

so in these set of lectures i will be give a brief introduction to thermal physics

so essentially i will be talking about thermal physics first thing will be heat and temperature i will be doing heat and temperature i will tell you what is heat and what is temperature secondly kinetic theory of gas thirdly thermodynamics and fourth thermal properties of matter

so as we know materials have properties elasticity and other properties which are mechanical properties here i will be talking about thermal properties of matter which means if i increase the temperature how does a material respond to that change in temperature that is what is reflected in the thermal properties of matter then what is kinetic theory i will elaborate on that and what is thermodynamics i will also elaborate on that now let me first ask the question what is heat

so first question which i am going to ask is what is heat well in physics we know everything we deal with has to do with energy

so we talk about mechanical energy which we learn at length in our mechanics course this had two pieces one is kinetic energy which we talk about and then for interacting systems which we talk about also potential energy if there is a force a particle is subjected to a force we can talk about a potential energy

so heat is nothing but a form of energy a form of energy ok well how do i know it is a form of energy we know that anything which is related to energy can be obtained from other forms of energy

so what do we know for example if i have a rough surface rough surface with a friction and then i drive an object on the surface i push it then i know i generate heat that means the mechanical energy is converted to heat energy okay

so energy flows from one end to the other we know heat energy goes from hotter to cooler bodies this is how it propagates

so it is the form of energy and what is temperature temperature is a measure which measure which dictates which direction heat flows ok it always flows from higher to lower temperature

so when i talk about temperature i know that temperature should be measured with something called thermometer ok we know of mercury thermometers in our day to day use and we can think of various other kinds of thermometer but here let us try to give some different description of temperature temperature in the sense of kinetic theory of gas kinetic theory of gas i can say temperature capital t i will soon tell you what is capital t capital t is the temperature measured in some scale which i will call absolute scale of temperature this i am going to define soon

so kinetic theory of gas there is a definition of temperature which says that t is proportional to average this word is very very important this word average ok average translational that is also very very important and i will be talking about ideal gases mostly it is a kinetic energy

so it will be proportional to kinetic energy of the molecules and that is a more well defined definition of temperature you know when we increase temperature there is always vibration in the molecules molecules can go from solid to liquid and liquid to gaseous in the process they gain more and more energy because temperature comes and average kinetic energy of the molecules keep on increasing ok but now comes the question if i define a temperature i can define a thermometer and we all know from our basic 9th 10th standard education that thermometer is a scale where we always talk about ice point which is the lowest ice point which is the lowest and steam point let us say

steam point which is the highest scale which we know zero degree and hundred degree celsius of water this can help me in calibrating my thermometer and this sets the scale

so we can measure anything with respect to these two temperatures in our celsius scale one is zero degree and other is 100 degree celsius now coming back to the point what do i mean by average why i am calling it say average distribution average well firstly i have written down already two things one is kinetic theory of gas and other is thermodynamics of gas now what do i mean by average ok firstly this is first time i will be dealing with a huge number of particles huge number of particles what i mean that i will be dealing with a system of particles with  $10$  to the power  $23$  molecules let us say which is typically the avogadro number we all know a huge number of particles numbering  $10$  to the power  $23$  what we have learnt in our mechanics each molecule described by newton's laws which is mass of the molecule let us say  $m$  and i can write  $d^2x/dt^2 = F/m$  the force acting on the molecule so this is my newton's law now you see this is a vector equation a position vector of the particle has three components now i will be totaling these type number of equations which is impossible for me to handle with i cannot handle with  $10$  to the power  $23$  particles i cannot handle with this many second order differential equations as you know we cannot solve this problem by any means even using the most advanced computer what we have today

so we must have an average description here comes the advantage and also the difference between kinetic theory

so i need an average description and here comes absolutely the necessity of doing kinetic theory and thermodynamics ok

so let me first ask the question what is kinetic theory and what is thermodynamics ok then i will go to the details of other things i will talk about firstly kinetic theory here i will talk about distributions distributions ok i will look at distribution i will look at gas molecules and probe the distribution for example of their velocities or speed so though i talk about a molecule here i am not really interested in an individual molecule and its behavior rather i will be interested in the distribution of their velocities from that i can talk about average of velocity some average of velocity which will give me some average of kinetic energy okay and from that i will try to find out what is the temperature i will relate it to the temperature i will relate it to the pressure and volume of the container

so here i will be talking about molecular level but please note i talk in terms of molecular levels in an average sense

so i need a distribution a distribution of velocity and that distribution of velocity will give me average properties which will be related to kinetic energy for example i will be talking about average kinetic energy these average kinetic energy will be later related to temperature pressure and volume okay this is the approach of kinetic theory what is the approach of thermodynamics then well in thermodynamics we really do not care about individual molecules ok i do not care about molecules their velocity distribution nothing

so kinetic theory if i use more formal language it is a microscopic theory microscopic theory at the microscopic level i am trying to see what is happening to the molecules thermodynamics in some sense more formal language is a coarse grained description coarse grained description what do i mean by quartz grinding coarse grinding means i do not look at molecular level rather i look at macroscopic levels well i look at macroscopic levels ok and the macroscopic level let me erase this part in the macroscopic level i will just

consider the measurable quantities for example measurable quantities all the physics all the equations i am going to write will involve only the measurable quantities namely pressure volume temperature and so on you see pressure volume temperature these are the quantities with measure in experiments but there is a difference volume is a quantity which subtly different from pressure and temperature which i am going to say later there are quantities of two types one is called extensive quantities and other called intensive quantity i just throw the nomenclature at the moment pressure and temperature are intensive variables so they are intensive variables whereas volume is an extensive variable ok now does these two do these two approaches which i mentioned here do they lead to different set of results no when i talk about this two approaches maybe they are two different approaches but if i am in equilibrium whatever i will talk about is related to equilibrium okay and in equilibrium whatever i measure ok in physics it is important that whatever we measure should be independent of the theory i construct so therefore in the equilibrium in equilibrium results arrived from kinetic theory or result arrive from thermodynamics they should be same identical result ok now before i proceed further i should tell you what is equilibrium i will give a very informal definition in the beginning that equilibrium means nothing depends on time ok nothing depends on time i measure pressure i measure temperature for example with a thermometer maybe it is my just medical thermometer clinical thermometer whatever i measure measurable quantities nothing depends on time so you can for example you can take a liquid in a container and stir it wait sufficiently long ok now everything settle down and you say that system has reached an equilibrium configuration which means no longer my measurable quantities depend on time so in equilibrium if i study kinetic theory will show a different approach to equilibrium may be thermodynamics will give you another approach to equilibrium but i will be constantly talking about equilibrium and in equilibrium whichever approach i take kinetic theory or thermodynamics my ideal gas equation  $p v$  is equal to  $n r t$  if you like  $p v$  is equal to  $n r t$  whatever  $n$  number of moles ok it does not change so this is very very important that equilibrium results do not depend upon whatever approach i am going to take now since i have come to ideal gas now question is what is an ideal gas ok first question is what is an ideal gas this is something which with which we have to spend plenty of time and then it idea should be clear name itself suggests its not real not real gas not real gas ok because you soon see the assumptions and it will be clear to you why i am saying that its not real first its i will assume there is a point particle so all the ideal gases i will assume to be point particles so its very very tiny or rather more formally one can say that i will assume that size of the particle is very very small compared to the intermolecular distance ok so that is what i mean by point particle that inter particle distance is very large in compared to the size of the molecule if you like but remember this is an approximation ideal up gas approximation second thing is i will assume there is no interaction this is not true we know that whenever we have molecules atoms they are occupying a container there must be an electrostatic force and typical interaction between two molecules if you like its attractive when they are far apart and they are repulsive when these two molecules approach each other

so you see i cannot assume that they are not at all interacting with each other ok

so this is also an approximation that they have no interaction and the energy is then entirely kinetic entirely kinetic ok now fourth condition this energy is entirely kinetic and they have collisions ok collisions but these are all elastic collisions this is very very important these are elastic collisions no interaction and collisions collisions collisions which are completely elastic in nature

so no energy is dissipated energy is entirely conserved now question is that whether i can have this type of ideal gas in nature well point is that i cannot get an ideal gas in nature because these two conditions is never satisfied but is this a situation now question i am going to pose to you that is there a situation when i can approximate a real gas as an ideal gas well often you will find the answer in the books but i will try to explain to you why in some limiting situation ok ideal gas can be approximated ideal gas can be approximated as a limiting situation ok now this can be very easily thought in terms of comparing different length scales of the problem well i am using a jargon length scale you will soon see what do i mean by length scales ok firstly inter atomic distance i told you or inter molecular distance in a gas average intermolecular distance that i can say is a length scale of the problem ok that easily can be found it is related to density if i have a container of volume  $v$  and in that volume i put  $n$  molecules

so i know  $v$  by  $n$  typically this to the power is typically on an average this is my intermolecular distance and now i should be able to compare this distance with other length scales of the problem let me bring in something which you will learn later or already you know that if i have a particle of momentum  $p$  ok roughly momentum  $p$  i know from wave particle duality picture that there is a  $\lambda$  associated with this which  $h$  over  $p$  ok now roughly in a very hand waving sense let us assume that the average kinetic energy of a molecule which i know is of the order of  $kT$  then you know  $p$  is of the order of  $\sqrt{2m kT}$

so you see there is a wavelength or there is a length scale associated with this is which is  $\sqrt{2m kT}$  ok now look at these two length scales this if you do not know you have to just look for de broglie wavelength what is the broglie wavelength and what i have said that there is a length  $h$  over  $p$  and typically kinetic theory tells us which i will elaborate on later that  $p^2$  over  $2m$  is of the order of  $kT$

so  $p$  is of the order of  $\sqrt{2m kT}$

so this is the other length in the problem

so i remind you two lengths one is  $a$  other is  $\lambda$  these two are to be compared if  $a$  is much much greater than  $\lambda$  lets say somehow or the other  $a$  is much much greater than  $\lambda$  all i can say particles inter atomic distance or inter molecular distance which is an important role ok is very very high in compared to whatever the de broglie length scale this de broglie wavelength tells you that particles are interacting with each other may be those interaction lengths are interactions may be of quantum mechanical nature let us not go into that i am just constructing two length scales in this one is de broglie wavelength which is given by  $h$  over  $\sqrt{2m kT}$  and other is  $a$  which is inter atomic distance now you will see the question i have i need to have  $a$  much much greater than  $\lambda$  how do you achieve that you can achieve that in two ways firstly increase the temperature if you keep on increasing the temperature very high temperature you see your  $\lambda$  becomes smaller and smaller this quantity out here becomes smaller and smaller

okay if this quantity becomes color this is automatically satisfied  $a$  is much much greater than  $\lambda$  you can say i am just having some isolated particles who do not interact with each other and this is a limiting situation where ideal gas condition could be valid now i leave it for you to think about it that  $v$  by  $n$  okay you can look at the  $v$  by  $n$  quantity this is inverse of density because what is density density typically given by  $n$  over  $v$  so if i make  $n$  by  $v$  is my density if density is lower and lower  $a$  is automatically increasing

so once again i can say  $a$  is much much greater than  $\lambda$  if you do not like the concept of  $\lambda$  you just like how i can make  $a$  comparably large very very large in compared to the other length scales of the problem first increase the temperature or reduce the density that is why in books you often see this statement that ideal gas approximation ideal gas is a good approximation good approximation when  $t$  is high and density is low ok this is the region where we can talk about ideal gas systems

so i told you what is an ideal gas ideal gas is a limiting situation of a real gas if i talk about very high temperature gas and low density gas and secondly we all know the following things for ideal gas for example  $t$  constant temperature constant  $p$   $v$  is equal to a constant these we know famous as boyle's law then if i constitute or cons have a given substance or given quantity of gas i can write  $v$  is proportional to temperature which is known as charles law and then this is boyle's law this is charles law and all together taken together for any substance ok or any amount of gas i can have this equation  $p$   $v$  is equal to  $n$   $r$   $t$   $r$  is the ideal gas constant  $t$  is temperature and  $n$  is the number of moles of the sample i do have ok

so now this also helps us in defining the absolute scale of temperature if you keep  $v$  constant lets keep  $v$  constant  $p$  is proportional to absolute temperature and we all know if i approach  $t$  is equal to zero or in celsius scale if i call it in celsius scale roughly minus two seventy three degree celsius this is how my absolute temperature is for example absolute temperature zero is my celsius scale temperature minus two seven three degree celsius and then if i have 10 which means minus 263 degree of celsius and if this is absolute zero that means i have reached in this lca scale minus 273 degree celsius i will know that pressure of an ideal gas will go to zero so if i take a very high temperature or whatever you like a very low density gas

so that it is roughly an ideal gas if i plot  $p$  as a function of  $t$  at  $t$  is equal to zero if we could reach  $t$  is equal to zero this is very very important we cannot reach  $t$  is equal to zero then pressure would be equal to zero if i keep volume fixed we know this is unphysical  $t$  is equal to zero is unattainable but why do you need the absolute scale of temperature given in terms of this ideal gas equations because of this fact that it is universal i am not using mercury i am not using any other particular substance rather i am working on something which is universal does not depend on the material i put in the thermometer

so i have a scale which is universal and which is independent of scale i am choosing ok secondly it is always positive temperature now you may ask me question can i have negative absolute temperature well that is not an equilibrium situation in some books you will find they mention very advanced book mention negative absolute temperature but remember here we are dealing only with absolute temperature which is equilibrium situation in equilibrium situation its always positive ok having this preamble and assume that we know bit of absolute scale of temperature now let me proceed to what i know as kinetic theory of gas ok

so kinetic theory of gas definitely as i mentioned to you before its a microscopic description ok but in an average sense i will explain to you what does it mean that i talk about in a average sense

so i wrote few minutes back what is called a distribution and there is some distribution of velocities

so i do not actually talk about an individual molecule rather i talk about a distribution ok

so average is important again i repeat the term i write the term average okay so what are the properties i will be talking about molecules are moving in all directions this is the first assumption i will make all directions ok and second assumption as i told you point particles i will absolutely ignore any size of the molecules ok which is an approximation but it is good approximation as long as size is smaller than inter atomic distance ok third will not assume any interaction no electrostatic interaction between the molecules i will not assume any interaction only interaction i will talk about is collisions

so these molecules are kept gas molecules are kept in a container there is a container in which this gas molecules are moving in all random directions ok and only they can exchange energy through collisions collisions between two molecules this molecule colliding with this molecule or they can collide with the wall of the container this is something very very important wall of the container gives me the pressure which i measure i told you whatever approach i take i take the approach of thermodynamics or i take the approach of kinetic theory i will always be ending up same equation of state same measurable quantities which i get from either of the approach if the system which i am dealing with is in equilibrium ok

so these are main assumptions secondly i will consider classical classical motion though when i talked about de broglie wavelength i brought in a little bit of quantum because all of you know that in the microscopic world in the world of electrons if we talk about the world is actually quantum mechanical thats why to tell you to give you an inkling about that i mentioned a bit of de broglie wavelength that helped us also to tell us the role of temperature in defining an ideal gas that temperature i can define for an ideal gas if it is temperature very very high i can assume that its typically an ideal gas so now i will make two assumptions more i will completely talk about classical motion

so all these molecules satisfy newton's laws of motion nothing more than that newton's laws of motion ok

so this elastic collisions which i mentioned here collisions they are all elastic collisions

so these elastic collisions are all dictated by the classical mechanics the mechanics we have learnt conservation of energy momentum that is what i am just going to use here and in the form of newton's laws of motion ok

so classical mechanics on who is the subject on which we will build our this kinetic theory course this is first second thing its homogeneous that means i will assume density is uniform everywhere i will assume that density wherever i have a container if i am very much inside the container wherever i am the density is independent this is same everywhere if i take the same amount of volume number of particles will on an average will be the same in this volume wherever i place it inside the container this is homogeneity thirdly which is very very important i have a three dimensional system in a three dimensional system i know if i talk about velocities velocities will be having three components  $v_x$   $v_y$  and  $v_z$  i will consider complete isotropy in today if this is our first thing first discussion our i am throwing some jargons which will

be familiar to you as I proceed complete isotropy means that three directions if you like three directions  $v_x$ ,  $v_y$  and  $v_z$  they are identical ok if I measure something in the  $x$  direction for velocity ok I will be having same for  $y$  and  $z$  there is no way I can distinguish that this is in the  $v_x$  direction this is  $v_y$  direction this is  $v_z$  direction now there will be a distribution of velocities which I will call velocity distribution an important point I would like to make that velocity distribution is same and as I am talking about equilibrium is independent of time I told you my definition of equilibrium is nothing depends on time so its same everywhere like I say density same everywhere the distribution is also same everywhere now since I have been talking without explaining what do I mean by distribution and what is probabilistic about it because I am talking about average you know if I have a dice dice has six faces so I can play the dice I can get one third three one two all with equal probability one sixth ok so you know there is a probability of getting six out of six in one throw is one sixth because these events are not correlated six percent doing it six person can get six different results this can be generalized to a continuous system I mean here when you talk about dice you throw a dice you can get one value out of six possible values now question is I have a continuous variable ok which is you can think of if I could construct a dice which had many many faces this probability of getting this things becomes smaller and smaller if you have 50 phases I can have 50 values but if it is unbiased it can fall on any side ok you have to extend your imagination to see that if I have a 50 dies with 50 faces so what do we have it can go from 1 to 50 what is the value we get 25th it is still 150th but you see probability has become smaller the possibilities had become larger so if I keep on increasing this eventually things become continuous one twenty fifth one fifteenth first it was one sixth now if dice somehow has fifty faces its one fifty if I could construct a dice with hundred faces ok in real world we cannot imagine because we are living in three dimensional world ok if I could then probability would have been 100 so if I increase the possibilities you see the probability also goes down ok it can take a continuous value let us take such a random variable  $x$  okay simple random variable  $x$  which can take any value  $x$  okay from minus infinity to plus infinity you may ask me that well what is the average value I see this information that  $x$  goes from minus infinity to plus infinity is not sufficient to tell what is the average value we need something what is the probability of having it between  $x$  to  $x$  plus  $dx$  that is very very important that is called the distribution ok so now I want to give you what is the meaning of distribution ok lets say I know  $p(x) dx$  ok what is the probability probability is  $p(x) dx$  it is the probability that  $x$  lies between  $x$  to  $x$  plus  $dx$  so you can think of I am doing many many experiments which in the standard example I have given means I am throwing a dice ok in the standard example I have given which means throwing a dice so now I am ask many many experiments and I am asking the question assuming now  $x$  is a continuous variable which can take any value from minus infinity to plus infinity I am asking the question what is the average value of  $x$  and that is given in terms of this probability distribution let us take a very simple example let us say  $p(x)$  is of the form  $e^{-\alpha x^2}$  ok well and then there will be some constant which is called normalization constant because you know  $p(x) dx$  minus infinity to plus infinity minus

infinity to plus infinity you are integrating what does it tell you it simply tells you the total probability and i know that total probability is one if you recall your dice problem okay then every probability is one sixth of any face i am getting a single throw i am getting one one ok or two all with probability one sixth but total probability  $1/6 \times 6$  is 1 this is all written in a mathematical language ok

so this gives me a constant  $n$  we can forget about this  $n$  for this time being but what we have to remember what is  $p(x) dx$  ok if you plot this function ok this is called a typical gaussian function which goes like this ok now look at this function you ask me what is the probability at  $x$  is equal to  $0$  that is given by this number  $n$  what is the probability of getting  $x$  plus infinity you can see it is exponentially small it is actually  $0$  alpha is something positive let me tell you alpha is something positive greater than  $0$  okay

so if alpha is greater than  $0$   $x$  infinity value is  $0$   $x$  negative infinity value is  $0$  i am plotting  $p(x)$  as a function of  $x$

so you can see  $x$  going to positive infinity or  $x$  going to negative infinity these probabilities are basically zero you can ask me what is the probability it lies between  $x$  two  $x$  plus  $dx$  if this is my small interval  $dx$  this is the probability ok what is the probability of  $x$  is this probability is  $x$  plus  $dx$  is this this is my  $x$  axis probability of having anything  $x$  and  $x$  plus  $dx$  lies within this region now you may ask me what are you doing because its after all thermodynamic course why are you talking about this probability distributions

i am just trying to give you the filling of average why do i need average you have to understand i have  $10^{23}$  particles at my disposal and given  $10^{23}$  particles i cannot write newton's laws i cannot solve them i have to go to a probabilistic distribution for that probability

distribution i need to tell you a bit about probability if you ask me what is  $x$  then average value of  $x$  now you cannot tell  $x$  is this if you write like your dice experiment if you are done it can take any possible value from minus infinity to plus infinity and you are asking what is the mean value if i do is many many many times okay this will be given by integration  $\int x p(x) dx$  so you are not talking about a value of  $x$  now please remember you are not talking about a value of  $x$  rather you are talking about an average value of  $x$  ok this is a brief introduction to probability theory now i will tell you how it is connected to very brief introduction to probability theory now i will tell you how it is connected to kinetic theory of gas kinetic theory of gas tells you that i told you that average sense things are to be dealt with ok in an average sense

so this brings in the concept of maxwell's velocity distribution ok maxwell's velocity distribution i will just briefly mention what is maxwell's velocity distribution what i have at hand i have at hand ideal gas molecules molecules in a container ok which is a volume  $v$  and these molecules are doing random motion velocity components are  $v_x v_y v_z$  i told you they are independent of each other ok this is far beyond your limit

so i just want to mention few things this can be argued this is maxwell's velocity distribution

so if you have  $v_x v_y v_z$  this can be shown  $p(v_x) p(v_y) p(v_z) dv_x dv_y dv_z$  i read out this mathematical expression for you remember container volume is  $v$  these are the components of velocity let us say distribution of this velocity if i track a single particle what is the probability of that velocity of that particle lies between  $v_x$  plus  $dv_x$  now this is a deviation from mechanics mechanics i give you a force give you initial condition and ask you the question ok i ask you the question what is the velocity after a time  $t$  you solve newton's equation you tell me the answer ok given the initial

condition and if it is a solvable force you can do that but here i have already gotten rid of force there is no force okay there is no force in the problem but what i am talking about is a probability distribution of velocities three components of velocities this is the  $p(v_x, v_y, v_z)$  it tells you what is the probability that velocity lies between  $v_x$  and  $v_x + dv_x$  ok

so this is a probability distribution this has a form which one can write as up to some constant some constant  $a v_x^2 v_y^2 v_z^2$  ok i am not telling you at the moment what is this constant  $a$  but you can guess what should be its dimension because you know from dimensional analysis if i write something in the exponential  $v$  already has some dimension okay so this  $a$  should be something that the whole quantity is dimensionless ok i am not telling you what is this  $a$  ok but it should be such that the whole quantity as a whole is a dimensionless quantity and there is also a speed distribution now i do not care about i do not care about the components rather i ask the question what is the probability that speed of the particle lies between  $v$  and  $v + dv$  what is  $v$  speed  $v$  is  $\sqrt{v_x^2 + v_y^2 + v_z^2}$  that is my speed ok now speed distribution similar form  $p(v) dv$  or you can ask me how many particles are on an average having velocity  $v$  whose speed lies between  $v$  and  $v + dv$  i put another constant  $a$  to the power lets say i call it  $b$  this time  $b v^2 dv$  i am not telling you what is  $a$  what is  $b$  but again  $b$  can be argued out remembering that exponential minus  $b v^2$  should be dimensionless ok so this is the distribution this is far advanced but i just wanted to tell you that what is average we often see in books that the people talk about i will talk about average over some distribution whenever there is a probability there is a probability distribution and if you ask me what is the average speed average speed you can calculate taking the integral of this form here given here

so this is the average

so we talk about average velocities average kinetic energy but let me ask you a question now i have random motion of the particles ok i am inside a container ok and here i have two boundaries let us say this is my boundary one and this opposite phase is my boundary two now if it goes randomly with equal probability with velocity  $v_x$  in the positive direction equal velocity minus  $v_x$  ok in the negative direction if this is my  $x$  axis let us say this is my  $v_x$  axis if you like it goes like this with  $v_x$  and comes back again with minus  $v_x$  what do you expect to the average to be i will tell this answer later i just don't want to tell you but its obvious since particle are moving in the equal and opposite direction with equal probability there is nothing that distinguishes plus  $v_x$  and minus  $v_x$  if you look at this expression it is given in terms of  $v_x^2$

so there is a equal probability of having  $v_x$  and minus  $v_x$  because it is given in terms of  $v_x^2$  probability is given in terms of  $v_x^2$  so average you would expect to be zero and that is indeed the case ok now we have next what i will do in the next set of lectures i will put ideal gas in a container and try to form an equation state which is  $p v$  is equal to one third  $m n$  lets say  $v^2$  average i will explain the meaning in the next class this  $v^2$  average is actually averaging in this sense so what i told you today that there are two approaches to study the thermal properties or equation of state of a gas or for that matter any system one is kinetic theory approach where you go microscopic other is thermodynamic approach in equilibrium results would be the similar i have started with the kinetic theory approach i have tried to tell you what is a probability

distribution how do you talk about averages ok and the next lecture which i am going to say take i will go to the details todays were more like preamble and introduction tomorrows or whenever our next meeting is i will tell you about the equation of state already it is very close to what we know about  $p v$  is equal to  $n r t$  can we see that from here i told you in the beginning that temperature is related to the average kinetic energy can we see it from here how do i get this form at all what is pressure pressure whose pressure particles are hitting the walls of the container and that gives me a force distribution there is a momentum transfer this momentum transfer will be related to pressure and i will arrive at this form in the next set of lectures thank you for today you

Prutor@mit.edu