Basics of Mechanical Engineering-3

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Week 02

Lecture 10: Basic Laws of Thermodynamics Part 5 of 5

Well, friends, welcome to the Basic Laws of Thermodynamics. So, for those who are directly jumping into this lecture, in the past lectures, what we saw was the zeroth law, first law, and second law. When does the first law exist or become valid? When is it invalid, or what is the limitation? Then, we moved to the second law of thermodynamics, wherein we discussed Kelvin-Planck's Statement. Then, we discussed Clausius's Statement.

Then, we also explored reversible and irreversible processes. And, while going through this journey, we examined different cycles. We studied the Carnot engine, Otto cycle, Diesel cycle, Rankine cycle, and Brayton cycle. Very fundamentally, we covered those topics. And finally, the reason we studied all those things was to determine the efficiency of the process. From that knowledge, we will proceed to the lecture on the basic laws of thermodynamics.

Contents

- Perpetual Motion Machine (PMM)
- Third Law of Thermodynamics
- Exergy

So, here, we will try to explore Perpetual Motion Machines, otherwise called PMM. So, henceforth, during the lectures, I will refer to it as PM or PMM. Then, we will examine the third law of thermodynamics and Exergy. So, energy. So, exergy is taken and X is added to it. You will see why it is added in the lecture. What is a PMM machine, or what is PMM?

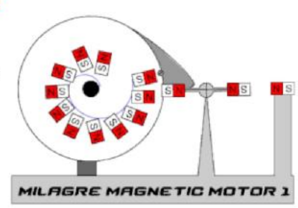
Perpetual Motion Machines (PMM)

- A **Perpetual Motion Machine (PMM)** refers to an imaginary machine that can operate endlessly without any energy input while continuously producing useful work.
- Such machines have fascinated inventors for centuries, but they are fundamentally impossible because they violate the basic laws of thermodynamics.
- The concept of PMMs reinforces the importance of the First and Second Laws, and reminds us that **"no energy system can be perfectly efficient or run forever without fuel or energy input"**.

PMMs are classified based on thermodynamic law they attempt to break.

➢PMM1

➢PMM2



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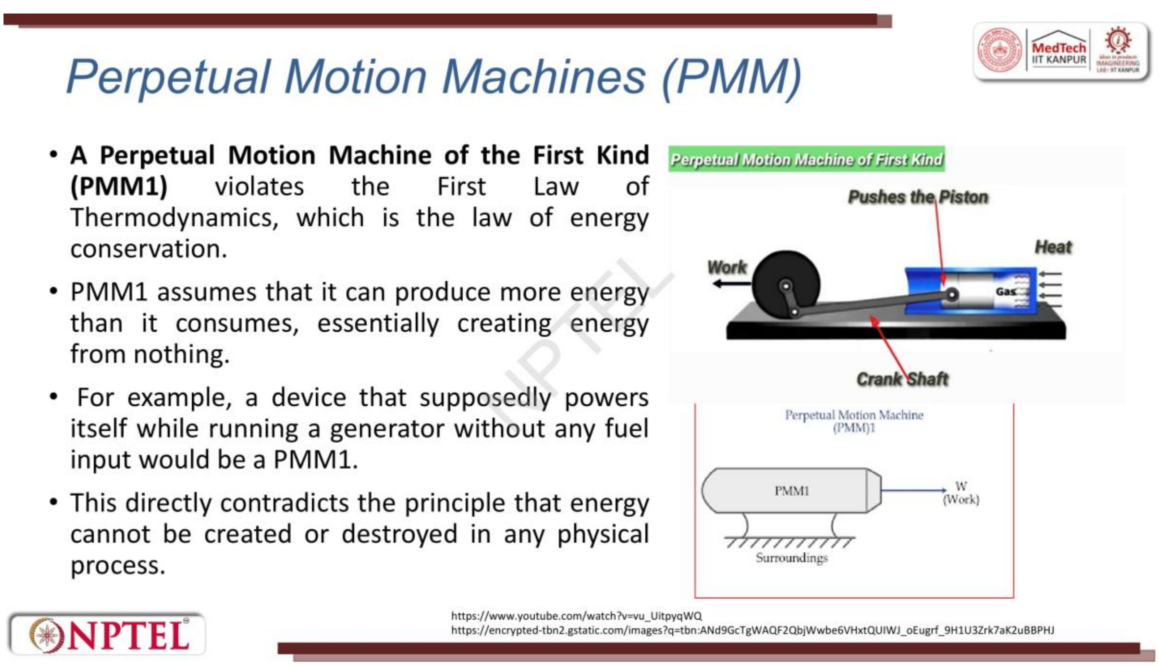
A PMM refers to an imaginary machine, which does not exist, that can operate endlessly without any energy input while continuously producing a useful output. So, you do not give any input, but the machine starts moving on its own.

So, those machines are called perpetual machines. Such machines have fascinated inventors for centuries. But they are fundamentally impossible because they violate the basic laws of thermodynamics. So, now it is very clear that the basic laws of thermodynamics exist. If the basic laws of thermodynamics are defeated, then it is always a perpetual machine.

The concept of PMM reinforces the importance of the first and second laws. Energy is converted from one form to another. The second law is that all the energy which is converted will never be fully converted into another form. So, that is what is stated in the second law and reminds us that no energy system can be perfectly efficient or run forever without fuel or energy input. Think of a scooter you buy, a car you buy; you fill it once and then you forget it.

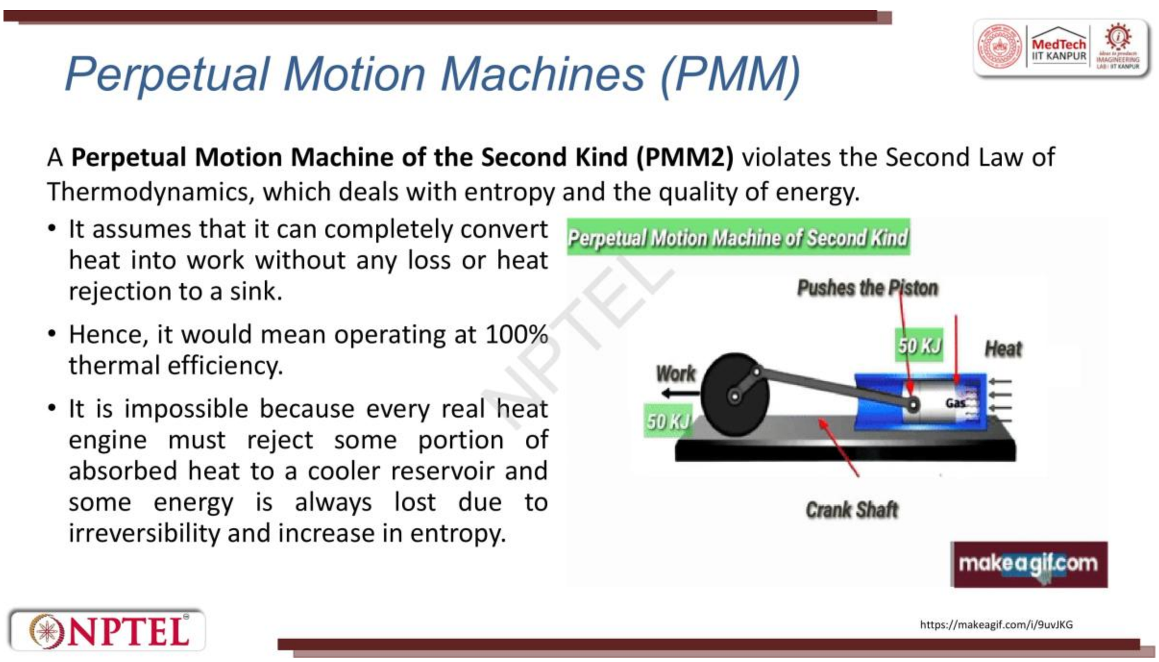
So, rest maybe it runs for all through your lifetime, no petrol requirement, wonderful, right, but that does not exist. If that could exist, then the laws of thermodynamics would fail. So, that's what I have written here. No energy system can be perfectly efficient or run forever without fuel or energy input. PMMs are classified based on thermodynamic laws. They attempt to break PMM 1 and PMM 2. There are two laws.



What is PMM 1? PMM-1 violates the First Law of Thermodynamics, which is the law of energy conservation. PMM assumes that it can produce more energy than it consumes, essentially creating energy from nothing. So, this is PMM-1, this is the surrounding, and you have a shaft. So, nothing is there; you do not give any input, yet it starts rotating.

There can be a possibility. What if I make the surroundings very violent? For example, I pump in a lot of air or keep it on my terrace where there is wind velocity. And friends, if you keep moving from floor to floor, suppose you are staying on the 25th floor, 30th floor, the wind velocities are pretty high. So, if you take this machine and go there, maybe you attach a fan here so that the fan keeps rotating.

But also, if you see, the wind velocity is somehow created. So, for example, a device that supposedly powers itself while running a generator without any fuel input would be a PMM1 condition. This directly contradicts the principle that energy cannot be created or destroyed in any physical form. This directly contradicts because, without anything, you are able to get an output.

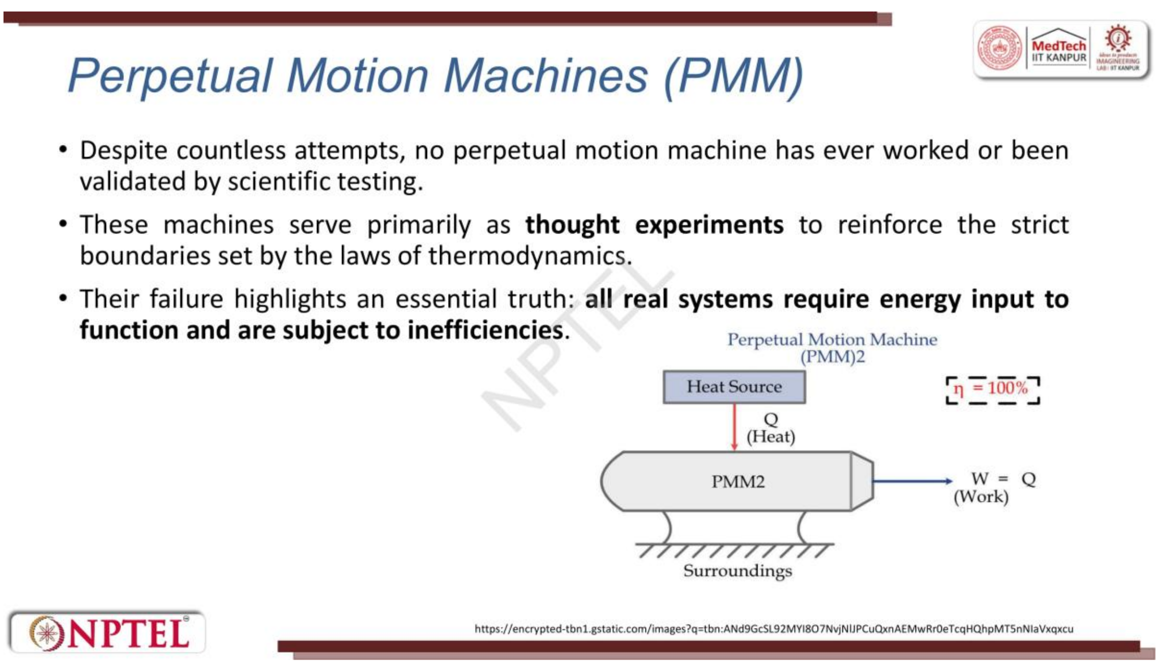


PMM-2 violates the Second Law of Thermodynamics It assumes that it can completely convert heat into work without any loss or heat rejection to a sink. 100% heat, 100% you try to convert it into work. It would be lovely if the turbine blade works, if the turbine machine works at 100% efficiency. Nothing better than that. So, you will save a lot of energy.

If you take a thermal power plant, what we do is we put coal, we burn the coal, and then this generates a lot of heat. This heat is transferred to water. This water gets converted into vapor steam, and then from that steam, with great pressure, it is pushed into a blade. This blade starts rotating. The moment the blade starts rotating, there is a shaft which is attached, and this shaft is again attached to a generator they draw.

So, what if one time you put in 100%—whatever you throw in gets converted? It will be lovely. So, you do not have to burn more coal. If you do not have to burn more coal, you do not have to excavate more coal. You see, nature is getting protected if we have PMM-2. It assumes that it can completely convert heat into work without any loss or heat rejection to a sink.

Hence, it would mean operating at 100% thermal efficiency. It is impossible because every real heat engine must reject some portion of absorbed heat to a cooler reservoir, and some energy is always lost due to irreversibility and an increase in entropy. We saw an increase in entropy in the last lecture. We were talking about S. S is nothing but the randomness—randomness created or the distortion, whatever is created.

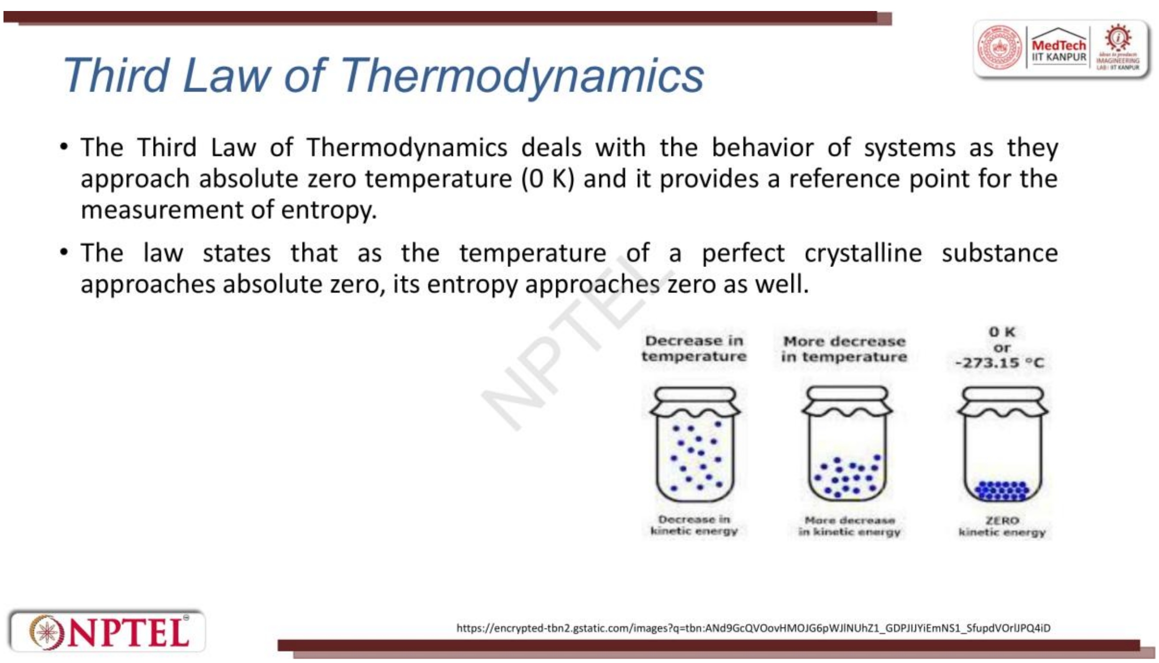


Despite countless attempts, no perpetual motion machine has ever worked or been validated by scientific testing. Though people do—you see a lot of WhatsApp, small videos, or people have demonstrated PMM in a very, very incubated condition. All these things are there, but it is never demonstrated very successfully. This machine serves primarily as a thought experiment to reinforce the strict boundaries set by the laws of thermodynamics. So, what are we trying to say? Thermodynamics laws cannot be violated.

There is no machine developed that violates the two laws. Their failure highlights an essential truth. All real systems require energy input to function and are subject to inefficiency. So, is that clear? So, why are we talking more and more?

This is because you should understand that there is a lot of wasted energy generated in any machine. And you will never be able to get 100%. So, the moment you don't get 100% to operate the machine, you will pump in more energy. So, to pump in more energy, you will have to generate that energy. You see, it's a cycle.

So, all real systems require energy input to function and are subject to inefficiency. So, there is always a loss. So, a heat source, then you have PMM2, then you have a surrounding.

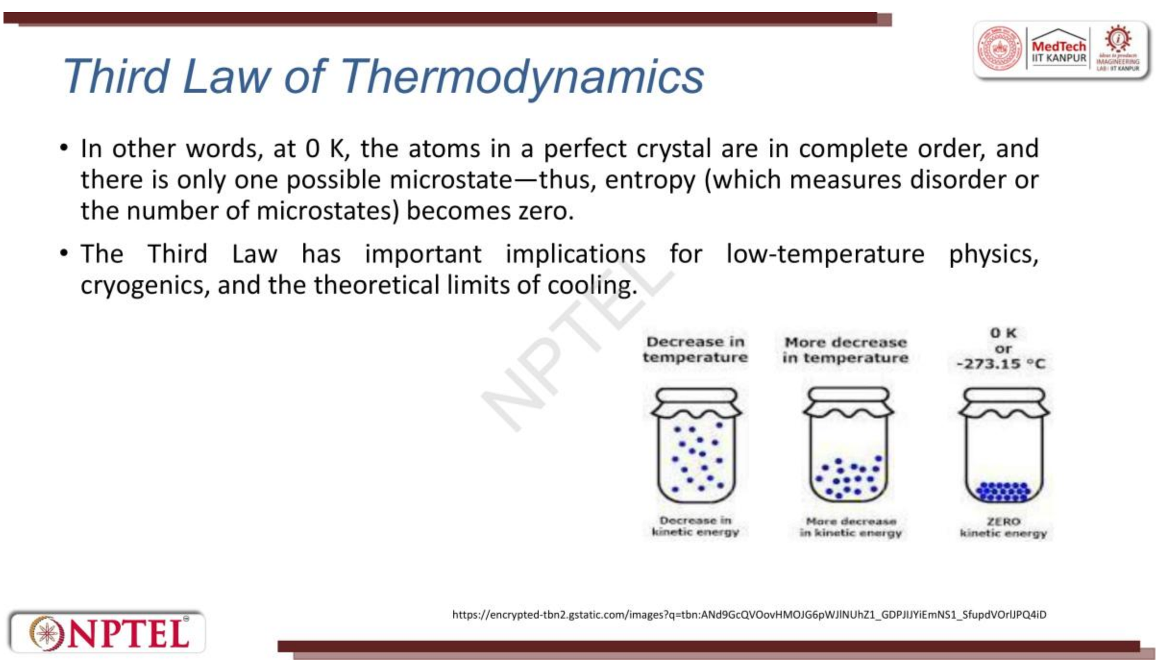


What is the Third Law of Thermodynamics? We saw the zeroth law, the first law, and the second law. Now, we will see the third law of thermodynamics. The third law of thermodynamics deals with the behavior of the system as it approaches absolute zero temperature. What happens at absolute zero? And it provides a reference point for the measurement of entropy. Only for this does the third law come into existence.

The law states that as the temperature of a perfect crystalline substance approaches absolute zero, its entropy approaches zero as well. Generating a perfect crystalline substance is difficult. We have covered in our materials portion what is crystalline and what is amorphous material. There are crystalline, semi-crystalline, and amorphous materials. So, as a perfectly crystalline substance approaches zero, its entropy approaches zero as well.

So, as and when the temperature decreases, there is a decrease in kinetic energy. The more the temperature decreases, the more the kinetic energy decreases. Kinetic energy is what? Potential energy leads to kinetic energy. Kinetic energy is basically half m v squared, right?

So, that is what it is. So, you are reducing. So, more and more energy gets settled down, and then you get zero kinetic energy, which happens at zero Kelvin, okay? So, here now you can understand when entropy will be zero. For not any given substance, but for a crystalline substance, it happens at absolute zero. Clear? What is absolute zero? Zero Kelvin.



In other words, at zero Kelvin, the atoms in a perfect crystal are in complete order. Because kinetic energy is zero, so everybody settles down, and there is only one possible microstate. Thus, entropy becomes zero.

Delta S, when is it equal to zero? It happens at zero Kelvin. That is important, and that is the third law. The third law has important implications for low-temperature physicists. Cryogenics and the theoretical limits of cooling. Cryogenics is where they talk about machines and parts working at lower temperatures than room temperature.

The lower can be minus 25, minus 50, or minus 100 degrees Celsius. That is what they are talking about—cryo. Cryogenic means low temperature. So, some people do cryogenic experiments. What they do is they take liquid nitrogen and pour it on top of a workpiece to study the material's response.

So, that is cryogenic. And if dry ice falls on your finger, it burns. The law also implies that it is impossible to reach absolute zero in a finite number of steps. How do I achieve it? How many steps do I take?

Can I go from 25 degrees Celsius to 0 K in one step? Very difficult. It is impossible to reach absolute zero in a finite number of steps. As the substance is cooled closer to zero, it becomes increasingly difficult to remove additional energy from it. This means no real system can attain absolute zero, though it can approach very close to it.

So, 0 Kelvin is very hard to achieve; you will get close to 0 Kelvin. So, otherwise, what happens is you see here minus 273. So, people talk about minus 50 degrees Celsius; people also talk about minus 100 degrees Celsius. When do we get this minus 50 and minus 100? Of course, when you are at the poles—the North Pole—you can get minus 35 degrees, minus 40 degrees, and so on.

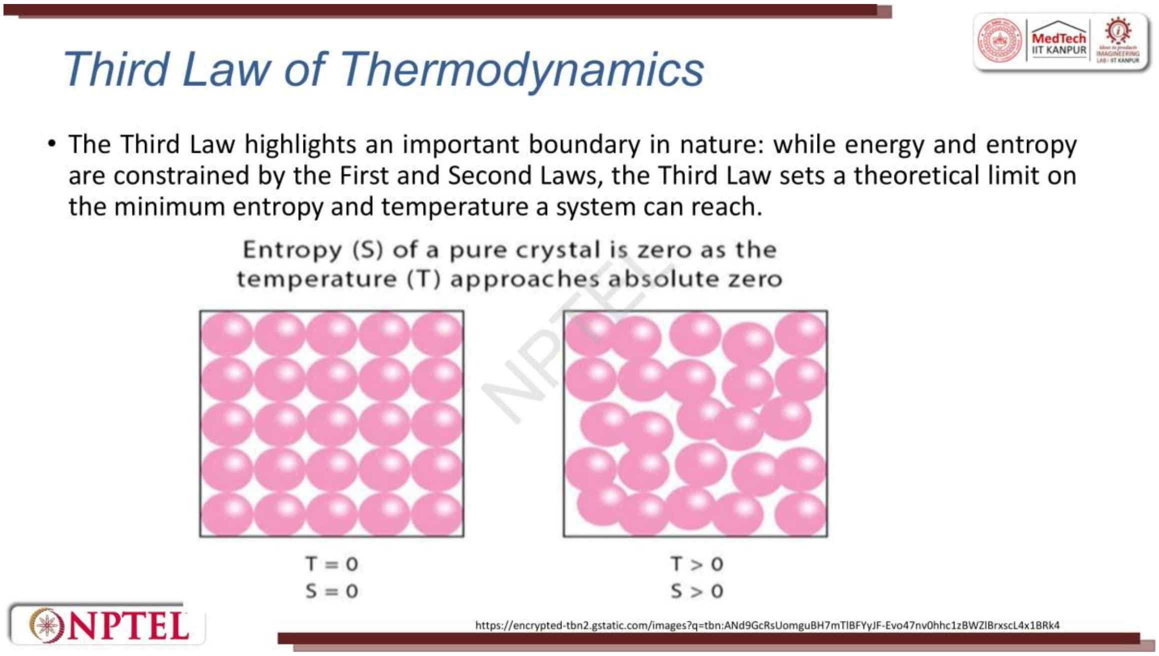
But when you are traveling in a flight, when you go to a very high altitude—30,000 feet—the temperature will be minus 10, minus 12, minus 30, whatever it is. So, it is in minus. So, think of an airplane that starts at room temperature—maybe 25, 30 degrees Celsius—and as it increases its altitude, it can go up to minus 10, minus 20 degrees Celsius when it goes high up. From there, it travels a long distance and then settles down faster. The biggest problem is, when you travel at minus temperatures, there is always a possibility that ice—if there is a droplet—the droplet gets converted into ice, and this ice can be a disaster for a plane. So, that is why people are working very cautiously and looking at how amazing the plane material and designs are. From a practical perspective,

Third Law of Thermodynamics

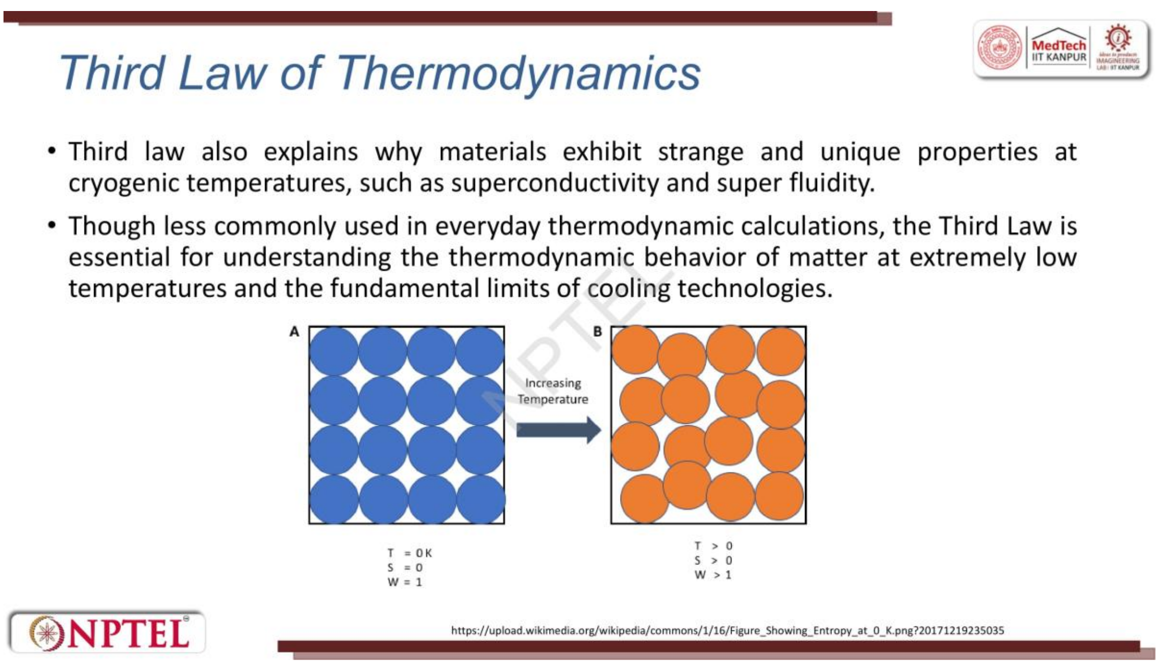
- The law also implies that **it is impossible to reach absolute zero in a finite number of steps**.
- As a substance is cooled closer to 0 K, it becomes increasingly difficult to remove additional energy from it.
- This means no real system can attain absolute zero, though it can approach it very closely.
- From a practical perspective, the Third Law allows scientists and engineers to define **absolute entropies** of substances, not just entropy changes.
- This is useful in chemical thermodynamics, where standard entropy values are used to predict **reaction spontaneity, equilibrium**, and **Gibbs free energy**.

The third law allows scientists and engineers to define the absolute entropy of a substance, not just the entropy change. I told you earlier in the lecture that delta S is very easy to calculate. But defining S is very difficult because delta S is from 1 kilometer to 2 kilometers. The difference is 1 kilometer. But you have to say this 1 kilometer with reference to 0.

That zero establishment in entropy is a challenge. So, that is what happens here. From a practical perspective, the third law allows scientists and engineers to define absolute entropies of substances, not just entropy changes. This is useful in chemical thermodynamics, where standard entropy values are used to predict reactions, spontaneity, equilibrium, and Gibbs free energy—these are very important. When we try to talk about Gibbs free energy, where does it come from? It comes from the standard entropy and reaction spontaneity. At what stage or time does a reaction happen?



The third law highlights an important boundary in nature. While energy and entropy are constrained by the first and second laws, the third law sets a theoretical limit on the minimum entropy and temperature a system can reach. So, this is delta T equals 0, delta S equals 0. When delta T is greater than 0 and delta S is also greater than 0, you see this distortion happening to the atoms there.

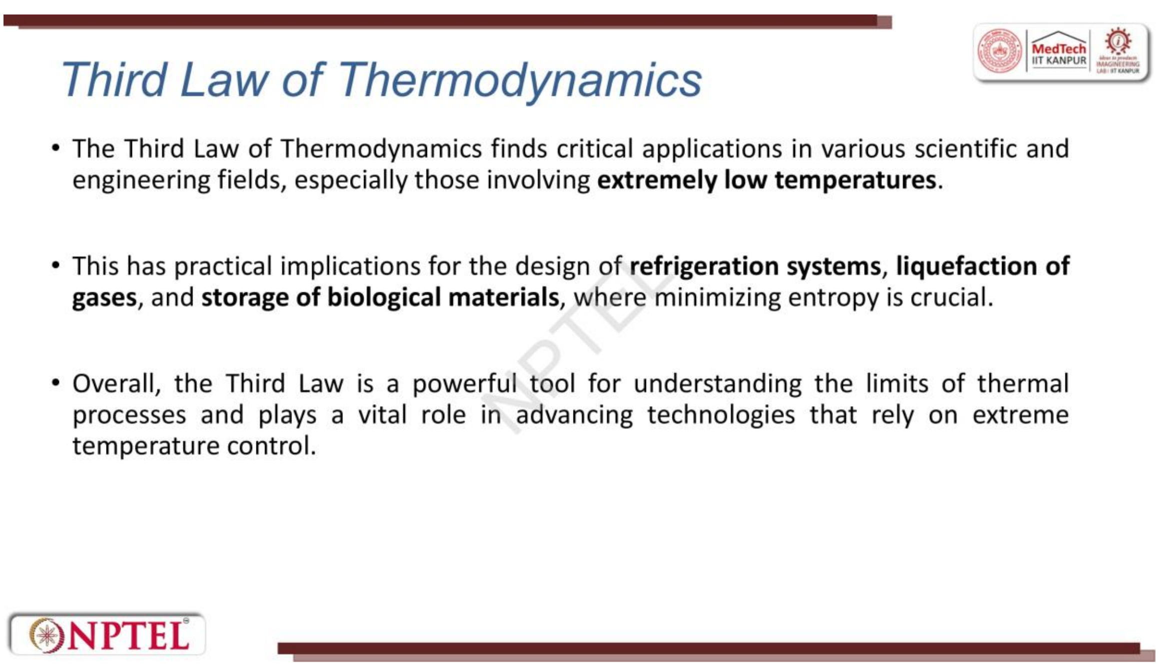


The third law also explains why materials exhibit strange and unique properties at cryogenic temperatures. So, at one point in time in the early 1980s or 70s, people were talking about superconducting materials and also about superfluidity. At that time, people were trying to conduct experiments to see what happens to the conduction behavior at low temperatures. Even now, a lot of people work on it, right? But the start—the kickstart—of superconductivity was in the 1970s-80s; it was at its peak.

So, that room temperature. So, what people are trying to do is, when they see at room temperature, suppose if the conductivity is 10, right? Forget units, right? 10x, whatever it is. Now, when they go to sub-zero, they see, it can go up to 1000 just for discussion sake, 1000x and it goes down.

So, now what they are trying to do is; they are trying to see whether I can create this ambient and keep the component there and see the conductivity is happening very fast. Conductivity, if it is happening very fast, the resistance is low, so there is not much of heat dissipation. So, you can use the advantage. So, that is what is this. And, superfluidity is also another major area which came into existence.

So, that is why people are more interested to work with this third law. Though less commonly used in everyday thermodynamic calculation, the third law is essential to understand the thermodynamic behavior of matter at low temperatures and fundamental limits of cooling technologies.



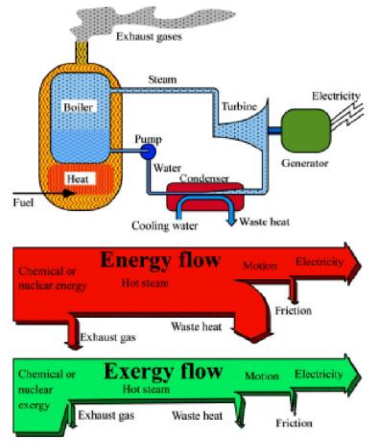
The third law finds critical application in various scientific and engineering field at extremely low temperatures we have seen and the practical implication for the design of refrigeration systems, liquefaction of gases, storage of biological material with minimum entropy is crucial. Liquefaction is, you have a solid, you have a liquid, you have a gas. Suppose, let us assume that you are having lot of natural gas available.

Maybe on the coast of Kerala, you have a lot of gas which is available. Now, there is a deficit of gas in the northeast part, just for discussion's sake, then what they do is, the gas has to be transferred from here to there. One way is, you pressurize it and send it through a pipeline. The other way around is, they make individual containers, and these containers do what? The gas is taken to a very high pressure and it is liquefied. So, that is what is called the liquefaction of gases. And, once it is liquefied, what do they do? They transport it to that place, whatever is required. And then at that point, the pressures are released, so then you get back the gas, and the storage of biological material is very important.

That is why, if you see, we always keep the food, once you finish your dinner, you put everything into the refrigerator because you want to maintain the food without any bacterial growth. So, that is why, you put it into a refrigerator at 12 degrees, 14 degrees, and it continues. In the same way, you can also store biological material. You have a tissue, it has to be moved, whatever. Storage of tissue where minimizing entropy is crucial. Overall, the third law is a powerful tool for understanding the limits of thermal processes and plays a vital role in advanced technologies that rely on extremely controlled temperatures.

Exergy

- **Exergy represents the maximum useful work that can be extracted from a system as it comes into equilibrium with its surroundings.**
- Energy is always conserved as per the First Law of Thermodynamics, but, **Exergy is not conserved – It is destroyed** in real processes due to irreversibilities such as friction, unrestrained expansion, mixing, heat transfer across a finite temperature difference and other inefficiencies.



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Now, let us try to understand X energy. X plus energy. It is called exergy. Exergy represents the maximum useful work that can be extracted from a system as it comes into equilibrium with its surroundings. We are trying to represent the maximum useful work that can be extracted from a system as it comes into equilibrium with its surroundings. Energy is always conserved as per the first law of thermodynamics, but exergy is not conserved. It is destroyed in real processes due to irreversibility, such as friction, unrestrained expansion, mixing, heat transfer across a finite temperature difference, and other inefficiencies. So, exergy is not conserved; it is destroyed. For example, you have a boiler, a complete system. Assuming this is a complete system, you have heat which is given.

So, coal—like I was talking to you about the thermal power plant. You can also have gas power plants. So, there is heat which is applied. There is a boiler here. In the boiler, what happens is there is always water.

This water is heated to a very high temperature. So, water gets converted into steam. The steam tries to move and then operates a turbine. So, then, as and when it moves, a smaller— So, you can—it need not be one attached to a shaft, one turbine blade.

There can be a series which exists. So, they rotate, and then whatever happens, this turbine blade rotation is attached to a generator. So, this generator is used to tap the electricity. So, now whatever is left here comes to a condenser. What happens in a condenser?

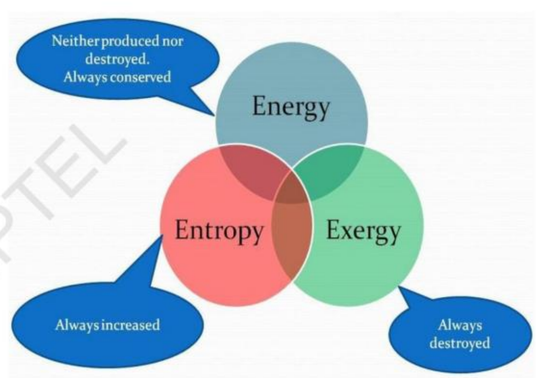
We try to condense the vapor back into a liquid. And then, when you want to convert the heat into liquid or the steam into liquid, you have to extract heat out of it. So, you pass in cold water, and then you extract this heat, getting the waste heat. So, the water which comes out will have a lot of energy—it will be very hot. So, then the cold, room-temperature liquid is taken, and a pump pressurizes it and pushes it back into the boiler.

So, this is how a typical thermal cycle works. This heat can be replaced by gas; then it is called a gas turbine cycle or gas power plant generation. So, if you look at energy flow, it is chemical or nuclear energy where exhaust gas comes out first, then you have a hot stream. The hot stream allows you to remove the waste heat, and the rest involves motion, friction, and then electricity is generated. So, this is how energy flows, and at regular intervals, you tap it out.

Now, let us see the exergy. Exergy flow is chemical or nuclear energy—whatever is used is here. From there, you try to get an exhaust gas. Then, a hot stream goes, and you get waste. From motion, you try to get friction, and then finally you produce electricity. So, this is the difference between energy flow and exergy flow.

Exergy (Linkage of 3E)

- Exergy provides a measure of the quality or usefulness of energy, helping to distinguish between energy that can perform work and energy that is unavailable for work.
- It depends on both the state of the system and environment, typically defined by reference conditions such as ambient temperature and pressure.



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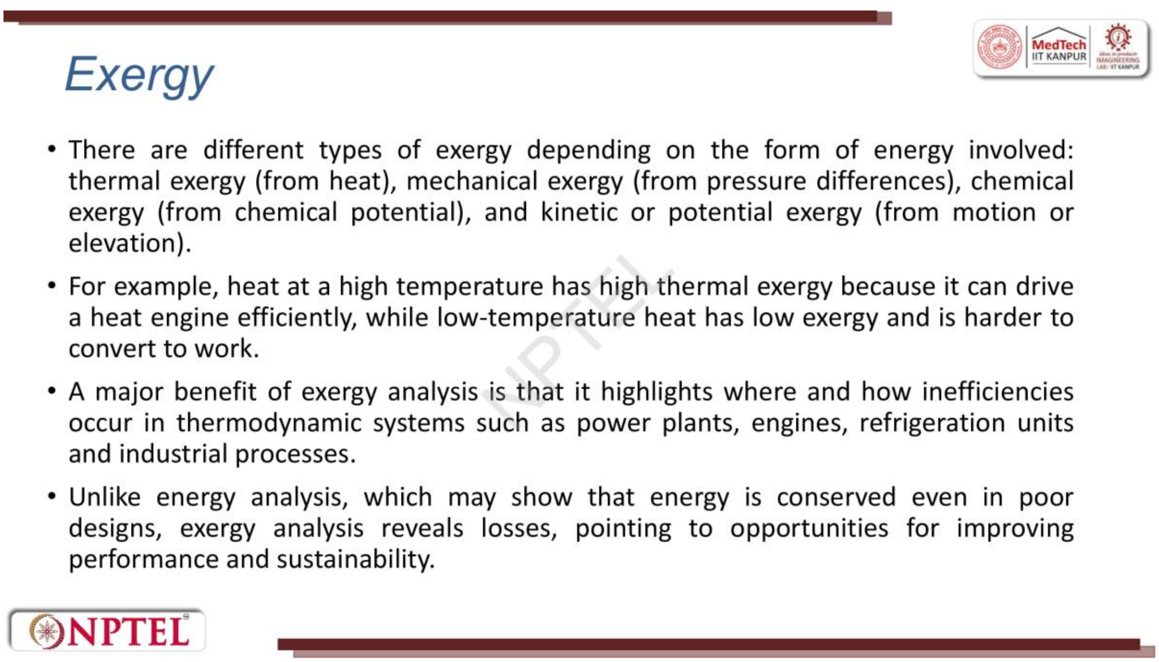
So, exergy linkage of the three E's. So, it is energy, exergy, and entropy that you have. So, it is always destroyed. Entropy always increases, and energy is neither produced nor destroyed—it is always conserved.

So, energy does this, exergy does this—always destroyed—and then you have this. Exergy provides a measure of the quality or usefulness of energy. It helps distinguish between energy that can perform work and energy that is unavailable for work. So, this is the distinction it makes. Exergy provides a measure of the quality or usefulness of energy.

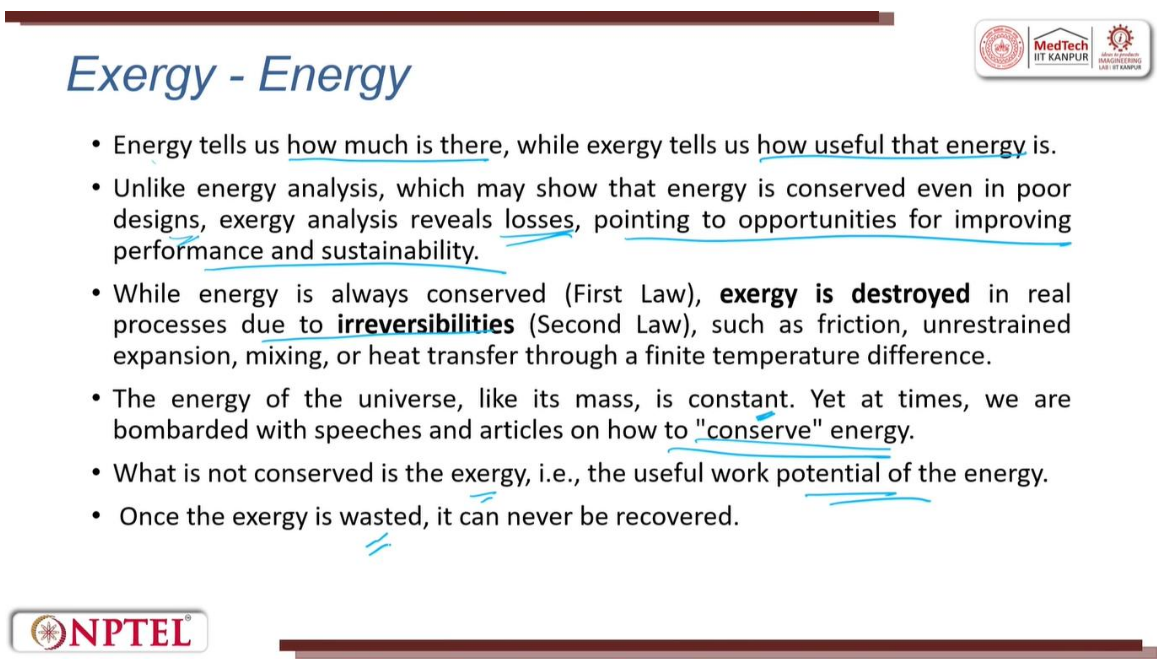
Helping to distinguish between energy that can perform work and energy that is unavailable for work, you can clearly differentiate. It depends on both the state of the system and the environment, typically defined by reference conditions such as ambient temperature and pressure.



Exergy: The type of exergy depends on the form of energy involved—thermal exergy, chemical exergy, kinetic exergy, or potential exergy. So, thermal energy comes from heat, mechanical energy from pressure, chemical energy from chemical potential, and kinetic or potential exergy from motion or elevation. The major benefit of exergy analysis is that it highlights where and how inefficiencies occur in thermodynamic systems such as power plants, engines, refrigeration, and industrial processes.

The major benefit of exergy analysis is to highlight where and how inefficiencies occur. So, that is why we always try to calculate the exergy. What is exergy going back? Exergy represents the maximum useful work that can be extracted from a system as it comes into equilibrium with its surroundings. So, if you see here, the energy flow, exergy flow, right?

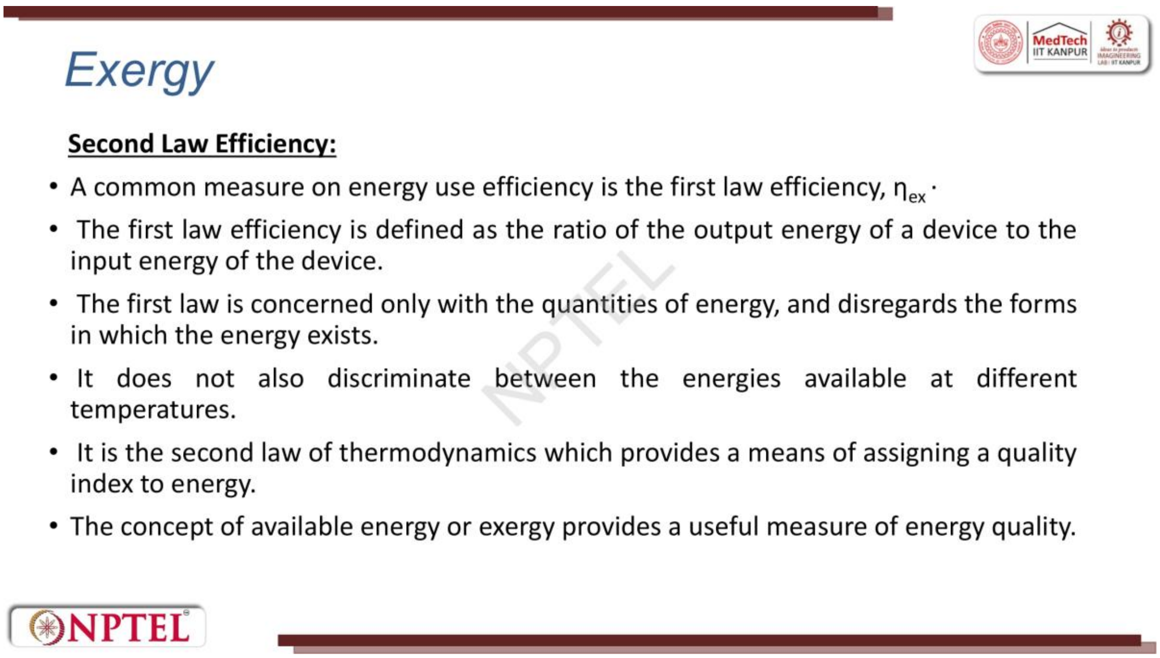
So, that is what it is. By identifying and minimizing the energy destruction, engineers can design more efficient systems. This makes exergy a powerful tool in energy efficiency optimization. It is especially valuable in modern applications such as combined heat and power systems, renewable energy integration, and low-carbon process engineering.



So, energy tells us how much is there, while exergy tells us how useful that energy is. Please understand there is a big difference. How much is there? What amount of energy do you have? How many kilowatts do you have? But while exergy tells you how useful that energy is.

Unlike energy analysis, while many show the energy is conserved even in poor design. It shows energy is conserved even in poor design; exergy analysis reveals losses, pointing out the opportunity to improve performance and sustainability. So, if you are looking into sustainability, try to measure the exergy. While energy is always conserved, exergy is always destroyed in real processes due to irreversibility. Friction, unrestrained expansion, mixing, heat transfer, etc.

The energy of the universe, like its mass, is constant. Yet at times, we are bombarded with speeches and articles on how to conserve energy. What is not conserved is exergy, that is, the useful work potential of the energy. Once exergy is wasted, it can never be recovered.



The second law efficiency, a common measure of energy use efficiency, is the first law efficiency nex.

The first law of efficiency is defined as the ratio of the output energy of a device to the input energy of the device. The first law is concerned only with the quantity of energy and disregards the form in which the energy exists. Quantity of energy—it discards the form in which it exists. It also does not discriminate between the energies available at different temperatures. It is the second law of thermodynamics that provides a means of assigning a quality index to energy.

The concept of available energy or exergy provides a useful measure of energy quality. I am sure with this, you will now be able to understand and appreciate what it is.

Exergy

- With this concept it is possible to analyze means of minimizing the consumption of available energy to perform a given process, thereby ensuring the most efficient possible conversion of energy for the required task.
- The second law efficiency, η_{ex}, of a process is defined as the ratio of the minimum available energy (or exergy) which must be consumed to do a task divided by the actual amount of available energy (or exergy) consumed in performing the task.

With this concept, it is possible to analyze means of minimizing the consumption of available energy to perform a given process, thereby ensuring the most efficient possible conservation of energy for the required task. The second law of efficiency, η (ex) of a process, is defined as the ratio of the minimum available—very important—minimum available energy or exergy which must be consumed to do a task, divided by the actual amount of available energy consumed in performing the task. So, this is very important.

Exergy

- Exergy is zero when a system is in complete thermodynamic equilibrium with the environment (i.e., same temperature, pressure, chemical potential, etc.).
- The general formula for exergy of a closed system (non-flow process) is:

$$E_x = (U-U_0)+P_0(V-V_0)-T_0(S-S_0),$$

where:

E_x = Exergy of the system (kJ)   U = Internal energy of the system

U_0= Internal energy of the environment

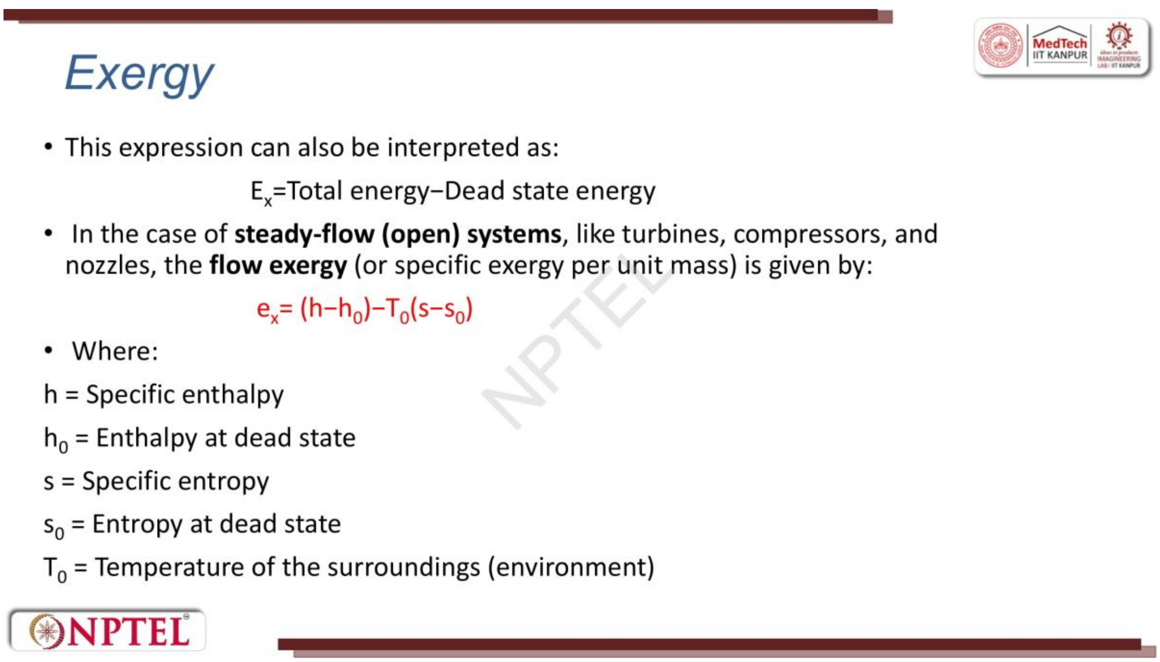
P_0,T_0 = Pressure and temperature of the environment

V = Volume of the system V_0 = Volume of the environment

S = Entropy of the system S_0 = Entropy of the environment

So, it can be represented by a formula in this way. Ex is equal to U. What is U? U is the internal energy of a system minus the internal energy of the environment. U minus U0 plus P0. P0 and T0 are the pressures at the environment.

V is the volume of the system. V0 is the volume of the environment. S is the entropy of the system, and S0 is the entropy of the environment. So, through this formula, you can try to find the exergy of a closed-loop system. Exergy is 0 when a system is in complete thermodynamic equilibrium with the environment. When it is completely in equilibrium, it is 0. But in general, this is how the formula works for a closed-loop system.



So, this expression can also be interpreted this way. Ex is equal to total energy minus the dead-state energy. In the case of a steady-flow open system, this is for a closed system, a non-flow process, right?

So, this is for a flow process: ex is equal to h minus h0 minus T0(s minus s0). So, h0 is the enthalpy at a dead state, and s0 is the entropy at the dead state, right?

Exergy

Types of Exergy:

- **Physical Exergy**: Due to differences in temperature and pressure with the surroundings.

$$e_{x,physical} = (h-h_0) - T_0(s-s_0)$$

- **Chemical Exergy**: Due to differences in chemical composition (e.g., fuel combustion).It is usually obtained from standard tables for common substances.
- **Kinetic Exergy**:

$$e_{x,kinetic} = \frac{V^2}{2}$$

Potential Exergy:

$$e_{x,potential} = gz$$

- So, **total specific exergy** is:

So, there are different types of exergy, as I told you: physical, chemical, kinetic, potential. So, physical is due to the difference in temperature and pressure with the surroundings. Chemical is due to the chemical composition.

It is usually obtained from the standard table of a common substance. So, kinetic energy is equal to V squared by 2. Potential energy is gz. So, the total energy is nothing but X physics plus this kinetic energy comes to this one. So, this is the total specific exergy.

Exergy

- **Exergy Destruction and Efficiency**

Exergy destruction quantifies **irreversibilities** in a process:

$$E_{x,destroyed} = T_0 \,.\, \Delta S_{gen}$$

Where Δs_{gen} is the entropy generation.

- **Exergy efficiency (Second Law Efficiency)** compares actual performance to ideal performance:

$$\eta_{ex} = \frac{\text{Useful Exergy Output}}{\text{Exergy Input}}$$

This efficiency is **always less than 1**, even if First Law (energy) efficiency is high.

So, the exergy destruction and efficiency, the exergy destruction quantities are irreversible in process. So, Ex is equal to T0 into delta Sg. So, delta S is the entropy generated. So, exergy efficiency compares actual performance to the ideal performance. Useful exergy output divided by exergy input. So, the efficiency is always less than 1 even if the first law efficiency is high.

Exergy

- The energy of the universe, like its mass, is constant.
- Yet at times, we are bombarded with speeches and articles on how to "conserve" energy.
- As engineers, we know that energy is always conserved. What is not conserved is the exergy, i.e., the useful work potential of the energy.
- Once the exergy is wasted, it can never be recovered.
- When we use energy (electricity) to heat our homes, we are not destroying any energy, we are merely converting it to a less useful form, a form of less exergy value.

So, the maximum useful work potential of a system at a specific state is called exergy, which is a composite property depending on the state of the system and the surroundings. It is always talking about system, surroundings, boundary, all these things; surroundings, system, surroundings, boundary—it always keeps talking about this only.

So, the maximum useful work potential of a system at a specific state, which you already know, is called exergy, which is a composite property depending on the state of the system and its surroundings. The system which is in equilibrium with its surroundings is said to be at a dead state having zero exergy.

While energy is conserved (first law), exergy is not; it can only be fully destroyed by irreversibility, making it a crucial tool for efficiency and sustainability analysis in real systems.

Exergy

Exergy is Completely Destroyed When:

1. The Process Is Fully Irreversible

In irreversible processes, such as:

- Friction
- Unrestrained expansion
- Mixing of different substances
- Heat transfer through a finite temperature difference
- These processes generate entropy, which directly causes exergy destruction.
- ❗ More irreversibility = more entropy generation = more exergy destruction

So, exergy is completely destroyed when the process is fully irreversible. In irreversible processes, friction and unrestrained expansion occur, mixing of different substances, and heat transfer through finite temperature differences. These processes generate entropy, which directly causes exergy destruction. More irreversibility, more entropy generation, more exergy destruction. This is a key take-home message for you. If there is more irreversibility, you will have more entropy and more exergy destruction.

Exergy

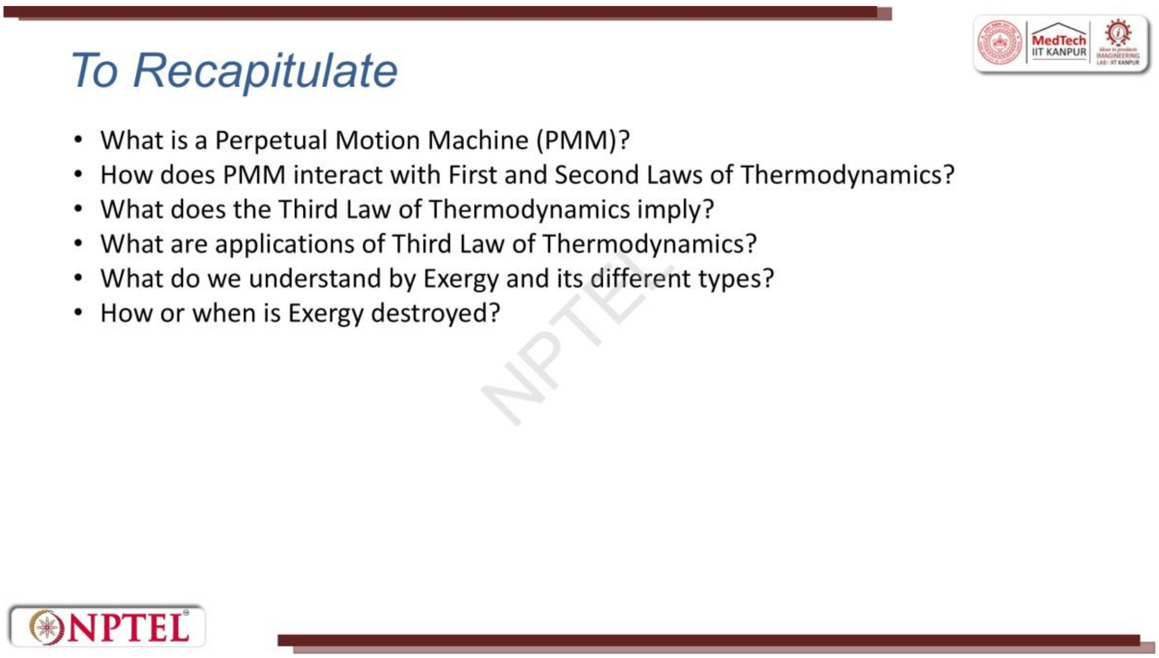
2. System Reaches Thermal and Mechanical Equilibrium with the Environment.

At this point:

- No temperature difference → no heat engine possible
- No pressure difference → no expansion work possible
- No chemical potential difference → no reaction-driven work

- The system has no potential to do useful work.
- Exergy becomes zero → it is said to be completely destroyed

The system reaches mechanical or thermal equilibrium with the environment when no temperature difference exists (no heat engine is possible), no pressure difference (no expansion work is possible), and no chemical potential difference (no reaction-driven work occurs). So, when there is equilibrium, the system has no potential to do useful work. So, exergy is zero. Exergy is said to be completely destroyed.



So, to recap, in this lecture, we saw: What is a perpetual motion machine? How does a PMM interact with the first and second laws of thermodynamics? What does the third law of thermodynamics imply?

So, what does it say? Should we recollect and see what it says? The law states that as the temperature of a perfectly crystalline substance approaches absolute zero, the entropy also approaches zero. That is what it says, right. So, we are trying to find zero entropy so that we can always have a relative measurement, a delta S measurement we can do. So, we saw that, then we saw what we understand about exergy and what its different types are—mechanical, chemical—this is what it is, how and when exergy is destroyed.

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So, these are the topics we covered in this lecture, and these are some of the references we have followed. Thank you very much.