Gas Dynamics
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Module - 1
Lecture - 1
Compressibility and Thermodynamics

Hello every one. Welcome to these classes on gas dynamics. We will first start with discussion on what gas dynamics is and how is it different from fluid dynamics? What will be the basic difference if it is fluid dynamics verses gas dynamics? What you will tell will be the difference? In simple fluid dynamics which we talk about density remains constant roughly. And when it goes to gas dynamics, we will talk about density changing. In a sense we are talk about compressible gases, we talk about compressible flow of gases is a better way to protect. We are interested in flow of gases and now we are thinking compressible flow. So, first we need to understand what is compressibility? That is the first thing we need thing about compressibility.

So, when we think about compressibility how will we define compressibility? Something that do with density gradient should be related to density how is it density changing. How we will density change in? What the various way is by which density of a gas element can change. A comfortable at gas element right like fluid element we can say now it is gas element will say specifically gases. So, how can fluid density change for a gas density how can I change various processes what all can it be. Change in pressure anything else change in temperature I could heat or cool the gas that will changes it density or I could think about changing its pressure. That is I can compression a gas or expand a gas that is these entire thing I can do to the gas.

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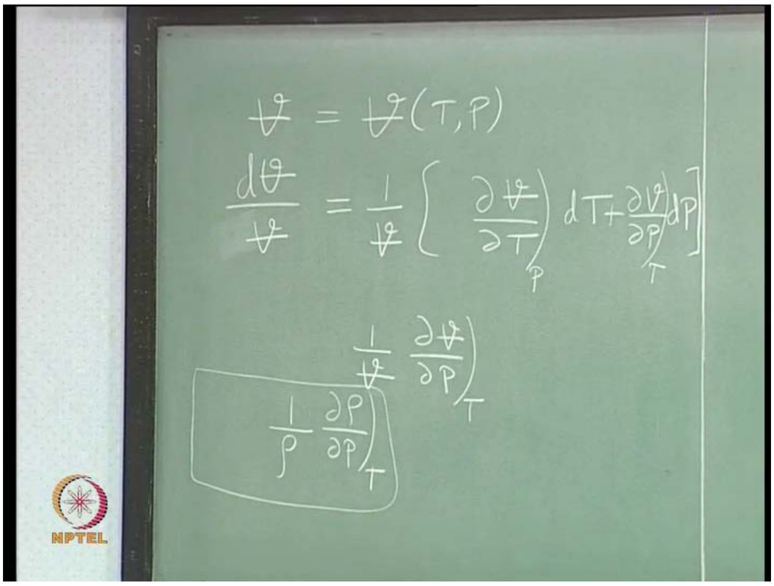

So, now will go write something on the board will say I will use this notation for specific volume, mass specific it is volume per unit mass. And I put this cut for v total that it is volume verses if there is no cut I will use it for velocity and we will keep it that way. We will write this as function of temperature and pressure because we know that this 2 can change. Now we want to use simple calculus and tell differential change in this specific volume. We will just write at d v by v what tell this b equal to previous know it already. So, I will just keep this one by v separate and then will just write d v in terms of derivate with respect to each of the terms. Next time I will be more careful about the corner line I will have these 2 terms. Of course, you have tell that this derivative keeping pressure constant and this derivative as keeping temperature constant. So, these are your expansion that is like heat the gas at constant pressure that is expand and these is your isothermal compressibility.

These are the 2 term we are look at so, if there is any fractional change in volume specific volume here. Then it would be because of a small change in pressure are because of a small change in temperature. Now we are more interested in thinking about this term if we are talk compressible fluid flow. It may also be changing because of heating or cooling we are more interested in this term mainly. So, we are looking for a term which is something like this, these are the coefficient for that d p. If these are very high then the frictional change in specific volume will be very for a given change in pressure. When that happens we call this highly compressible gas that is the way we have to gone to look at it. So, this is related at compressibility this is what will call as compressibility of the gas it can be return in term of density also. What does specific volume? It is volume per unit mass density will be mass per unit volume just reciprocal of it.

I can write it in terms of density compressibility can be defined as this these is also probable called compressibility which are way you look at. In most of gas dynamics will think about this these easier to work with. So, we will typical think about density of a gas compare to specific volume of a gas it is equivalent just one is a reciprocal of other we will strict to this. Now these is 1 way looking at the compressibility, but if you go look at books. There are some many books for compressibility they will tell you different definitions for compressible flows. One of the definitions happens to be it is related to compressibility where we will tell if the compressibility is very high. Then we will call it is a compressible flow other definition exist what are the others. I did not get that, what that repeat? We can the, is defined this compressibility in term of bulk model next setting in term of bulk modeless of next. Yes in a way the bulk modeless is related to the this term this is related to bulk modeless. Yes we can express this in terms of bulk modeless that is 1 by of 2 units there are other form as in terms of velocity there is one way of defining. How will I call flow of compressible?

Not number related we will keep that also in mind will come back to it after sometime I will just tell you roughly what it means. I am going to define something call mach number which is ratio of the fluid flow fluid element velocity divided by the speed of sound at that local point in the flow. So, that will be the local mach number of that fluid element. Why are we under we are gone say that it is if it is very low compared to one? Then will call it in compressible and if it is pretty high compare one or even higher than one will call it compressible flow that is what we are looking at. Should there on negative sign I guess the term will come out to be if you want call it as compressibility. If you want call it as compressibility and you want say I want to keep my compressibility positive. Then I have to put a negative sign or else what will happen is this density to pressure relation will be opposite to each other. Non density to pressure volume to pressure will be opposite to each other. I will have to put minus sign if I want to think about it as bulk modeless if you want to leave it like this it should not affect.

In here it will not be a negative, we will use only the density. Based on then we become no need of, if you look at the density term that, we are looking at density based term. If you are looking at specific volume term the pressure will be is increased. If pressure increases typically volume deceases at constant temperature. So, d v by d p will be negative, but we want to call bulk modeless as a positive modeless quantity. So, if that is the case that we will put my negative sign in front of it, but if you are using in density it should not affect. If it is density it should not affect at all will keep at same.

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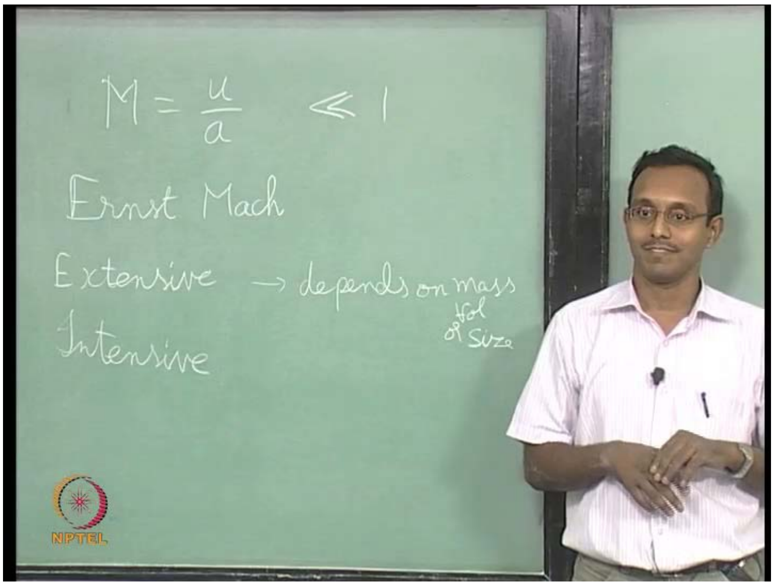

Now, we said something called Mach number and we said if it is for less than 1 it is incompressible otherwise it is a compressible fluid. Why are we comparing with a I speed of sound of that particular fluid element at that point? Why are we comparing with speed of sound? It not just any reference I would have picked speed of light if you want as reference that is not what you pick. Sound travels by compression and rarefaction how is that related to what I want to tell compressibility. We want worry about obstacle right now in the flow even if it is flow with non obstacle just clean flow if it is mach 3 flow. Why are we comparing it speed of sound one answer is something like sound wave is related to compression and expansion of the gas fluid element locally. If I am speaking you I am sending compression expansion waves to you. That compression and expansion how fast can compression expand the gas will tell you how fast the fluid will go towards?

A quick way of talking about compressibility I always like giving this example as imagine a metal rod and imagine air column exactly the same volume of there. Now what we are thing as I want to take a hammer and hit the metal rod here. And I put my finger on the other hand to see when I will first feel the wave that there is something happening on this corner when I will feel it on the other side. If I do the same thing on air which one I will feel quicker small length metal will be quicker why? Density is higher is not the answer. Molecules are for more closely, but that is not the answer, but that is related to that term compressibility setting there. Quick answer is speed of sound. Any information that needs to travel from one point to another point goes through collision of molecules think about it. I hit with the hammer on this corner layer of the metal rod those set of molecules are atom sitting there ion atoms. Let says its ion rod ion atom sitting there are gone to be displaced by this hammer when they move they collide with the next layer.

And then that will collide with the next layer next layer next layer and then how are they moving in how does the last layer know that the first layer had something by collision. These is only process and after the first few layer the molecule do known that it was because of the hammer that the molecules are moving. Only the first two layers may know that it is because of the hammer. Other layer will just know that the first layer moved that is the only thing it knows. If there is one thing it knows is just that there is way of that is coming from that end into the metal medium. Just a wave that is going through this lattice of your medium that metal rod in our lattice is just arrangement of metal inside the metal rod metal atoms inside the metal rod. So, that is being displaced and lattice vibrations are going to send that wave in a particular speed only it would not send that any speed it field like.

For the particular material for that particular temperature there is just one particular speed at which it will go, that happens to be speed of sound in that medium. If I think about air same concept I have lets a tube which has air inside and I hit with hammer here. What will happen that molecules are more random they gone to move and push the next set of molecules. They gone crush into next layer of molecules. Now those molecules should move away to give way for this now these will go and crush into the next layer of molecule. Like that crushing process one into the other is slowly transformed from one and to the other. If I assume the molecules are setting ideal and in particular matrix formation like in lattices.

Then lay of a simple I can tell first layer to goes and collides with second layer, but that is not case where gases it is a little more flexible they find gap between then. So, when one molecule comes it need not hit this one it may just move of. In which case that wave did not really matter to the second layer, there is more gap. So, it will not affectively go that first will go a little slower. So, speed of sound in gas medium will be less than speed of sound in lattices base medium like solids. You know the speed of sound in air at room temperature rough number 340 per second 340 for all kind of room temperatures, not in a c room. Instead of and we think about metal rods a steel of the order of 5000 to 6000 meter per second. Now we know that if I hit the wave travels faster and ion steel compared to air that is what we just found out rights moving in speed of sound, where did sound coming here?

We are talking about a wave of molecules moving with that information that hammer hit it suddenly I am talking sound. How do I link it with sound? What exactly happened there was, one layer being displaced let say this is one layer this is the next layer this is the layer that was hit by the hammer is concern. And now there is a short will 2 layers are closed by what does that mean? Density of molecules here is higher; that means, the gas is compressed locally, gas are it does matter even if it is steel rod matrix is getting compressed locally it getting compressed. And what happen when this molecule layer moves to the next layer this region get expanded. So, there is compression expansion a wave going through from one and 2 the other when I hit with the hammer that is what is happening.

I am sending compression expansion waves which is what we call as sound waves, a loose definition for sound waves of course, you got talk to acoustic people they will tell different definitions for a sound wave we will keep it as this. Any wave which is at bunch of wave produced due to collision of molecules that is what we will call as the compression expansion wave related to speed of sound. Actually it is related to sound and the speed of which is what we will call as speed of sound. Now we are linking thinks with this Mach number expression what do you want to say? We want to compare the velocity of the fluid with the speed of sound in that medium.

So, we are telling there is of fluid element now we do not have any steel anything else there is just air. And we are look at air column there is one fluid element which wants to move first. Now as it is moving it is trying to push layer in front of it there will be sound wave going if that sound wave reaches ahead. And then tells that this fluid element here that this is moving then my speed here is less than the speed of sound. Then my mach number is less than 1 if I had the opposite case that is fluid is going faster much ahead of the collision wave travelling then, what will happen? By the time wave goes and hit it is that fluid element, the fluid element here will also go and hit it. If that is the case this fluid element does not know that this flow was happening. What will happen to the entire fluid element in between? They get crushed will see that that is the flow behind the shock later we would not get for right now that get crushed. We will look that will give you more physical field Ernst, but that is the idea. Now, will get back to this name mach there was eminent scientist Ernst mach, who did pioneering work in explaining moment of sound waves in gases explaining stock wave, blast waves.

He did most of his work in blast waves a most of his major contribution are in blast waves how blast waves propagates in time. If there is explosion of bomb how far will I feel the pressure wave that kind of work he did a lot. But he explained the mach wave a mach reflection, mach wave all that at all become his contribution there is a lot of hit. So, we just give its very apt name I would say I support that. So, will follow that mach number now will go back to the original definition we got from you people which is, if mach number is for less than 1 will call it in compressible and if it is higher than that lower limit whatever. If it anywhere comparable to be 1 higher than 1, for higher than all that is compressible will keep that way.

This is another definition for it we are given 2 definitions will try and link these 2 definition at later stage not right now, will find that there all the same eventually we will see that. Now will get little more into the course, these course is predominantly designed as starting from basics as if we are starting at under graduate level. This is the first compressible course you every having after you high school. that is we are starting with, but I want build up to a point where you can do graduate analysis with it full level, research level analysis you should be able to do with this. And I just am trying to give you a lot of physical intuition in understanding these concepts then mathematical alone.

Of course, I am going to give you a lot of mathematics I will write a lot of differential equation on the board and all that. And give you lot of mathematical derivations, but finally, I want have to the physical feel for this if something is happening you should start visualizing the wave travelling from one and to the other. And because of that this is what should happen should be able to tell that that is the way I am thinking I will design this course. If you are not getting any physical field for it any time in the middle just stop me and ask then I will give you even better physical field for it.

Of course, the any scientific analysis should start with lot of physics and it uses a lot of math then only we can understand anything. Engineering always starts with loss of thermodynamics and then loss of mechanics which is again subset loss of physics. Of course, will ignore currently loss of gravity, electro magnesium, nuclear physic whatever we ignore all those other loss we will strict to only loss of thermodynamic, loss of mechanics. Will start deriving all kinds of governing differential equations which are essentially for understanding, this particular, flow field system.

As in compressible flows, any type of compressible flows. Once we have that differential equation remaining think is all about putting specially boundary conditions. And you will solve different flow of properties which ever flows you want you can solve for it that is a basic idea. So, now, I had to start with basic thermodynamics this is just review. So, full you will understand this and will go through this quickly, but I will spend some time on loss of thermodynamics. But before that we had to define what a system is what is the system? Collections of narrow identically, any part of the universe is a better definition any part of the universe which we are currently interested we are interested in looking at some property of same this small volume of gas. Then this becomes my system then what is a surrounding everything else around this whole universe everything around this in whole universe is now considered surroundings to this, whatever we are interested in is called system. I may be interested two three system together may be system a system b system c and then everything around is surroundings that is also a possibility. What is the closed system? There is no close system is a just a system where there is mass interaction with the surroundings.

We want to call it just there is only energy interaction as if now we level it we can back to if you want. Will say close system is a system where there is no mass interaction mass exchange across the boundaries of the system. An open system is where mass exchange is allowed. An isolated system is no exchange of any interaction processer nothing is interacting completely isolated system. So, in that specific case we do not need to look at the surroundings, there is no interaction the surroundings thermodynamics is simpler will consider only this unit nothing else. Next thing we need to define is a state. What is a state of a system?

We are trying to define the system we want to tell it is applying. So, much force on the walls of my box it is having. So, much temperature it is having. So, much energy inside it is having. So, many molecules inside all that is a description of the system completely. If can define the system completely then all the defining statements I made put to together forms your state. For our simple systems we are talking about I want to call as state say I pick an example I can tell this volume of gas here is that a particular pressure particular temperature. And it is having a volume that will tell me that will enable me to tell you any property of this volume of gas.

If you want to me to give any specific property I will able to give it. So, I have defined it completely then I have define the state what I already I use pressure, temperature and volume. Like that how many such properties should I have to define a state completely two at least two this needs a little more? So, I will wait a little bit and come back to this. What is the process? The combination of sets not exactly a correct word to use. Some change some change from one state it is going to another state that change is what we call as a process. Now what is a path? It is a sequence of states that the system goes through in a process from beginning to ending of the process it went from this state to this state and the whole connection of all the states together becomes your path of the system. Path for the particular process which the system under goes now.

I needed the next definition before I go back and answer the previous statement which as how many variable to I need to define a state? For that I need to define intensive and extensive properties. What is an intensive property? Those properties that depend on mass, that is independent of mass or size or number of molecules in the mass whatever. If it depends on all these quantities then that is an extensive property extensive mass, volume or size which are way you look at it. Intensive will be it does not depend on those. How will I tell whether a properties intensive or extensive? Say I am giving you some crazy property which is Gibbs free energy for number of molecules thus it depend on mass or not or does it is. It intensive or extensive properties how will I tell? say I am going to tell you an example which is enthalpy per unit volume it does not contain mass. So, what is it vocalized-noise] that is not a easy way of doing things. So, I will give you a clean definition or simple experiment which you can do to find out whether it is extensive or intensive.

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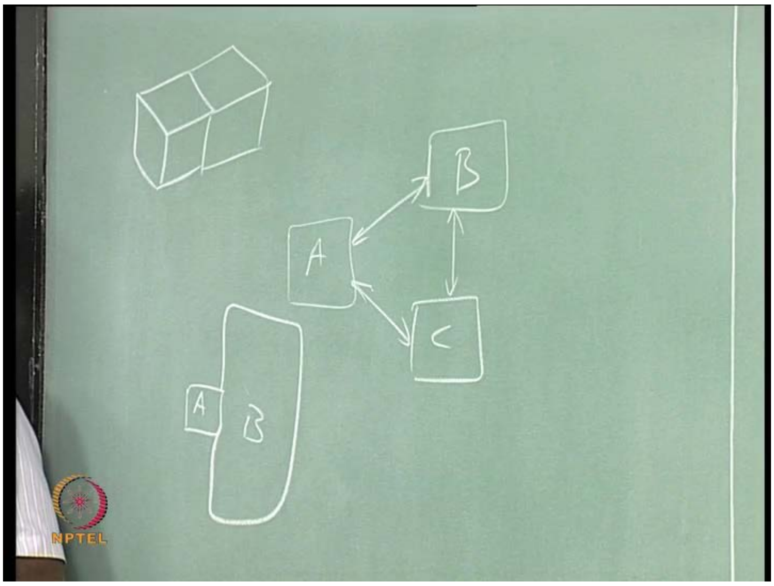

Let us say, will do I have a box this is one system lets say system 1 and it has that particular property which we want to explore whether it is extensive or intensive we want to explore. So, I have some property here I will create exactly identical system one more I created. I put them next to each other remove the boundary between them now I will call the new system as these 2 put together. If my property value doubled then it is extensive, if it remain the same then it will be intensive. A quick check now we can do the analysis let say I thick volume doubled. If I have same volume 1 more 1 meter cube and 1 meter cube became 2 meter cube it doubled. So, volume is an extensive property. If I think about pressure same pressure here and here, then I remove the wall and between it still the same pressure inside. So, that will be intensive property.

If I think about that specific case we pick enthalpy per unit volume let us say enthalpy per unit volume here is 1 joule per meter cube, same 1 joule per meter cube here. Now I want to find enthalpy per volume for the whole unit for whole full box this will be 2 joules per 2 meter cube, which will be again 1 joule per meter cube it did not change. So, that is an intensive property. You guys comfortable with this kind of easy check analysis if you do this you will never make a mistake. Now we will go back and again ask the same question to define a state of a system how many properties do I need?

1 from extensive and 1 from intensive I hear. 2 intensive is enough if you are interested in intensive properties only for our whole analysis I need only 2 intensive properties if I want some extensive quantity. Then I need to give one of them at least as extensive I could have it as 2 intensive 1 extensive. Or I could give you a special case which will work for some simple simplifications 1 intensive 1 extensive that is also fine. So, that is what we typically need to define a system, now will enter in to laws of thermo dynamics, we will go for zeroth law of thermo dynamics. What is zeroth law of thermo dynamics? Typically you would have heard first law and second law what is the zeroth law of thermo dynamics? Thermal equilibrium if mechanical engineering heat transfer people taught you thermo dynamics. Yes it is defined as equilibrium thermal equilibrium, but we are beyond them.

We are going to say not just heat transfers happens in my fluid it can also have pressure variations can also have chemical reactions, if I want, we will look at that one by one it depends on how you define things thermal equilibrium does not contain everything. Thermo dynamic equilibrium defines everything will get back to that. So, first we have to give the statement of zeroeth law of thermo dynamics which will be if I have a system a I have a system b and I have a system c. If I look at system a and system b and I say that they are in equilibrium I have not defined the word equilibrium yet. If I say that these two are an equilibrium and I also say that these two are in equilibrium a and c are in equilibrium. Then zeroeth law thermo dynamics states that, these two are in equilibrium. This is law which is needed for comparing systems we are comparing one system with another system and by saying what can be different between them. So, in this analysis we came to a point where we need a definition for equilibrium. How will I tell that system a and system b are in equilibrium? Now, we are talk about different properties and tell system a and system b are in equilibrium.

If something is equal to that if I tell that temperature a is equal to temperature of b then we call this thermal equilibrium. What did I introduce here and new variable call temperature this is how temperature is introduced. We have we have introduced a concept called equilibrium; we have introduce a variable called temperature. To tell that, these 2 systems have the same degree of hotness that is your temperature. If temperature a and temperature b are same and temperature a and temperature c are same, then temperature of b and c are same that is what is the actual statement we are looking for. What about mechanical equilibrium?

Now we have to think about how can I have system a and system b in mechanical equilibrium with between each other. Forces should be the same and we are going to make an assumption about our gas here. We gone to make an assumption saying it is a simple compressible substance. A simple compressible substance is a substance where the only form of work that can be done mechanically on it happens to be compression work and nothing else. Only compression work which means it is just that p delta v kind of work that is the only form of work possible. Of course, you can still have heat transfer through it that is another way of interaction with energy that is thermal interaction this is mechanical interaction. If I define that then I ask for mechanical equilibrium, now I can tell these 2 will be in equilibrium. If the pressure of a, and the pressure of b are equal then they will not apply force on each other. you can see the it does not matter what the volume is. I may have a case where a is a small system b is a big system I put them together they do not interact mechanically here as long as the pressures are equal.

They would not push against each other or they are pushing equally nothing happens. Pressure in to area is your force forces on both sides are equal that is you are mechanical equilibrium all. So, now, we have introduced the concept of pressure we introduce equilibrium concept, while we are defining equilibrium we define thermal equilibrium where we said temperature is needed. We have to define temperature then we said we have to define pressure for mechanical equilibrium. Now I will tell you one more thing, chemical equilibrium where will say we need to know the composition of the gases.

If the composition here and composition here are exactly the same then they will not start doing any crazy exchanges across it or when we go to chemical equilibrium of a given system instead of comparing systems. If I just look at one system they think about it even in otherwise they will say I look at the system now 10 seconds from now 10 hours from now 10 days from now. Whatever if the composition of gases, inside do not change then the system is in equilibrium, even if it changes after 10000 years the system is no more in equilibrium. It may be changing very slowly, but if it changes it is not consider to be in equilibrium, that is the idea of equilibrium.

In theory the same thing here temperature of a temperature of b are equal and I put them together they will not exchange energy they will just keep the same temperature in the both of them. If that is the case then they are in equilibrium if they exchange energy, then they are not in equilibrium. if I have a hot metal and a cold metal I put them together hot metal will give energy to the cold metal. So, they are not in equilibrium at that moment if I wait long enough half they both will become same temperature then it has reach the equilibrium. After that if I wait for 10000 years it may not change, that is the basic idea.

So, we had defined if the temperatures of the 2 metals blocks have become the same then it has reached thermal equilibrium. If the metals blocks are still having different temperature and the hard metal is giving energy to the cold metal then there is exchange of energy, which means it is not in equilibrium yet. If I wait long enough half it may exchange enough half that they will become equal at, that point I can tell that the system is in equilibrium not till that point. And from that point on if I wait how much ever time no change in temperature. But now I will take a practical example I will take a metal block 50 degree Celsius I will take another metal block in this room another 50 degree Celsius.

I put it here what will happen the room temperature is 25 degree Celsius both the temperatures will lose equally they will lose energy equally. What is happening here, exchanging with surroundings when we talked about systems here we did not consider anything else here. We just considered system a system b we did not have anything called a surroundings, which means we considered isolated systems we did not have a surrounding. If we have a surrounding of course, I could take that in to account by putting a big circle around this and call that region as d. If there is exchange between a and d then a and d are not in equilibrium with each other, may be t a and t b are still equal. These 2 are in equilibrium with each other, but they are not in equilibrium with the surroundings that was the example I just gave you. 50 degree Celsius 2 metal blocks they will not exchange heat within themselves, but they will give heat to all the air around. If you just be very clear about all this that is zeroeth law of thermo dynamics.

Where we introduce the concept of equilibrium introduce a variable call temperature for thermal equilibrium, introduced a variable call pressure for mechanic equilibrium, and introduced variable call composition which is actually a whole bunch of variables. Mole fraction of each of the speech is present inside say if it is air nitrogen, oxygen, carbon dioxide, water vapor everything mole fraction of everything I have to give if I want to define the state very correctly. Now if I go for first law of thermodynamics what does that say? Energy remains constant energy can never be created at energy cannot be destroyed such statements exist of course; we are neglecting nuclear reactions on stuff in this particular case. If you are taking in to account nuclear reaction then will have energy to mass conversion should be taken in to account we will ignore that for now does not affect us. The primary statement will be simply put energy is conserved what did I do with this a law thermodynamics. I introduced a variable call energy we did not define anything very well we just said there is something called energy.

How do we define it? We have not defined we just told energy is a fundamental quantity which defines the state. We just said that will give expressions for it later and then we are going to say systems can have exchange between one and another system a and system b can exchange energy. But the overall energy of my complete system does not change; overall energy of my universe never changes that is the law we are going to keep. It does not change at all of course, in a simple compress able substance the only kind of energy exchange with my system happens to be through heat exchange or through compression or expansion work nothing else. We would not consider the case like I put a fan inside my system and rotate it that is storing of my gas which we are ignoring as a simple compressible substance. We would not have storing case if I store a gas for long time its temperature will increase, but we will neglect that kind of energy transfer.

Now we go for second law of thermodynamics, what does that say? Direction of energy transfer and I heard something call entropy there. So, they are linked the actual statement is something like there exists is a quantity called entropy. We define the word entropy suddenly we introduce the word entropy in second law of thermodynamics. And then we say, if there is a process that is naturally occurring in nature then entropy must be increasing entropy of what must be increasing? Entropy of universe must be increasing a quick example is refrigerator, think about a refrigerator if I cool the system entropy decreases. You would already have a little bit of thermo dynamics and just using it like this loosely statement. If I make the temperature go very low molecules cannot move around there is no energy for it.

So, they will just sit ideal in one place that is the most restricted condition entropy will be the lowest. So, if I take my gas to say 1 Kelvin or 0.1 Kelvin then I will be in a situation where my entropy will be very low, but there are physicists doing such experiments. What are they doing really? They using a very big refrigerator and they are having this small gas controlled to that 0.1 Kelvin while all the other gases around in the whole room may be heated up if you go feel your refrigerator back side. It will be very hot it is taking the heat from inside and sending it outside. Let energy is still concerned, but this process is naturally occurring why I am cooling a small volume and heating a big volume. That is the idea I am cooling a small volume and heating a big volume that is what I am thinking about. So, over all what happens is I have given heat to a large number of molecules removed it from a small number of molecules they are unhappy, but the large number of molecules which I gave heat to a they are all happy.

So, it is in my opinion its entropy is like how happy are the molecules in a universe they want to be more and more disordered. if I give it lot more energy they will move in random directions at whatever speeds. So, they are more happy in a way, will come back to this happy and entropy relation later come back to it again. But when we think about isolate systems only of course, isolated system does not have a surrounding. Its only system there only will say the s is greater than 0 if you want to system occurs spontaneously that is the idea. If for a imaginary process which I think about if d s is less than 0 that process will never occur in nature. Is this the law put by man on nature or is it something else? It is just law of nature we do not know who put it may be it is the god, but nature obeys this. It is called law of nature, for that reason it is just law of nature all the thermo dynamic laws we defined are obeyed by nature. Laws of mechanics are also avoid by nature, but part of them are used to define variables moment has to be defined by first law like that you have to define various laws.

Even here zeroeth law was used o define equilibrium first law was use to think about energy, second law was use to think about entropy. So, we said that if I have these variables I am sufficiently equipped who introduced. It was introduced somewhere around 1800 by I do not remember exact set of people, but Gibb’s was one of them. And then Boltzmann came and defined or gave numbers to yet and gave a universal scale by which we can measure entropy and all that. So, that is where we are right now will go to next class and will more talk more about other thermodynamic variables. Other thermo dynamic variables, we still have not gone to gas yet perfect gas. We will not define a gas then we will define perfect gas, then we will go further along that direction. And then we will enter thermodynamic processes then we will switch to laws of mechanics we are still in review mode first 3 classes are devoted to review. Of what you should know by the time you enter gas dynamics course, see you next time.