

let me start by recapitulating what i did  
in the first lecture and what did we learn

so we learnt the basic  
approach of kinetic theory

so what is our purpose purpose is to understand the thermal properties thermal  
properties of matter and connecting to the corresponding equation of state ok  
what do we mean by equation of state

i told you let us take an ideal gas ok the equation of state for n mole of  
ideal gas

is equal to  $pV$  is equal to  $nRT$

so n mole of ideal gas satisfy this equation of state ok now  
we are dealing with

so called chemical systems a chemical system is described by the variable  
pressure volume and temperature there could be something called chemical  
potential which is

actually beyond our limit will not get into what is called chemical potential

so i told you

in the very beginning that i am taking the first approach to study the thermal  
properties of matter

that approach is called kinetic theory approach in the kinetic theory  
approach we consider molecules if i do not mention otherwise i will be  
dealing with monoatomic system of molecules and i analyze the motion of this  
molecules inside a container to connect to the

so called equation of state which i have

written for an ideal gas  $pV$  is equal to  $nRT$  now question is which i tried to  
emphasize

many many times in the last class that this system has a huge number of  
particles

i have  $10^{23}$  particles they are identical particles i am assuming  
for the

time being but these particles are huge in number of the order of  $10^{23}$  all of them

satisfies classical newton's equation of motion now question is how do i  
handle

so many

second order differential equations i cannot do that here comes the concept of  
average

okay here comes the concept of average where i will be talking about average  
distribution i

will come talk about average velocity okay now to emphasize what do i mean by  
average i have to

bring in the concept of distribution function okay i have to bring in the  
concept

of distribution function and probability

so that is where we are deviating

from our well known world of newton's laws here i am bringing in the concept  
of probability

this is where i gave you the example of dice if we have a completely unbiased  
dice

then i know for sure that i throw the dice with probability one sixth i get  
one of the six possible values but what will be interested

in is a continuous variable ok let us say continuous variable which is  $x$

okay this can take any value let us say idealized situation from minus  
infinity to plus infinity

okay and there is a probability distribution which i can draw for you for example  $p(x)$  as a function of  $x$  ranging from minus infinity to plus infinity it takes some value like like this

lets say

so now it is not meaningful if i ask you what is the value of  $x$  rather i can ask you the

question what is the average value of  $x$  what does this curve signify for  $x$  this is  $x$  if i call this

$x$  plus  $dx$  okay then this gives me the probability ok this gives me the probability that my

variable the random variable i am considering lies between  $x$  to  $x$  plus  $dx$  okay

lies between  $x$  to  $x$  plus  $dx$  and there are conditions which

i imposed firstly normalization which tells me that total probability  $\int p(x) dx$  is equal to identity ok

so recall the example of dice it has six

phases each number comes with a probability one sixth but total probability is one sixth into

six ok one six into six which gives me identity ok the same thing is written in mathematics now

you can ask me what is the average value of  $x$  that average value of  $x$  will be given by again

integrating from minus infinity to plus infinity  $\int x p(x) dx$  note  $p(x) dx$  is the probability  $x$  lies

between  $x$  to  $x$  plus  $dx$  and corresponding value is  $x$

so i integrate i get the average value now in

kinetic theory we will be encountering situation like this i cannot talk about the velocity

of a molecule rather i can talk about the velocity distribution this is beyond us

but let me just for the sake of completeness tell you that probability distribution

of lets say  $x$  component of velocity as i considered in the first lecture probability

$p(v_x) dv_x$  is probability that the velocity  $x$  component of velocity to be precise lies between

$v_x$  to  $v_x$  plus  $dv_x$  this is the probability and as i emphasized in the first lecture there is

no difference between  $v_x$ ,  $v_y$  and  $v_z$  this is the isotropy density is same everywhere if you like

that is called homogeneity

so  $p(v_x) dv_x$  usually is of the form  $\alpha v_x^2 dv_x$

ok its proportional to  $dv_x$  and there is an exponential term what is  $\alpha$  are not

going to specify but this  $\alpha$  must be such that this whole thing is dimensionless a is

once again the normalization constant which ensures that if i integrate over minus infinity to

plus infinity i get unity now if you calculate  $v_x$  average you look at this mathematical form this

is  $v_x^2$  which says that probability that  $v_x$  has a positive value or negative value let

us say  $v_x$  is plus 5 with appropriate unit or  $v_x$  is minus 5 the probability

will be the same that means it is equally probable to have positive velocity and negative velocity of the same magnitude  
 so  $v_x$  average from this argument immediately is equal to zero  
 so mean velocity is not very helpful for us we should go for something more we will talk about something called rms velocities now there is one more concept which turned out to be very useful ok that is called speed distribution define speed which is root over  $v_x^2 + v_y^2 + v_z^2$  and define a probability distribution  $p(v) dv$  some normalization constant  $b e^{-\frac{1}{2} v^2}$  again a  $v^2$  term  
 so these ask the question what is the probability that speed of a molecule lies between  $v$  to  $v + dv$   
 plus  $dv$   
 so speed lies between  $v$  to  $v + dv$  ok you see there is a  $v^2$  term here in comparison to this this distribution i have talked here  
 so this makes a lot of difference one can talk about a main speed one can talk about a most probable speed but those are the things  
 i am not going to introduce here what i try to harp on you emphasize here that there is a distribution if you even if you talk about molecular level you are dealing with a huge number of molecules you have to have some distribution function this is the velocity distribution function for  $v_x$  similar form will appear for  $v_y$  and  $v_z$  because of the isotropy then more important to look at the speed distribution where speed is defined like this and this is the probability that speed of a molecule lies between  $v$  to  $v + dv$  ok having said this  
 let me erase whatever distributions i have discussed but please remember that whatever we will be deriving in the next part of the lecture will be connected to these distributions  
 we will talk about some rms speed which is an average quantity and having emphasized once again on the importance of the probability and probability distributions let us talk about ideal gas quick recapitulation that an ideal gas i said its a limiting situation of a real gas limiting saturation of real gas at high temperature and low density limit of real gas ok this is your ideal gas and its a high  $T$  and low density limit of real gas now i told you briefly also about the laws of ideal gas which experimentally one can verify with a real gas at low density and high temperature firstly i talked about boyle's law  $pV$  is equal to constant given  $T$  is constant then for a given volume

of gas you can say pressure is proportional to  $t$  which is one form of Charles's law  
ok this  $t$  is defined as the absolute scale absolute scale soon the physical implication of this absolute scale will be clear i said  
absolute scale is  $t$  cell shears plus 273.  
16 let us say roughly two some seventy degree celsius this is your absolute scale now these are the equations this is Boyle's law  
this is Charles's law  $p \propto 1/t$  taken everything together i can say in equilibrium  
again remember that whole study we are doing here okay is based on the concept of equilibrium that  
means i have reached a state where none of my measurable quantities depend on time if you like  
to see things in the microscopic level i would say that distribution absolutely does not depend on time  
so now  $pV$  is equal to  $nRt$  this is the ideal gas constant this is the number of moles ok  
this is the ideal gas equation actually this ideal gas equation helps us in establishing the absolute  
scale if you skip  $V$  constant as i said in my last lecture if you keep  $V$  constant and plot  $p$  as a  
function of  $t$  you will find a linear plot because  $p$  is proportional to  $t$  but there will be deviation  
if you go lower and lower and temperature i told you low temperature that means some length  
scale which i call the de Broglie wavelength will shoot up because it is root over of  $kT$  but one  
thing one we can see from here that if i go up to  $t$  is equal to zero rather if we could go up to  $t$   
is equal to zero pressure vanishes ok that is my absolute zero ok  
so  $t$  is equal to zero i will refer to as absolute zero ok now what is the advantage of choosing ideal gas  
it does not  
this scale does not care whether i am using a mercury thermometer a clinical thermometer  
whether i am using a thermocouple it gives me a universal description this is important that i am  
giving a universal distribution to my temperature scale this is first secondly  
 $t$  practical  
purpose is very useful  $t$  is always positive and  $t$  is equal to zero is something which i can  
never attend ok you will later see when i go to Carnot engine that if i could reach  $t$  is equal  
to zero then Carnot engine efficiency will go to unity which is never possible  
ok  
so it is not  
that because i do not have a proper thermometer i cannot reach  $t$  is equal to zero its a law of  
nature nature enforces on me that i can never reach  $t$  is equal to zero and  
later i may tell  
you that there is something related with entropy if i discuss about entropy a bit i will tell

you what is the implication of  $t$  is equal to zero on a dropping ok i succinctly summarized whatever we have done

so far please remember these concepts at the back of your mind when we go to the next step let's consider first an ideal gas i tell you the purpose i will do a microscopic approach to arrive at something macroscopic

so i will take a microscopic approach to arrive at something macroscopic that means i will try to arrive at pressure given in terms of microscopic variables in an average sense

ok now ideal gas confined in a volume  $V$  this volume i choose to be a cube well it need not

be a cube it could be a sphere also this whole calculation goes through but mathematics will be slightly more complicated you will need a different coordinate system which you will learn later which is called spherical polar coordinate system

so but for the simplicity i will use a cube which is  $l^3$  ok three edges of the cube each given by  $l$

so this is my container and this is my cube within which gas particles are moving in every direction randomly and let us say  $i$  have a velocity axis which is  $v_x$ ,  $v_y$  and  $v_z$  if you like

so let us take a particular individual molecule which is denoted by  $i$  ok let me call it  $i$  and two faces two phases well two faces of the cube let us say these are  $yz$  plane in the  $v_x$  direction and this is the component  $v_x$  i call it  $v_{ix}$  which is  $i$ 's  $x$  component of velocities and this is going

normally hitting normally these two faces which are  $yz$  perpendicular to the direction of velocity you know and what we will calculate that i want to calculate pressure

so what  $i$  will calculate is momentum transferred what  $i$  will use to calculate this momentum

transfer ok i will use elastic collision and of course as i said everything will

be done in the framework of newton's laws

so i will do everything within the framework

of newton's laws now this fellow  $m_i$  goes and hits this face of the cube let me call it a one let me call it a two it goes and it gets elastically collided and it

comes back we know from the momentum conservation we can immediately see what is the

momentum change of  $i$ -th particle of  $i$ th particle that i can immediately write its  $m$

$i$  lets say  $m_i$  ok and  $v_{ix}$  this was the if say final or i can say this is the final and initially

it was moving with  $m_i v_{ix}$  ok or both negative it should be subtracted this is the final this

is initial i am subtracting one from the other now i assume which is very reasonable to

assume that i will call all of them having mass  $m$  and also sometimes i will need soon that its mono atomic  
 so i write it a mono atomic ideal gas  
 so this is the net change of momentum this is the magnitude in change in the momentum magnitude in change in momentum ok in change in momentum is just this quantity ok this is just this quantity  
 so this much momentum has been transferred also to the wall right so particle number i change in momentum of the particle number i is this and this amount of momenta has been transferred to this a one phase now this is single collision what will happen to this particle now i assume extreme dilute limit ok i assume extreme dilute limit dilute limit when i talk about dilute limit i assume that this particle goes and hits here and comes back here without any collision this i can approximate only when there is something called mean free path i will explain to you very soon in couple of lectures what is the meaning free path ok mean free path is the average distance again i emphasize whatever we are talking about here is in terms of averages so we emphasize that there is a average distance for a particle between two successive collision between two successive collisions a particle will face no force eventually it will have a linear motion ok before it hits another particle and if this mean flipper is very very large i can assume that this particular guy is not having any further collision coming back and hitting the wall and same story happens this  $v_x$  is same it keeps traversing between these two walls but remember it is an elastic collision there is no change in velocity ok so it simply keeps bouncing between these two walls with a velocity  $v_x$   
 so you can ask me then what is the number of time what is it net number what is the net number or of heat this fellow will make on this ok you can ask me the question ok how many times does it hit over a time interval let us say  $\Delta t$  if i call there is a time interval  $\Delta t$  and remember the velocity remains the same throughout it is  $v_x$  component i am interested in so it is  $v_x$   
 so  $\Delta t$  between two collisions ok lets write it in the way  $2l$  is the total distance this is  $l$  it has to hit here it comes back goes back total distance is covered between 2 heatings to the wall a one is actually two  $l$   $v_x$  is the velocity of that particle  $v_x$  component of the velocity so this is the  $\Delta t$  time ok so this is  $\Delta t$  and how

many collisions per unit time if someone asks you per unit time how many collisions i will be having i will be having a collision which is  $n$  one by  $\Delta t$  ok  $\Delta t$  is time for one collision this is the number of collision per unit time so it should be one over this and this will be if i put it  $v_i x$  over  $2l$  ok we already have seen what is the total momentum transferred total momentum transferred at each collision is  $2m v_i x$  and per unit time okay how many collisions are there concentrating on a particular face  $e_1$  that is given by this number so total momentum transfer per unit time if i may erase this part let that figure be there for some time other part so i just use half of it so i calculate total momentum transferred in unit per unit time is simply given by lets say  $\Delta f n$  times  $2m v_i x$  we have calculated what is  $n$  i can substitute it as  $v_i x$  over  $2l c n$  is an arbitrary number  $\Delta t$  is an arbitrary number which never appear all that appears mass length these two we already know and  $v_i x$  which we really do not know but we can talk about it in an average sense ok so this  $2m v_i x$  so that takes care of the  $v_i$  was talking about and then i can calculate for all molecules lets two cancels out  $m$  so sorry this  $2l$  two cancels out with this two i can forget about these two this is what the total momentum transfer per unit time now i have considered only one molecule okay now for an one molecule this is the momentum transfer i am dealing with many many molecules number of molecules is of the order of the avogadro number so i have to average all these molecules i am assuming they are non interacting all these molecules on an average hits this boundary and providing momentum transfer here causing momentum transfer here ok so now what is  $f$  total momentum transfer momentum transfer per unit time here due to molecule i let me complement it and total momentum transfer for all such i's will be given by  $m l$  sum over i  $v_i x$  i square this is the net momentum transfer ok now this is very important concept you see if i have a distribution and i divide it by a quantity  $n$  i will come back to this issue ok i just multiplied upstairs and downstairs by a factor of capital  $m$  so i am finding out a quantity which is like a mean you can see take first particle  $x$  components of its velocity square it and then add them divide

by this and this has a very important significance  $v_x$  told you the velocity distribution is of this form that velocity average velocity of  $x$  component should be is equal to zero because probability is same for any plus  $v_x$  and any minus  $v_x$  since plus  $v_x$  and minus  $v_x$  are equally probable mean value should always be zero if you take a coin and flip it many many times you know probability of up is half probability of down is also half if i assign a number up means plus one down means minus one on an average i will get a zero so velocity is zero but that does not stop mean velocity average velocity is zero but that does not stop us from coming to an equation involving mean which is the mean of the square so one more thing i just now will do that we have come to this point now i will use something which i have been harping on from the beginning isotropy what do i mean by isotropy i mean that  $v_x^2$  square average or sum over this should be equal to  $v_y^2$  square average should be equal to  $v_z^2$  square and sum over  $i$  and you can if you divide everywhere by  $n$  this  $n$  you can have same average value so all i wanted to say is from the beginning that  $v_x^2$   $v_y^2$   $v_z^2$  there is nothing to distinguish between them ok i will now i am now going to use this formula for the next thing since these 3 are equal i can always write whatever i wrote as  $v_x^2$  square ok sum over  $i$  is equal to one third sum over  $i$   $v_x^2$  square  $v_y^2$  square  $v_z^2$  square ok all i have used i have added same thing three times and divided by a factor of three ok i divided by a factor of 3 and then i am going to use it here to arrive at so called momentum transfer and from this momentum transfer i will go to the expression of pressure so we reached up to this point that  $v_x^2$  square is one third average of these three quantities so what i am doing i am adding three same thing and dividing by a factor of one third so i am getting the same result but it gives me the whole picture of this space if you remember which i erased we started with a cube ok so and particles can move with equal probability in any of the directions so we should have a net average sense so total momentum transfer if i now allowed to write is i can write it simply in terms of one third  $m$   $m$  divided by  $l$  if you like  $v_x^2$  vector square just telling you that i have taken the consideration all the components of velocities  $x$   $y$  and  $z$  where  $v_x^2$  vector its nothing but  $v_x^2$  square plus  $v_y^2$  square plus  $v_z^2$  square for the  $i$ th particle but remember what i am getting is essentially average because i am adding over

all the particles which are there in the container ok  
 so now to give you the more better sense of average what i can do this is remember i have been telling this is the net momentum transferred to the wall by all the particles those i am considering  
 so total net momentum transfer is this quantity and now i can have a sense of average how do i do that let me write it  $\frac{1}{n} \sum_{i=1}^n v_i^2$  ok  $v_i \cdot v_i$  i can write simply it as a scalar  
 as long as we remember that its just  $v_i \cdot v_i$  as long as remember this is a scalar quantity now  
 you see its speed ok now you see this is a average quantity ok you are adding the speed if you like of each particle squares of this take speed square it add them and divide by the number of particles  
 so what it is giving me it gives me mean square mean square ok first i square that i take the mean i add them and take them in this is the mean square velocity i will go further  
 i will call this whole thing as  $v_{rms}^2$  ok  
 so what is  $v_{rms}$  square it is this quantity square root of this is  $v_{rms}$  i told you though  $v_x$  average is zero i will talk about rms velocities  
 so what is rms mean square root first we are squaring taking the mean and square root that defines as  $v_{rms}$  for us  
 so i can write this entire thing as  $\frac{1}{n} v_{rms}^2$   
 so you see this rms has the information that i have n particles in my container ok and it has the information about the average i have been talking about i cannot simply talk about a particular individual molecule rather i can talk about average and this is reflected here so far i am dealing with things which are very very esoteric in some sense because who calculates momentum transfer nobody calculates in their laboratory what is momentum transfer nobody calculates rms velocity in that sense ok  
 so what do we calculate we calculate the pressure that we can always calculate  
 so whatever i have derived so far should be related to whatever related to measurable quantities that is called pressure let us do it in the following way ok  
 let us try to calculate pressure pressure we know momentum transferred per unit time that gives me the force and then  $\frac{dp}{dt}$  is equal to force if you like and divided by the area you are considering  
 we took a cube  
 so this area was  $l^2$  this area was  $l^2$  this is the pressure and this is the pressure pressure we experimentally measure  
 so this is pressure now i have expression for this f i know what

is pressure pressure is one third  $m n$  over  $l$  ok well  $m n$  over  $l$  divided by  $l$  square and  
 then  $v$  rms square this is my pressure this is my expression of pressure and  
 now see  
 we have come to something very very interesting  $m$  into  $n$  divided by  $l$  cube  $l$   
 cube is the volume  
 of the container what is small  $m$  times capital  $n$  that gives me the total mass  
 so i immediately  
 know pressure is one third of  $\rho v$  rms square ok  
 so this is how  $v$  rms if you like is  
 related to macroscopically measurable quantity that is pressure now someone  
 says well i want to  
 write my  $p v$  equation because you know for an ideal gas we have been constantly  
 saying if temperature  
 is constant then this thing should be related to  $p v$  is equal to constant you i  
 am dealing with  
 an ideal gas  
 so i should get a situation in which my boyle's law holds true  
 so  $p v$  is  
 equal to then one third into  $\rho$  one third into  $\rho$  but i am multiplying  $\rho$   
 times the volume  
 that gives me the mass and that gives me the  $v$  rms square  
 so if you like this is your pressure  
 derived from completely microscopic approach in an average microscopic  
 approach this is my  
 pressure or i can write it further this is  $m n v$  r m s s square ok  
 so this is the  
 expression of pressure after all this work we have related an equation  
 involving the  
 pressure and volume and we know for an ideal gas this quantity is related to  
 temperature right  $p v$   
 is equal to  $n k t$  if you like or  $n r t$  if i have  $n$  moles of systems lets talk  
 about one mole  
 and lets see whether i can talk about this  $p v$  equation ok let us first assume  
 that then  
 i will try to explain it more details that how this concept of temperature  
 comes into business so  
 microscopically we have found out some expression of  $p v$  question i am asking  
 is this preview  
 related to temperature some way or the other and this is what i am going to do  
 in this  
 few minutes  
 so now let us consider one mole of ideal gas then we know  $p v$  is nothing but  
 $n k b t$  or  $r t$  here  $n$  is the avogadro number here is the end  $k b$  is the  
 bohemian  
 constant  
 so immediately you see that if i accept both of them together  
 so what we  
 have found out we have found out one third  $m n v$  r m s square is actually  $p v$   
 so what  
 happens here simply you can see temperature is related to this i can simply  
 write out  
 half  $m v$  r m s s square is equal to one third one third  $m v$  r m s square is  
 nothing but  $k b$

t

so if you define absolute scale temperature this is how you get to your form of temperature  
so what is temperature temperature is related to temperature is related to whatever you  
talk about temperature is related to the rms velocities ok but we will go we can go further ok  
if i say that total translational kinetic energy molecule ok a single molecule remember though i  
am talking about single molecule the rms gives you already the sense of average ok this  
quantity is simply given by  $\frac{3}{2} k b t$  ok you see  
so total translational kinetic energy of the molecule is given by the temperature so what is the definition of temperature in kinetic  
theory you will simply say it is nothing but total translational kinetic energy of the molecule  
that i am considering ok now i can go further i can use this to derive something  
which is fundamentally more important let's see what did i arrives at sofa i have got  $p v$  is equal to one third  $m n v r m s s$  square ok and  
then i have found out half  $m v r m s s$  square is equal to  $k v t$  these are the two important  
things we have gotten so far  
so you see its three by two ok now you can ask i can ask you the question that can i go further remember i am talking about total translational energy total  
translational kinetic energy firstly y kinetic why kinetic why kinetic because there is no  
interaction there is no potential part there is no potential contribution to the energy it has to be all kinetic why translational why translational because  
i am assuming mono atomic ok mono atomic ok there could be other degrees of freedom  
these molecules i am assuming mono atomic and they can only translate ok that is why  
this is a translational kinetic energy but you know there is one form of kinetic energy also which is half  $i \omega$  square right if i allow the molecules to  
have a rotation axis and rotate about that then you have to take the total kinetic energy  
and appropriately add this number three by two ok now y three you can ask me why it is  
so sacrosanct that you have three there because i am talking about a three dimensional  
container if i could have in for example imagine that it was six dimensional con container  
this number three should be changed to six ok  
so the first question which might occur to your mind that why this is three because i have a three dimensional container

second question may come that why this two ok these two comes from the fact that you are assuming  $E = p$  energy of any particle with momentum  $p$  is of the form  $p^2$  square to  $m$  i told you you are using newton's laws ok now very interesting situations can happen if you have relativistic gas some of you may know or if you do not know if you can look up you will find out relativistic gases if rest mass is 0 this is the relation between momentum and energy and in that case you will not get a 2 here rather you will get a 1 here so this is the significance of getting 3 here 3 because it is dimensionality or a two because  $E = p$  goes off  $p^2$  over two  $m$  ok so having said this now i will put something more fundamental to it ok now you have total translational let us say i am talking about ideal gas i am talking about three dimensions now immediately these two things this is the total translational kinetic energy total translational kinetic energy will be given by half ok  $\frac{1}{2} m v_{rms}^2$  ok now this quantity and this quantity if you connect these two you immediately have a relation  $p v$  is equal to two third  $E$  ok this is something i want to emphasize because this is a very very important relation this is a very very important relation in the sense  $p v$  is equal to  $n k T$  is typically for a classical ideal gas that means you are working at a very high temperature and low density limit okay but these  $p v$  is equal to  $2/3 E$  its valid even at low temperature if you go to your higher studies on thermal physics you will see this is valid at very very low temperature when you know low temperature you cannot throw away interactions you are talking about atoms and molecules these interactions are quantum mechanical nature so you cannot get rid of them even then if it is ideal gas that means only kinetic energy no potential energy ok okay to make things clear i make it  $E$  translational only translational energy ok you are in three dimension and single particle in some form you can write as  $p^2$  over two  $m$  ok maybe in operator form but it is  $p^2$  over two  $m$  this relation holds true so temperature is completely out of the problem so what we have learnt so far we have found out a connection between  $p v$  given in terms of rms velocities ok and then i recall ideal gas ok in the next lecture i will not directly use this equation rather i will try to emphasize physical arguments that this quantity should be equal to temperature now once you have this you have two fantastic

relation pressure is given by this ok and  $pV$  is equal to  $nkT$  total translational kinetic energy is given by this  $pV$  is equal to  $230$  now of having heard this much if someone asks you what is so called temperature in your problem temperature is given in terms of mean translational kinetic energy mean translational kinetic energy is given in terms of  $v_{rms}$  ok so we reached  $p$  using  $pV$  is equal to  $nkT$  we reached this and i am now going to play little bit with this expression  $m v_{rms}^2$  square is equal to three by  $kt$  ok and then things will be very easy for me ok first two limits of this i want to discuss before i go to tomorrow's lecture ok i want to calculate two aspects of it and then i will wind up for the day so you see this is this and again i say mean translational kinetic energy  $e_{total}$  is given by three  $n$  by two  $kT$  ok experimentally you never measure energy what do you measure is the response what you measure is specific heat so how do you calculate specific heat from here you can calculate specific heat just taking the derivative of this with temperature so what i am trying to calculate i am calculate what is the a change in total energy given that i have changed the temperature by small amount this is what we experimentally can measure using calorimetry you already know how calorimetry relates total heat content remember heat is an energy and we are talking about one more energy here which is translational energy ok so heat being an energy mechanical energy being an energy they are transferable from one to other so this gives me this definition of specific heat  $e_{total}$  i will come back to this point connection between this total energy and internal energy in thermodynamics which is related to the heat directly when you tell you tell when i tell you about first law of thermodynamics ok which is nothing but first law of thermodynamics is nothing but the conservation of energy so you do this you get a relation which is this ok this is the specific heat you take many gas do the experiment at high temperature measure the specific heat ok if you measure the specific heat you find out this formula which immediately gives me three by two and  $kV$  ok so this is called two long petites law ok so it has a got a name this is called do long petite so it follows immediately from this expression of the mean kinetic energy or total translational kinetic energy of the system second thing second thing is fundamentally very very important i have found out half  $m v^2$  i

will not write the word rms any longer is equal to three by two  $kT$  ok but whenever i talk about  $v^2$  you should interpret that i am writing  $rms^2$  square now

you see that it has three contribution ok now you have already used that that it has three contribution if you like i can think of only moving in one direction okay

i can think of this quantity as three half  $kT$ 's three half  $kT$  is ok you see three three and

i told you why there is this number three is coming because i have three velocity components my

gas molecules can move in three direction

so this immediately hints to me that what should be the quantity if i calculate  $\frac{1}{2} m \overline{v_x^2}$  average because that must be equal to  $\frac{1}{2} m \overline{v_y^2}$  average clear it should be then necessarily  $\frac{1}{2} m \overline{v_z^2}$  average so in the average sense these three things should be same ok if these three things seem same and total kinetic energy is  $\frac{3}{2} kT$  i immediately come conclude that  $\frac{1}{2} m \overline{v_x^2}$  average is nothing but half  $kT$  ok its very very important that each kinetic energy is half  $kT$

i do not have any potential energy in the problem

so  $\frac{1}{2} m \overline{v_y^2}$  square is equally would be half  $kT$

so each degrees of freedom each degrees of freedom contributes a half  $kT$  to the system ok each degrees of freedom gives you a half gradient system now this is very very important this is called equi partition of energy ok

so this is called the equi partition of energy which is very very important for many aspects and one of the aspects i already mentioned that it goes to the specific heat

so i think i will stop here today and tomorrow i will recapitulate this ideal gas equation and do everything with a recap and take it beyond this ideal gas thing and i will give the notion of mean free path which i have not

so far used thank you for today you