

## **fBasics of Mechanical Engineering-3**

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**Week 01**

### **Lecture 01: Introduction to Thermodynamics**

Welcome to the next course of Basics of Mechanical Engineering Part 3. In this course, we will predominantly focus on thermodynamics and fluids. It will have 60 percent of the course in the area of thermodynamics and then 40 percent in the area of fluids. The moment I say thermodynamics, 'thermo' means something related to temperature. Something related to heat will be discussed.

Dynamics, so with respect to movement, something is changing. So this course will be more focused on heat, temperature, and its applications. If you look at a refrigerator today, it is nothing but a machine that works on the concepts of thermodynamics. The outside temperature is 48 degrees during summer, and the inside temperature or room temperature is around 24 degrees Celsius. How is this machine trying to create the difference?

Inside a machine, there are several subsystems. Which subsystem does the job such that it throws cold air into the room? And of course, there is a conversion of energy from electrical energy to mechanical energy such that the subsystem works and provides cold air. So, in this introduction, I have introduced subsystems, systems, machines, and then I have talked about thermodynamics. You see, in real time, there are a lot of applications based on thermodynamics. Friends, let us get into the course.

This course will be jointly handled with me, Professor Ramkumar, Department of Mechanical and Design, IIT Kanpur, along with Dr. Amandeep Singh.

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In this first lecture, we will try to focus on Introduction to Thermodynamics, Overview of Laws of Thermodynamics, there is a big difference between a law and a concept. Law are science based, where in which it has been developed over several iterations. And wherever you are, it works universal. So, those are called as laws. So, overview of laws of thermodynamics. Then, there are different approaches in thermodynamics.

One is called as microscopic, the other one is called as macroscopic. Both, we will try to see an introduction. Throughout the course, it is only giving you an introduction to all these concepts. Then, we will try to look into Kinetic Theory of Gas: History, Assumptions and Postulates. Then, we will try to look into Pressures of Gas and Kinetics Interpretation of Temperature.

We will also see Thermodynamic System. What is a Closed loop system, what is an open loop system and what are Isolated systems. In thermodynamics, there are two major properties, which are Intrinsic Properties and Extensive Properties. We will see that. Then, State and Path Function, Thermodynamic Energies, Work, Heat, Internal Energy as a State of Function. And finally, at this end of the lecture, we will try to have Recap.

Friends, when you go through this lecture, you should always look around you, and see what are all the machines around you which works on these concepts.

## Introduction

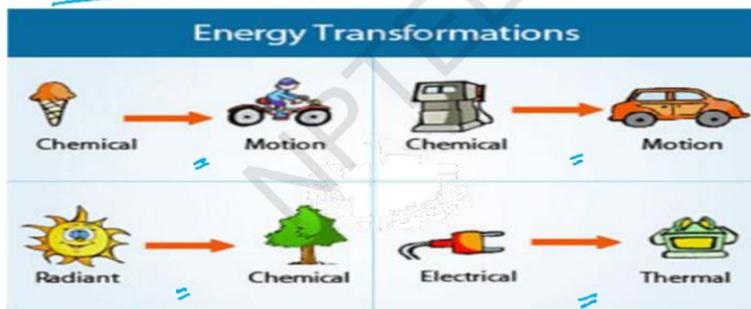


The term "thermodynamics" was made up by William Thomson in 1749.

**It is about understanding how heat and energy work.**

It looks at how different types of energy can change from one form to another.

There are three main rules that explain how energy behaves.



Examples of Energy Transformation



Image Source: <https://www.chemistrylearner.com/laws-of-thermodynamics> 3

The term thermodynamic was invented by William Thomson in the year 1749. It is all about understanding how heat and energy works. So, if you overlap your thought process, if you see, during this time 1749, there will be front and back lot of industrial revolution would have happened. Small small machines would have happened.

People would have understood the concept of water. Water when you heat, it gets into steam. The steam has energy to do or to move certain things. This happened during industrial automation or industrial revolution. So that's where they talk about heat and energy.

It looks at how different types of energy. You can see that there are chemical energy, radiating energy, electrical energy, chemical energy, you have mechanical energy. Suppose, let us assume, this motion of a car is replaced by a lift and then that lift is used to move up and down people. So, you have mechanical energy also. So, you can have chemical energy, radiation energy, electrical energy which gets converted.

So, the thermodynamics looks at how different types of energy can be changed from one form to an another. When it is getting converted from one form to an another, there are three main rules that explain how energy behaves. We will see that. So here, you look at radiation. Sun radiates from this photosynthesis happens, the tree tries to grow. Electric energy, you plug into a socket and you can see induction furnace working or you can see

an induction cooker working or induction pan working or microwave working. When you try to talk about chemical energy, it is petroleum. When it is dumped into a car, then it gets activated by a spark plug or by some other thermal.

So, there is a combustion happening. Based on the combustion, the heat is converted into mechanical energy and then the car moves, right. So, if you see that, all these things, the energy is transformed from one form to the other and wherein which you try to make use of it. So now this conversion whatever happens, they say that there are three main rules. What is Thermodynamics?

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## What is Thermodynamics



- The branch of chemistry that deals with the movement of energy from one form to the other and the relation between heat and temperature with energy and work done is called **thermodynamics**.
- Molecules store chemical energy, which can be liberated as heat when fuels such as methane, cooking gas, or coal undergo combustion in the presence of air. This released energy can be harnessed to perform mechanical work in engines or converted into electrical energy through devices like dry cells.
- *The diverse forms of energy are interconnected, and under specific circumstances, they can transform from one form to another.*

Thermodynamics is the field that explores and analyzes these energy transformations.

*Thermodynamics is the science stream that deals with the study of combined effects of heat and work on changes in the state of matter confined by the laws of thermodynamics.*



It is a branch of chemistry that deals with the movement of energy from one form to another and that relation between heat and temperature with energy and work is done is nothing but thermodynamics. It tries to bring in a relationship between heat and temperature with energy and work. In the first basic course we have covered what how do you define energy, how do you define work. When you try to take a solid and try to break it or try to take a liquid in a container and when you try to look at microscopical, they will always be molecules. These molecules store chemical energy, which can liberate as heat when fuels such as methane, cooking gas or coal undergoes combustion in the presence of air.

You have a cylinder. Inside a cylinder you will have air mixture of petrol, and air getting mixed. It is pushed into a cylinder. And then in the cylinder, you have a piston. The piston moves up and down, so the piston tries to compress. You have a spark plug which sparks, and it ignites. The air mixture now almost like explodes and creates lot of energy. With this energy the piston moves down. Now, you see chemical energy getting converted into mechanical energy through a process of combustion. In the same way, you can see that in your house also. You have a CUGL or a pressurized gas line coming or you will have a indent gas through which the gas comes and then it gets mixed with air and then you start. There is a combustion happening and that on top of it you keep a pan and in a pan you keep water, the water boils. You see how the combustion gets converted into a heat energy. This release energy can be harnessed to perform mechanical work.

You can do it for mechanical, you can do it for electrical. For example, you can try to extract energy. The piston moves back and forth. From there, if I wanted to run a machine, so you can try to do it. So, it is not that mechanical work is converted into energy is the only thing.

It can also convert electric energy. Example, diesel generator. Same principle, you have a diesel, you have a combustion, this combustion tries to operate a subsystem, from that subsystem you try to extract electricity, that electricity is given to rest of your house or rest of your office. So, when there is a power cut, we use DG. So, here it is an example which gives converts electrical energy and forms a new thing or it converts into electrical energy through devices like dry cell.

For example, if you try to buy a AAA battery and this AAA battery is put inside a camera or a wall clock, it activates the quartz crystal behind it and then starts working. So, this is what they are talking about here. The diverse forms of energy are interconnected. Please understand that the diverse forms of energy are interconnected. And under specific circumstances, they transform from one form to another. So, two important words: interconnected and specific circumstances.

Under specific circumstances, they are confirmed. So, now you are able to see what thermodynamics is. So, thermodynamics is the field that explores and analyzes these energy transformations. So, thermodynamics in brief is nothing but a science stream that deals with the study of the combined effect of heat and work on changes in the state of matter, confined by the laws of thermodynamics. We will see what the laws of thermodynamics are.

Now, are you able to appreciate this definition? Thermodynamics—it's not a definition, it's an understanding, right? Thermodynamics is a science stream that deals with the study of the combined effects of heat and work. Heat, temperature—you try to excite something, and that gets converted into mechanical work, and then you do something. So, that is heat and work on changes in the state of matter. The state of matter can be solid or liquid.

Yes. Confined by the laws of thermodynamics, okay. So, where do you use thermodynamics? As I told you, a car uses thermodynamics. Your induction furnace uses it.

Your gas stove uses it. Your DG set uses it. So, everywhere you see, there is heat and there is work. So, we use thermodynamics in all of them. AC uses thermodynamics.

Automobiles use thermodynamics—two-wheelers, four-wheelers. Rockets use thermodynamic principles. So, everywhere, to a large extent, thermodynamics is used. A hospital's centralized cooling follows thermodynamic laws. A mall's centralized cooling follows thermodynamics, right? So, thermodynamics is very important. All engineers should understand its importance and basic laws, so you do not get carried away when someone presents data to you. That is all. So, this course is not an in-depth study of thermodynamics. It is superficial, helping you understand these small topics with a few calculations for clarity.

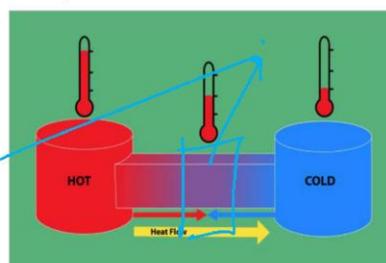
## Utilisation of Thermodynamics



- **Feasibility of a process:** It helps to lay down the criteria for predicting the feasibility or spontaneity of a process, including a chemical reaction, under a given set of conditions.
- **The extent of a process:** It helps to determine the extent to which a process, including a chemical reaction, can proceed before the attainment of equilibrium.
- **The efficiency of a process:** The study of thermodynamics is based on three generalizations derived from experimental results.

*These generalizations are known as the first, second and third laws of thermodynamics based on human experience.*

Process  $\left\{ \begin{array}{l} \text{reversible} \\ \text{irreversible} \end{array} \right.$   
Reaction



So, the utilization of thermodynamics is the feasibility of a process. If somebody says, 'I will add A to B without applying heat,' then it is not possible. So, if I want to mix two different immiscible liquids, right, and I will try to make a component called C. A and B mixed together to form component C. Now, you should understand whether A and B can be mixed, and if they have to mix, there has to be a process. So, now when we try to understand thermodynamics, we will try to see whether the process is feasible or not.

So, the feasibility of a process helps to lay down the criteria for predicting the feasibility or spontaneity of a process. That means to say, there is a process which is there, and whether this process will work. Whether the chemical reactions will happen. Whether thermodynamic mixing can happen. Right.

So, for that, thermodynamics plays a very important role. It helps to lay down the criteria for predicting the feasibility or spontaneity of the process. There are some places where it ignites and then progresses. So, that is the spontaneity of a process, including a chemical reaction under a given set of conditions. So, if something is there, you will be able—if you understand thermodynamics—to try to understand whether the process is feasible or not.

For example, I wanted to cook, and I wanted to cook where the external ambient temperature is minus 24 degrees, and I have a burner where the maximum temperature can only reach 20 degrees Celsius. I want to boil water, okay. So now, you can clearly see that the external temperature is this. The maximum temperature this burner can reach is 20 degrees Celsius. So, this process is not feasible. If I use a big 10-liter tank of water and then drop an egg in it, I wanted to see whether the egg would boil, but it is not possible. It may be possible, but it is energy inefficient.

So, all these things you will be able to understand and appreciate when you know the utilization of thermodynamics. The extent of a process. It helps determine the extent to which a process, including a chemical reaction, can proceed before attaining equilibrium. So, the extent of the process, feasibility extent, can be determined. And the last point is going to be the efficiency of the process.

The efficiency of the processes. The study of thermodynamics is based on three generalizations derived from experimental observations. These generalizations are known as the first, second, and third laws of thermodynamics, based on human experiments. So, you can see here. There is a heated surface, a cold surface, and a junction in between. Suppose you want to derive the temperature from this point for a reaction to happen.

Then, you should know what this temperature should be, what that temperature should be, the distance, and how the gradient decreases. And at which point I should tap to get my reactions done.

So, this can be understood if you understand thermodynamics. So, the utilization of thermodynamics is plenty. It can be used in process industry, product industry, automobile and then if you want to look at different sector everywhere, these laws will be used. So, feasibility of a process, extent of the process and efficiency of the process all can be understood when we understand the thermodynamics. And in thermodynamics, we have been repeatedly talking about three. What are the three are first, second and third law of thermodynamics based on human experience?

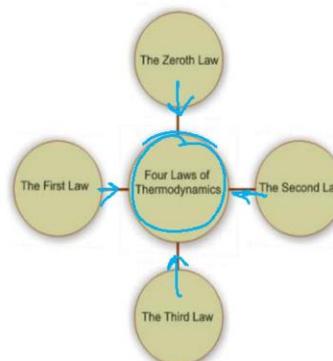
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## Overview: Laws of Thermodynamics



The principles of thermodynamics are summarized in form of four thermodynamic laws:

1. The **Zeroth Law** deals with thermal equilibrium.  
*It provides a means for measuring temperatures.*
2. The **First Law** deals with conservation of energy.  
*It introduces the concept of internal energy.*
3. The **Second Law** provides guidelines on conversion of internal energy of matter into work.  
*It also introduces the concept of entropy.*
4. The **Third Law** defines absolute zero of entropy. The entropy of a pure crystalline substance at absolute zero temperature is zero.



Now, let us try to see what are the Laws of Thermodynamics. I have been talking about one, two, three, but even before that could happen, there is something called as the Zeroth law. So, the principles of thermodynamics are summarized in form of four thermodynamic laws. So, this is the center which looks at the four thermodynamic laws. So, you will have Zeroth law, first law, second law and the third law.

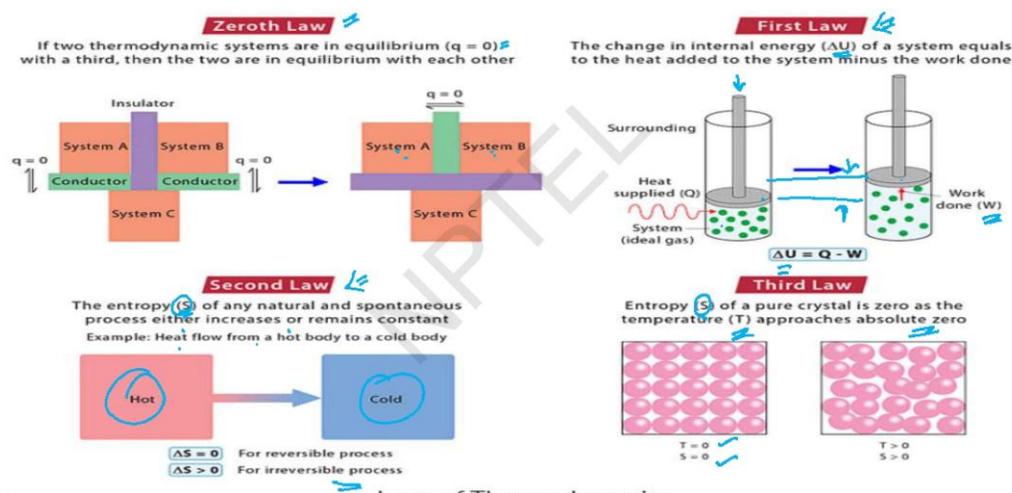
The zeroth law deals with thermal equilibrium. Two systems, hot, cold, there is a junction. So, there will be an equilibrium reached. So, it provides the means for measuring temperature. So, the zeroth law talks about thermal equilibrium.

The first law talks about the conservation of energy. It introduces the concept of internal energy. We will see what internal energy is in due course. So, the first law deals with the conservation of energy. The second law provides guidelines on the conversion of internal energy of matter into work.

So, the first was to provide a means for measuring temperature. Next was to introduce the concept of internal energy. The third one is to understand the change of internal energy into work. So, it introduces the concept of entropy. And the third law defines the absolute zero of entropy.

The entropy of a pure crystalline substance at absolute zero temperature is zero. So, these are the four laws. Zeroth law, first law, second law, and the third law. The first law talks about the means of measuring temperature. Then, it talks about the concept of internal energy. Then, internal energy conversion into work. So, the last one is talks about the absolute zero of entropy.

## Overview: Laws of Thermodynamics



So, here are some with few examples. We have put the same laws. Let us go one after the other. Zeroth law. If two thermodynamic systems are in equilibrium. That is when  $Q$  equal to 0 with a third, then two are in equilibrium with each other. For example, you have a system A, system B, a conductor, and then you have a system C, right. So,  $Q$  equal to 0 is the equilibrium. So, when two thermodynamic systems are in equilibrium when  $Q$  equal to 0 with the third system called C, then the two are in equilibrium with each other, right.

So, you can see here conductor, conductor, and you have a insulator. So, it is said, this one you can see here insulator, and then you can say this also there. So, this is insulator and the conductor is in between. So, system A, system B is in equilibrium. The first law talks about the change of internal energy  $\Delta U$ .

$Q$  equals 0.  $\Delta U$  of a system equals the heat added to the system minus the work done. So, the change in internal energy. For example, you have a surrounding and then you have a piston. Assume that this piston has a weight of its own. So, it slides down and then it tries to compress the air inside. So, here we try to assume it is an ideal gas. So, then heat is applied. The heat will try to expand the gas, and the piston will move up.

So, I will repeat. Here is a surrounding. The heat is applied to the ideal gas. There is a piston which falls down by its own weight. It falls down. Gravity. It falls down. It tries to compress. When it is trying to compress, you apply heat.

Then there is an expansion. So, now this expansion will try to push the piston from here to here. You see, there is work done. So, here whatever is applied is called  $W$ , the work done. So,  $\Delta U$  is nothing but  $Q$  minus  $W$ . What is  $Q$ ?

$Q$  is nothing but the heat supplied. This talks about the first law of thermodynamics. Let us look into the second law of thermodynamics. The entropy  $S$  of any natural and spontaneous process either increases or remains constant. So, the heat always flows from a hot body to a cold body.

So, here there are two types of processes. One is called a reversible process, the other one is called an irreversible process. When  $\Delta S$  entropy is equal to zero, then it is a reversible process; if it is greater than 0, it will be an irreversible process. So, you should also understand because here, if you go back, I was talking to you all the time about processes. Then, in the process, there are two things, right? One, it is to be reversible or irreversible.

An irreversible process means where there is chemical energy; the chemical reaction happens, it releases energy, then based on that energy, you try to do work. For example, an automobile. You fill in petrol, there is combustion that tries to move the vehicle—it is irreversible. Reversible means I am able to shuttle between hot and cold. So, for example, I make one surface hot, the other surface cold. Then, hot gets transferred to cold, and then when the cold becomes hot, it gets transferred back. So, reversible is also there.

In reversible processes, the entropy will always be equal to 0. That is why we are talking about the processes: irreversible process and reversible process. The third law is the entropy  $S$ —you see  $S$ . The entropy  $S$  of a pure crystal is 0 as the temperature  $T$  approaches absolute 0. When  $T$  equals 0 and  $S$  equals 0, it looks like this. See, that means it is all occupying a fixed location, and it is a pure crystal.

So, the entropy  $S$  of a pure crystal is 0 as the temperature  $T$  approaches absolute 0. When the temperature is away from 0 and the entropy is away from 0, then you see the randomness that is there in the process, okay. So, these are pure crystals, and these are all random. So, they are all moving here and there. So, the system is active. There is energy inside the system. So, knowing the loss, we will now try to see the different approaches.

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## Different Approaches



### 1. Macroscopic Approach (Classical Thermodynamics):

- The macroscopic approach deals with the **overall behavior** of a large amount of matter without considering the molecular nature of the substance.
- *It focuses on measurable quantities like pressure, volume, temperature and entropy. This approach is practical and forms the basis of classical thermodynamics.*

#### Key Features:

- It treats matter as a continuous medium.
- It does not require knowledge of molecular behavior.
- It uses a few easily measurable variables.
- It is suitable for engineering applications.

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## Different Approaches of Thermodynamics



### Example:

1. When studying the **performance of a steam engine**, we consider pressure, volume and temperature of steam without worrying about how individual molecules behave.
2. **Heat transfer** in a boiler is calculated using macroscopic laws like Fourier's or Newton's laws.



There are two types of approaches, which I already told you: one is called the macroscopic approach, and the other is called the microscopic approach. The macroscopic approach is sometimes called classical thermodynamics. In the macroscopic approach, it deals with the overall behavior of a large amount of matter without considering the molecular nature of the substance.

So, here to a large extent it tries to average it out. It does not take per molecule heat vibration something like that. It tries to take the overall system into existence. The macroscopic approach deals with the overall behavior of a large amount of matter. See molecular dynamic simulation does take molecular atoms, every atom you can try to add mechanical properties, thermal properties, electrical properties and run a simulation and get it done, right.

It tries to tell the behavior in a small cross section area. But when we are looking at mechanical energy systems, there are always massive, big, large. So, we will try to take the overall behavior of a large amount of matter. It focuses on measurable quantities like pressure, volume, temperature and entropy, which is massive. I can measure the pressure.

What is pressure? Pressure is nothing but force per unit area. Volume, I can measure the volume, then temperature, then entropy, right. This approach is practical and forms the basis of classical thermodynamics. So, if somebody talks I will follow classical theory, classical thermodynamic approach in evaluating the work done.

That means to say, he is taking a larger system, and his measurable quantities are going to be force or pressure, then volume, then temperature, and then he will also try to do entropy, right. So, the key features: it treats matter as a continuous medium, right. If you try to take an atom, between two atoms there is discontinuity. So, here what we do is, we say, oh, nothing doing, everything is uniform. So, it treats matter as a continuous medium.

It does not require any knowledge of molecular behavior. Atomic vibration or bond stretching does not matter in classical theory. It uses few easily measurable variables. It only takes measurable variables. Interestingly, when you are doing engineering, you should always try to have a measurable parameter as your output. For example, if you try to say the thickness of the hair is 100 microns, I do not have any tool to measure it.

So, then it is very difficult. You should say, if the thickness of the hair is around 100 microns, which is 0.1 millimeters, I have a vernier to measure it, then yes, you can think of it. So, here in thermodynamics, we always try to use a few easily measurable variables. It is suitable for engineering applications. We always follow classical thermodynamics.

If you talk to any automobile engineer, when we talk about anything that is there. When we talk about explosives, RDX and this and that. So, there we go into a microscopic approach. But here, we always go on a bigger scale. So, the examples under microscopic approaches, when studying the performance of a steam engine, what is the efficiency of the steam engine?

What load can it pull? What amount of coal do I dump in so that I get steam such that it can pull so many coaches? What is the quantum of coal I should store with me as I keep moving a certain distance? So, you are trying to talk about the feasibility of the process, the efficiency of the process. So, when studying the performance of a steam engine, car, or rocket, we consider pressure, volume, and temperature of steam without worrying about how individual molecules behave.

I am sure now you will be able to understand. Heat transfer in a boiler is calculated using macroscopic laws like Fourier's and Newton's laws. So, by doing so with a macroscopic approach, we always try to get the ballpark number to a large extent. This ballpark number, or the thumb rule we follow or first principles we follow, helps us understand what is going on in engineering systems. So, we are happy with a macroscopic approach because we have the parameters to measure pressure, volume, and temperature. Now, let us look at the microscopic approach.

Microscopic approaches, you are going to look at very small scales. So, then the statistical thermodynamics, it is microscopic approach is otherwise called as statistical thermodynamics. So, the microscopic approach; the behavior of individual molecule or atoms in a system is studied.

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## Different Approaches of Thermodynamics

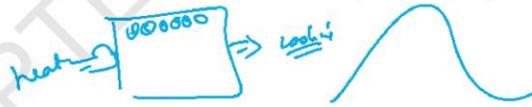


### 2. Microscopic Approach (Statistical Thermodynamics):

- The microscopic approach studies the behavior of individual molecules or atoms in a system.
- It applies principles of statistical mechanics to determine the average behavior of a large number of particles. This approach helps to explain thermodynamic properties at a fundamental level.

#### Key Features:

- Requires molecular-level knowledge.
- Uses statistical methods to relate microscopic behavior to macroscopic properties.
- Involves variables like molecular velocity, energy, and distribution.
- Provides deeper insights into the nature of thermodynamic processes.



So, here a bulk is studied, here we study in a very small minuscule level individual molecules. It applies principles of statistical mechanics to determine the average behavior of a large number of particles.

The inside a dabba, there is one ball. I know when I heat it, what will be the ball's vibration and what will be the influence of one ball on the other ball in terms of force, in terms of temperature transfer, everything. So now what do I do? I did it with one ball. Now what do I do?

I have 100 balls. So, now I average it out, right. So, the statistical mechanism to determine the average behavior of a large number of particles and heat what happens is it follows Gaussian distribution. Now, in the box whatever I had I had balls. Now I will have to see how the heat distributes in a Gaussian pattern, what will be the influence of one over the other, right. Once I apply heat, there is also a possibility, heat is applied there is also a possibility that here cooling happens.

So, there is a radiation, there is a diffusion, these phenomena's will come. So, now what I do is? I try to average out the behavior of large number of particles. This approach helps to explain thermodynamic properties at a fundamental level, very small. Today, when we are talking about micro, nano mechanisms, we are more interested in statistical thermodynamics. Requires molecular level knowledge.

Use statistical method to relate the microscopic behavior to a macroscopic property. So I know atom, now I average it out to a macroscopic property. Macroscopic property are measurable. Vibration is very hard for you to measure. It is visually you cannot measure.

So what you do is, you try to look into the average property and talk about macroscopic, what will be the pressure distribution. Involves variables like molecular velocity, energy and distribution. I said the ball, ball is nothing but a molecule. Provides deeper insight into the nature of thermodynamic process. However, this is very important, but for an engineer who is interested always to make sure that there is a work which is getting converted for a system to operate. So, you will be interested to make sure the system operates.

So, there he will always use a macroscopic approach, but if you want to go from fundamental understanding, then you have to go for statistical thermodynamics, which is nothing but a microscopic approach.

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## Different Approaches of Thermodynamics



### Example:

- The **Maxwell-Boltzmann distribution law** describes the distribution of velocities among gas molecules.
- Understanding **entropy** using the Boltzmann equation:

$$S = k \ln \Omega$$

where,  $S$  = entropy,

$k$  = Boltzmann's constant, and

$\Omega$  = the number of microstates the system can occupy.

So, there are two types of approaches in thermodynamics: one is the macroscopic approach and the other is the microscopic approach. So, in the microscopic approach, the Maxwell-Boltzmann distribution law describes the distribution of velocities among gas molecules. So, understanding entropy using the Boltzmann equation requires an understanding at the microscopic level,

$$S = k \ln \Omega$$

where,  $S$  = entropy,  
 $k$  = Boltzmann's constant, and  
 $\Omega$  = the number of microstates the system can occupy.

So, now you try to get it for a microsystem that can be expanded. So, gas is one of the most important states in thermodynamics.

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## Kinetic Theory of Gas: History



- **Ancient Origins:** The idea that matter is composed of tiny particles dates back to Greek philosophers like Democritus and Epicurus. Around 50 BCE, Lucretius described atoms as rapidly moving entities bouncing off each other.
- **Early Scientific Basis:** In 1738, Daniel Bernoulli proposed in *Hydrodynamics* that gas pressure results from molecules in constant motion and related their kinetic energy to temperature—laying the foundation for kinetic theory.
- **19th Century Advancements:** James Clerk Maxwell introduced molecular speed distribution and Ludwig Boltzmann developed statistical mechanics to explain the probabilistic nature of molecular motion, strengthening the theory's foundation.
- **Modern Importance:** Now central to statistical mechanics and thermodynamics, the kinetic theory explains gas behavior and key phenomena like pressure, temperature, diffusion, viscosity and thermal conductivity.

So, let us try to understand a little bit more about gas with respect to the Kinetic Theory of Gases. So, I just wanted to present one slide on the history. The ancient origins, where the idea that matter is composed of tiny particles, dates back to the Greek philosopher Euclid, who described atoms as rapidly moving entities bouncing off each other. This was way back in 50 BC.

Then, the early scientific basis came in 1738 after a long period. Daniel proposed in hydrodynamics that gas pressure results from molecules in constant motion and related

their kinetic energy to temperature, laying the foundation of the kinetic theory. The kinetic theory was given by Daniel in 1738, who established the relationship between gas pressure and the constant motion of molecules. So, that means to say you have a vessel and an atom is moving. So, that is what he says: gas pressure results from molecules in constant motion and relates their kinetic energy to temperature.

And little advancement happened in the 19th century when James Clerk Maxwell introduced molecular speed distribution and Ludwig Boltzmann developed statistical mechanics to explain the probabilistic nature of molecular motion, strengthening the theory's foundation, which happened at the beginning of the 19th century. Of late, the modern importance is now central to statistical mechanics and thermodynamics. The kinetic theory explains gas behavior and key phenomena like pressure, temperature, diffusion, viscosity, and thermal conductivity. Diffusion is very important. So, you can have solid-solid diffusion, solid-liquid diffusion, solid-gas diffusion, or gas-gas diffusion. So, all these things have to be understood.

Suppose, if I wanted to infiltrate a porous structure. For example, I have a porous flat plate. I am now passing gas to it. This gas has metal vapors. Now, at what pressure should I push this pressurized gas into the porous media such that the metals occupy the three porous sites? Or when two atoms are held together very strongly, what pressure should I apply such that these fellows slightly deviate and a diffusion phenomenon can happen?

So, in order to understand that, the modern importance was now central around statistical mechanics rather than thermodynamics. The kinetic theory explains gas behavior and key phenomena like pressure, temperature, diffusion, viscosity, and thermal conductivity. For example, viscosity is an important parameter. You can take honey and put a drop of honey on a hot pan, right? So, let us assume you put it at room temperature and slowly try to heat it.

You can see the viscosity change. Take butter, take ghee, put butter on a hot pan it becomes ghee and you keep on be increasing the viscosity keeps on be reducing, right. You will have once the solid becomes a liquid viscous media this viscous media becomes perfectly liquid and the next state if you keep on be heating it becomes vapor and you can condense the vapor and do whatever you want. So, viscosity is also a parameter which is important which has to be understood from the microscopic effect.

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## Kinetic Molecular Theory of Gas



- Kinetic molecular theory of gases and the kinetic gas equation were first developed by Bernoulli in 1738 to derive the molecular properties of gas molecules on basis of the ideal gas law and mechanical energy formula.
- For the study of physics and chemistry, the kinetic theory of gases consists of many postulates or assumptions. In 19<sup>th</sup> century, the efforts of Joule, Kronig, Clausius, Boltzmann and Maxwell brought out postulates or assumptions of the kinetic theory of gases and kinetic gas equation or formula on basis of root mean square velocity (RMS) and momentum of the gas molecule.
- *Molecules in the gaseous state of matter move generally at very large speeds and the forces of attraction are not sufficient to bind the molecules in one place.*



So, the Kinetic Molecular Theory of Gas and the kinetic gas equation were first developed by Bernoulli in 1738. You should understand all these names because you will see later somewhere Boltzmann constant comes, somewhere Maxwell equation comes, somewhere you will see Bernoulli's equation comes. So, you can connect all these things now.

Kinetic molecular theory of gas and kinetic gas equation were first developed by Bernoulli in 1738 to derive the molecular property of a gas molecule on the basis of ideal gas laws and mechanical energy formula. So, he tried to use this and tried to talk about the kinetics of gas. For the study of physics and chemistry, the kinetic theory of gas consists of many postulates or assumptions.

There are a lot of assumptions, porcelets are there. In 19<sup>th</sup> century, the effort of Joule, Coring, Clausius, Boltzmann, Maxwell brought out porcelets or assumptions of kinematic theory of gases and kinetic gas equation or formulae on the basis of root mean square velocity and the momentum of gas molecules. So, this played a very important role. You can say RMS value and the momentum of the gas molecules was studied by the molecules in the gaseous state of matter moves generally at a very large speed molecule in gaseous state. So, liquid you apply heat it goes to gas, gas the velocity now they are talking about.

The molecules in the gaseous state of matter move generally at a high speed, and the force of attraction is not sufficient to bind the molecules in one place. So, in the gas state, which is always when you convert liquid into a gas. So, in a gaseous state, the molecules travel at a very high speed, and the force of attraction is not sufficient to keep them in one place. Now, what is happening? You have to understand this concept, and you will have to give a molecule in a gaseous form to be deposited on top of a flat plate. What is that?

That is nothing but coatings. I should try to now understand the molecule size, the gas, the gas pressure, and whatever it is—the heat you apply—such that the molecules travel at a speed, then hit, attract, and stay there. I have to play with the process, right? So, that is what it talks about. At a high speed, the force of attraction is not sufficient to bind the molecules in one place.

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## Solid, Liquid and Gas Molecules



- **Solid Molecules:** Solid molecules or particles are held very closely together and are entirely devoid of any translatory motion. When a specific heat is supplied to a crystalline solid, it takes the form of vibrational motion with the rise of temperature.
- **Liquid Molecules:** With further increase in thermal energy, the vibrational motion rises and the molecules break down to transform into liquid state like ice to water.
- **Gas Molecules:** When the thermal energy is much greater than forces of attraction, then we have a gaseous state of matter. The gas molecules move randomly and collide with the walls of container (wall collision) and with themselves (intermolecular collision). These collisions are perfectly elastic.

*Therefore, there occurs conservation of energy because of no loss of kinetic energy or momentum of the molecules by this collision.*

Now, let us start understanding the molecules. So, solid, liquid, and gaseous molecules. Solid molecules. What are solid molecules? Solid molecules are particles held very closely together and are entirely devoid of any translatory motion.

When specific heat is supplied to a crystalline solid, it takes the form of vibrational motion with the rise in temperature. Solid, you have a box; take a solid, then you have several atoms there which are sitting here. Now, what do I do? I start heating. Now, when I start heating, after some point in time, you can see the balls vibrating.

So, that is what atoms are—they vibrate. So, when specific heat is supplied to a crystalline solid, it takes the form of vibrational motion and raises the temperature. So, the temperature moves from the source; it starts moving, right? That is what vibrational motion is—it raises the temperature. Liquid molecules: with further increase in thermal energy, the vibrational motion rises, and the molecules break down to transform into a liquid state, like ice to water. I will apply a lot of heat.

So, when further increase in thermal energy occurs, the vibrational motion rises, and the molecules break. So, there are atoms. So, now, these atoms are in one position; you apply heat, then they start vibrating. Now, as you apply more and more heat, they vibrate so much that at one point, they dissociate. And they dissociate—that is what they say.

And the molecule breaks down to transform liquid into water. So, now it moves. So, now if you further continue to apply thermal energy, which is much greater than the force of attraction, then the gaseous state of matter occurs. So, when we want to give metallized coatings, or when we have to create metal fumes. So, for example, you have a liquid metal.

So, then you heat it, it becomes a liquid metal, then you further heat it, it becomes vapor. Now, we have metal vapor. This metal vapor is used for coating. This metal vapor can do many things. When you want to coat cutting tools, they are done by this principle.

You can try to apply heat or you can try to sputter. Whatever, that's a different story. Basically, heat is applied. So, then the gas molecules move randomly and collide with the walls of the container and with themselves, right? These collisions are perfectly elastic.

Therefore, there occurs a conservation of energy because no loss of kinetic energy or momentum of molecules by this collision. So, we assume that it collides and it does not lose energy. That is why it is called as perfectly elastic. So, solid molecules, liquid molecules and gaseous molecules the takeover message of this slide is going to be. Therefore, there occurs conservation of energy because of no loss of kinetic energy or momentum of the molecule by this collision.

## Kinetic Theory of Gases: Assumptions



1. Gas molecules are in continuous random motion in all directions, colliding with each other and the walls of container.
2. The actual volume of individual gas molecules is negligible compared to total volume occupied by the gas.
3. Collisions between gas molecules and with container walls are perfectly elastic, conserving total kinetic energy.
4. There are no attractive or repulsive forces between gas molecules except during the brief moments of collision.
5. The motion of gas molecules follows Newton's laws of motion, especially the second law relating force, mass and acceleration.
6. A gas in a container reaches a steady state over time, where macroscopic properties like pressure and temperature remain constant.
7. At a given temperature and pressure, the gas exhibits uniform density and properties throughout its volume.



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What are the Assumptions? If you see the assumptions are plenty. Gas molecules are continuously random motion in all directions colliding with each other and the walls of the container. Assumption, we assume, right. Maybe it is true, maybe it is staying there itself we don't know but when we try to solve a problem, we assume a gas molecule are continuous random motion. So, it is not expected that it will go like this and come back.

It can go like this, it can go like this, something, that is what is are continuously random motion in all directions which collides with them and which collides with the wall. The actual volume of the individual gas molecules is negligible as compared to that of the volume occupied by a gas. So, now please understand we are talking about gas molecules and gas. The actual volume of individual gas molecules. is negligible compared to the total volume occupied by the gas. The third one is, the collision between the gas molecules and with the container wall are perfectly elastic conserving total kinetic energy. That means to say, whenever it tries to hit, it tries to rebound it does not try to lose energy it keeps moving.

So, collisions between the gas molecules and with the container walls are perfectly elastic, conserving total kinetic energy. There are no attraction or repulsion forces between the gas molecules except during the brief moment of collision. No attraction, no repulsion. But you should understand when you try to take a molecule, there are also charges, right? There is no attractive and no repulsive force between the gas molecules except during the brief moment of collision.

The motion of gas molecules follows Newton's laws of motion, which we have seen in the previous course, especially the second law relating force, mass, and acceleration,  $F = ma$ . The gas in the container reaches a steady state over a period of time, where macroscopic properties like pressure and temperature remain constant. So, this is very important: pressure and temperature remain constant. For example, if you try to see an oven where pizza is kept. So, when the pizza moves, the temperature increases, but in the oven, it is very long. So, there are zones where there is a saturation of temperature happening, and there will be cooling happening.

So, the gas inside the container reaches a steady state over time where macroscopic properties like pressure and temperature always remain constant. And the last point is, at a given pressure and temperature, the gas exhibits uniform density and properties throughout the volume. So, at a given temperature and pressure, the gas exhibits uniform density. So, what is density? The molecules divided by the unit area, uniform densities, and the properties throughout its volume.

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## *Postulates of Kinetic Theory of Gases*



1. A gas consists of a large number of extremely small particles (atoms or molecules) that are in continuous, random motion.
2. The size of each gas particle is negligible compared to the average distance between them; hence, the actual volume of the particles is much smaller than the volume occupied by the gas.
3. There are no intermolecular attractive or repulsive forces between the particles; they move independently of one another except during collisions.
4. Collisions between gas particles and between particles and the container walls are perfectly elastic, meaning total kinetic energy is conserved during collisions.
5. The average kinetic energy of gas particles is directly proportional to absolute temperature of the gas and is same for all gases at a given temperature.

So, the Postulates of the kinetic theory of gases: A gas consists of a large number of extremely small particles that are in continuous, random motion. This is the kinetic theory of gases assumption. These are the postulates of the kinetic theory of gases. The

size of the gas particles is negligible compared to the average distance between them. There is no intermolecular attraction or repulsion.

The collisions between the gas particles and between particles and the container walls are perfectly elastic, and the average kinetic energy of the gas particles is directly proportional to the absolute temperature of the gas and is the same for all gases at a given temperature. So, these are some of the postulates which are there in the kinetic theory of gases.

## Pressure of an Ideal Gas



- The pressure exerted by a gas results from collisions of gas molecules with the walls of container. According to the kinetic theory, the pressure is proportional to both the frequency and the force of these molecular collisions.
- An ideal gas is modeled with the following assumptions:  
*Gas molecules are point particles with negligible volume*  
*There are no intermolecular forces except during collisions, and*  
*All collisions (between molecules and container walls) are perfectly elastic, meaning no energy is lost.*
- The pressure 'P' of an ideal gas is connected to its volume V, temperature T, and the number of moles n by the ideal gas equation:

$$P \propto f + F_{g \text{ mol collision}}$$



$$PV = nRT$$

where R is the universal gas constant.

$$PV = nRT =$$

$$P = \frac{nRT}{V}$$



So, now let us try to look at the Pressure of an Ideal Gas. The pressure exerted by a gas results from collisions of gas molecules with the walls of the container. The pressure exerted by the gas—what is pressure?

Pressure is force applied per unit area. According to the kinetic theory, the pressure is proportional to both the frequency and the force of these molecular collisions. Please keep in mind, pressure is proportional to the frequency and force of these molecular collisions, the force of molecular collisions. An ideal gas is modeled with the following assumptions. Gas molecules are point particles with negligible volume.

There are no intermolecular forces except during collisions. All collisions are perfectly elastic, meaning no energy is lost. So, these are all for ideal gas because many times in

problem-solving we will say that it is an ideal gas. So, what is an ideal gas? The gas molecules are point particles with negligible volume.

That is what they say: gas molecules are point particles with negligible volume because it is a dot. All collisions are perfectly elastic, meaning no energy is lost. The pressure  $P$  of an ideal gas is connected with volume  $V$ , temperature  $T$ , and the number of moles  $n$  by an ideal gas equation. So, which is nothing but  $PV = nRT$ . An important formula. The pressure of an ideal gas is connected to volume  $PV$  (pressure volume), which in turn is connected to temperature and  $N$  (number of moles), right.

And what is  $R$ ?  $R$  is the universal gas constant. So,  $PV = nRT$ . So, if you want to rearrange it, you take  $P = nRT/V$ . So, now you see the relationship of pressure. So, the pressure of an ideal gas is connected to its volume, temperature, the gas constant, and number of moles. This is a very important equation.

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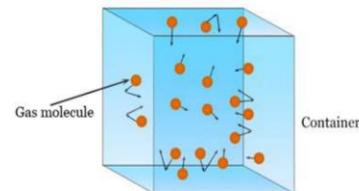
## Kinetic Interpretation of Temperature



- Temperature is a measure of the average kinetic energy of particles in a substance. The kinetic energy arises from the motion of particles: vibration in solids, sliding in liquids, and free motion in gases.
- The average kinetic energy per particle is directly proportional to the absolute temperature  $T$ . This relation is given by:

$$KE_{avg} = \frac{3}{2}kT$$

where  $k$  is the Boltzmann constant.



- The lowest theoretical temperature, absolute zero ( $0\text{ K}$ ), corresponds to zero kinetic energy, where molecular motion would theoretically cease.

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The temperature is a measure of the average kinetic energy of a particle in a substance. The kinetic energy rises from the motion of a particle, vibrations in solids, sliding in liquids and free motion in gas. So, the  $K_{avg} = \frac{3}{2}kT$  What is  $k$ ?  $k$  is the Boltzmann's constant which is a constant. So, you have a container, you have these gas molecules. When the heat is applied, you see how randomly it moves.

The temperature is a measure of the average kinetic energy of the particles. The kinetic energy arises from the motion, when it starts vibrating in the solid or sliding.  $K_{\text{avg}} = \frac{3}{2}kT$ . The lowest theoretical temperature absolute 0 Kelvin corresponds to 0 kinetic energy where molecule motion would be theoretically ceased. So, at absolute 0, there will be no vibration. Everything, everybody will be frozen and it will stand that is what we say.

The lowest theoretical temperature: When no vibration happens, there is a freeze. So, that is called as the absolute zero (0 K), corresponding to 0 kinetic energy where molecular motion would theoretically cease. That means to no motion will happen. Thermodynamic systems.

Thank you very much.