is the area. So, the total volume element which we are looking into it is a volume element in a confined space of the total volume V in which we are going to be having the molecules that is reaching the wall.

Now, again we have to define another term, we know the number of molecules number of moles of a particle in a definite volume gives the density of the particle or a concentration of the particle. Similarly, if I have to find out the total number density; the number density is total number of particles and total moles of the particles in the container multiplied by the Avogadro's number in the total volume gives you the number density.

You should remember what we are going to be we should remember that these are the two factors I am going to keep repeating every time. This is the volume element volume element is nothing, but the a on which the area and on which we are having the location of interest in the wall and this is the distance in which within which we are looking in the molecules to be striking.

So, within this distance and within this area so, the total volume element I have determined is this, and again we need to find out the number of molecules which is contained in this total volume of the gas. If the total volume of the gas is V then the number of molecules which we are having is going to be total moles into the Avogadro number this will give you the number density of the particles. So, the number density total number of particles in our molecules contained in this volume element this will be the number density into the volume element, right.

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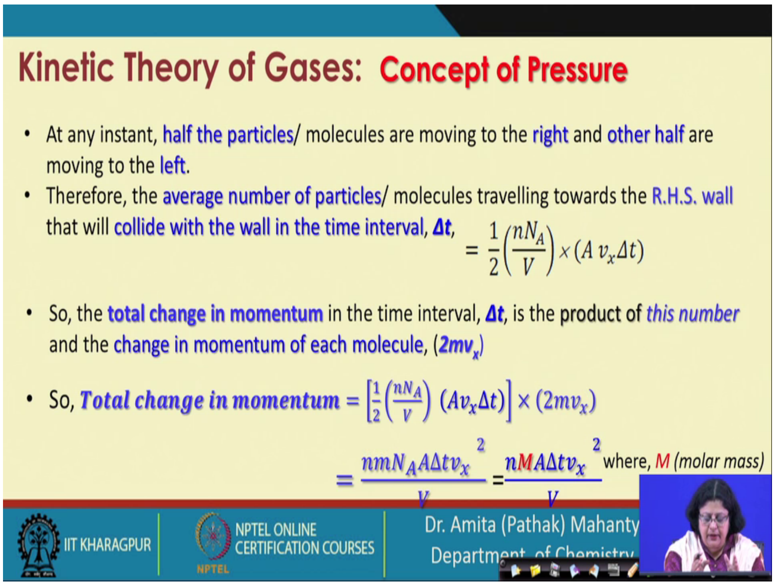

Now, when we are looking into a space of within the distance A delta t and the area hitting a surface A then within this area what are the total number of molecules if I have total number of molecules, say n how many will be moving towards the wall and how many moving will be moving away from the wall? By it is if you take a snapshot of time if you look into it we will say since if the all the molecules are equally probable to move in any direction x, y, z.

So, we will see by laws of probability we will have only half of the molecules moving in the right hand side and the other half will be moving towards the left hand side. So, the average number of particles or molecules that will be traveling to the right hand side wall which are contained in the volume element A into the dx v dx dv dt. So, total number of particles which are going to be reaching the walls surface of the container in delta time t will be nothing, but half of the total number density which we have into the total volume element.

The total change in momentum in time delta t will be what now, what is the total change in momentum the change in momentum per one collision into the total number of collisions that is taking place and all the particles which are coming towards the right hand side wall are supposed to be colliding. So, this is the number of molecules that will generate the collision. So, this is going to be the collision which is going to a number of collisions which is going to taking take place. So, this will be multiplied by the change in momentum for on one particle to get us the total change in momentum.

So, now I substitute this and try to manipulate. What is this? This is the multiplication of these two, the number density into the volume element which we are looking into half comes from only probability of only half of the molecules contain in volume element this moves to the right hand side and this is the total change in momentum for one particle.

So, if I can rewrite this is what I rewritten, what you see here you get the 2 cancelled off. The 2 gets cancelled then you have the mass 2 into m into the Avogadro number into this is the volume element divided by the total volume, this is the total volume of the container. So, if I can rewrite this I we get a expression in terms of M where the molar mass can be written as the mass of the gas into the Avogadro number.

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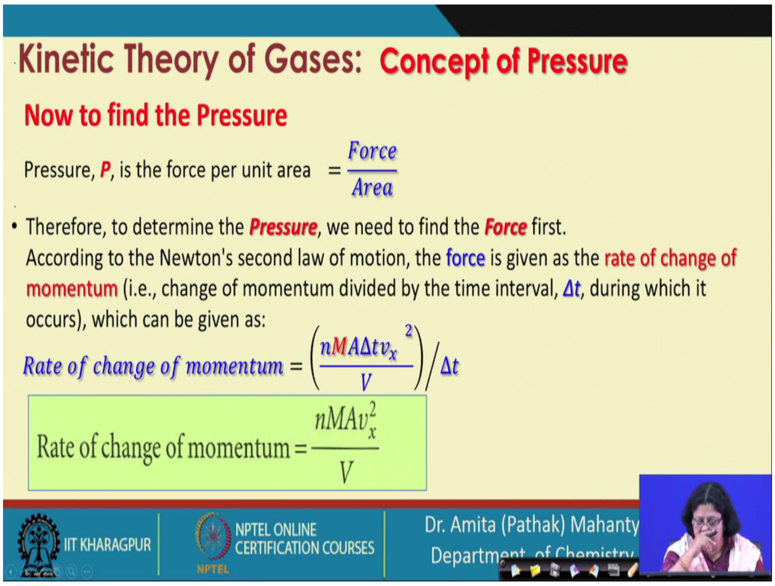

So, now we come to the term which we are looking into is force, a pressure this force per unit area force is the rate of change of momentum. So, we have already calculated what the momentum is. So, total change in momentum is this. So, if we want to find out now that pressure, we have to now talk about pressure, we have found out the total change in momentum pressure is force per unit area and force is nothing, but rate of change of momentum. So, we substitute this and the rate of change of momentum will be given by whatever the momentum we have obtained total momentum divided by the time and if this is the expression we have from rate of change of momentum that will be divided by the area, will give you the pressure of the gas which we have generated.

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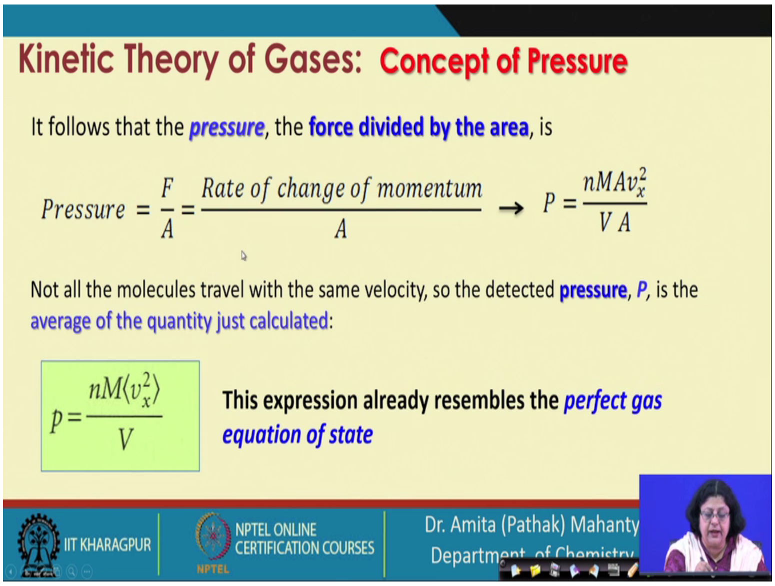

So, the pressure of the gas is the rate of change of momentum which we have generated divided by area we have this. And from this we can see that when we have generated the expression for pressure this expression of pressure is something similar to what we have in the equation of state for the ideal gas.

So, I hope you have understood how we have got this in the pressure in terms of the total rate of change of momentum divided by area, this is the force which we have calculated in previous slide, divided by the area, area gets cancelled. So, what we are left with is a number of moles into the molar mass into V square by total volume.

So, the total this volume is the total volume of the container of the cube and here we let us remember we have to talk about what is v x means, we are talking about the velocity component of the particle in the x direction parallel to the x direction, but which is the particles are possible to be having moving in a x, y and z direction, right.

Thank you.