

Basics of Mechanical Engineering-3

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Week 02

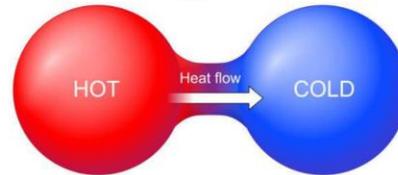
Lecture 08: Basic Laws of Thermodynamics Part 3 of 5

Welcome to the third part of the Basic Laws of Thermodynamics.

Second Law of Thermodynamics



- Joule's experiments amply demonstrates that energy, when supplied to a system in the form of work can be completely converted into heat (work transfer → internal energy increase → heat transfer).
- But the complete conversion of heat into work in a cycle is not possible.
- So heat and work are not completely interchangeable forms of energy.
- Work is said to be a high grade energy and heat a low grade energy.
- **The complete conversion of low grade energy into high grade energy in a cycle is impossible.**



Thermal energy only flows from higher energy to lower energy



<https://www.merchantnavydecoded.com/wp-content/uploads/2023/09/steam-engine-49-compressed-1140x570.jpg>

The Second Law of Thermodynamics. Joule's experiment amply demonstrates that when energy is supplied to a system in the form of work, it can be completely converted into heat. Work transfer increases internal energy through heat transfer. The Second Law of Thermodynamics and Joule's experiment.

Joule was a scientist. Joule's experiment amply demonstrated that when energy is supplied to a system in the form of work, it can be completely converted into heat. This is what the second law was. But the complete conversion of heat into work in a cycle is not possible. So, heat and work are not completely interchangeable forms of energy.

So, work is said to have higher-grade energy, and heat is said to have lower-grade energy. The complete conversion of low-grade energy into high-grade energy in a cycle is impossible. That's what Joule demonstrated in his experiments. This is also very important. The complete conversion of low-grade energy into high-grade energy in a cycle is highly impossible.

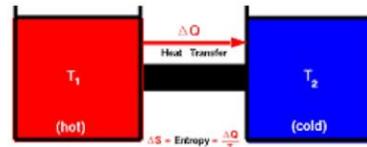
Second Law of Thermodynamics



It states that **not all energy can be converted into useful work**, and that there is a natural tendency for systems to evolve toward a state of increased **disorder or randomness**, quantified by a property called **entropy**.

Aspects of the Second Law

1. To identify the direction of process.
2. Establishing conditions for equilibrium.
3. It also asserts that energy has quality as well as quantity.
4. It is also used in determining the theoretical limits for the performance of heat engines and refrigerators.
5. Defining a temperature scale independent of the properties of any thermometric substance.



<https://stdhomes.izmirekonomi.edu.tr/ahsensagcan/images/demo/termoresim/5.png>

The second law states that not all energy can be converted into a useful form. So, the first law says energy will be transferred from one form to another. The second law states that not all energy can be converted into a useful form. So, that means there is a loss in the conversion. And there is a natural tendency for a system to evolve toward a state of increased disorder or randomness.

This is quantified as entropy. So, the conversion, whatever happens, leads to a natural tendency for the system to evolve toward a state of increased disorder. In the second law of thermodynamics chapter, we will keep focusing on entropy. And entropy, if you want to correlate with previous knowledge—when we draw a PV diagram, we also draw a TS diagram, a temperature-entropy diagram. So, that is what entropy is.

Entropy is nothing but represented as S. What are the aspects of the second law? It helps identify the direction of the process. That is very important—in which direction the

energy is getting converted. Next, it establishes conditions for equilibrium. The third thing is, it also asserts that energy has quality as well as quantity, both.

It also asserts that energy has quality as well as quantity. Quantity means it also refers to the magnitude. These are all aspects of the second law. Then, it is also useful in determining the theoretical limits for the performance of heat engines and refrigerators. So, if you want to work on the efficiency of a machine, that is addressed by the second law of thermodynamics.

Why is efficiency important? I should know: if I apply a certain power, what will be my energy conversion and what will be the loss? So, it is also used in determining the theoretical limits for the performance of heat engines and refrigerators. Defining a temperature scale independent of the properties of any thermometric substance is also an aspect of the second law. So, in conclusion, the second law states that not all energy is converted into useful work; there will be some deviation. That deviation is the tendency for the system to evolve toward a state of increased randomness.

So, these are the aspects. You have a hot body and a cold body. Generally, a temperature gradient exists. So, energy is transferred from the hot body to the cold body. So, that is what I have described here as the direction of heat transfer.

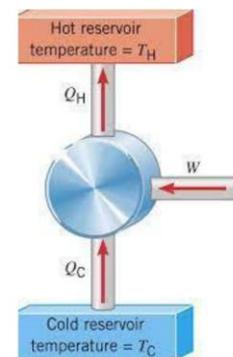
So, I said here that it identifies the direction of the process, which is ΔQ heat. Then, there is randomness. I said entropy, that is ΔS entropy, which is nothing but ΔQ heat transfer by the temperature. So, this tries to help in determining the limits—thermal limits of the performance of the system.

Second Law of Thermodynamics



Thermal Energy Reservoir (TER):

- It is a hypothetical body with a relatively large thermal energy capacity that can supply or absorb finite amount of heat without undergoing any change in temperature. Examples: Oceans, rivers, atmospheric air etc.
- TER that supplies energy in the form of heat is called a source
- TER that absorbs energy in the form of heat is called a sink
- Thermal reservoirs are essential in the analysis of **Carnot cycles**, refrigerators, and other idealized systems, providing boundary conditions that help determine the **maximum possible efficiency** of thermodynamic devices.



So, now, let us try to understand the concept of a thermal energy reservoir, which is shortly or abbreviated as TER. It is a hypothetical body with a relatively large thermal energy capacity that can supply or absorb a finite amount of heat without undergoing any change in temperature.

This is a hypothetical body wherein a relatively large thermal energy capacity can be absorbed from the sun. You have heat which is trying to hit the earth. So, a large thermal energy capacity that can supply or absorb a finite amount of heat without undergoing any change in temperature. Examples, as I told you, are the ocean, river, and atmospheric air. The TER that supplies energy in the form of heat is known as the source.

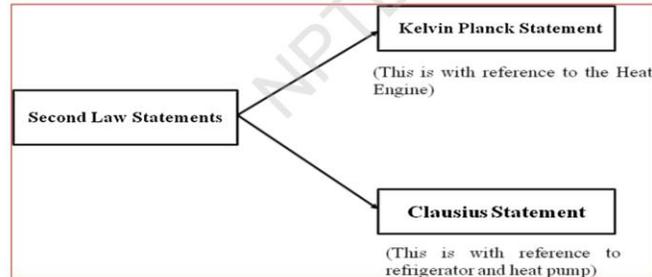
So, now we are trying to introduce the concept of source and sink. Source is the supply of energy, and sink is a place where it absorbs energy. The thermal reservoirs are essential in the analysis of the Carnot cycle or a refrigerator and other idealized systems, which provide boundary conditions that help in determining the maximum possible efficiency. So, from source to sink, how is the energy getting transferred? We are trying to use the Carnot cycle and see what all the conditions are when applied, so you can try to get the maximum efficiency because every engine would like to run at its maximum efficiency, or we would like to run the engine at maximum efficiency.

If the engine has to run at maximum efficiency, then there are only two things. Either you move the engine, or you operate the engine in a process-parameter-optimized, energy-efficient way, or you try to work around the engine. So, that means to say, working around the engine refers to the surrounding or the boundary. So, that is what providing boundary conditions that help in determining the maximum possible efficiency of a thermodynamic device. So, if you want energy from a sink, there is an engine there.

This engine, when you apply work to it, will try to increase and go to the source. So, this is cold (Q_c), this is hot.

Second Law of Thermodynamics

- The Second Law of Thermodynamics is essential for understanding the **limitations and direction** of energy transformations.
- The Second Law of Thermodynamics can be stated in several equivalent but differently worded forms, each highlighting a specific limitation of energy transformation processes.



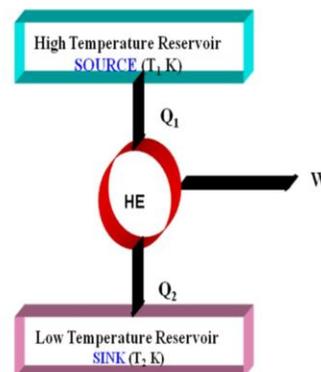
So, the second law of thermodynamics is essential for understanding the limitations and the directions of energy transformation. The second law of thermodynamics has two basic statements. One is called the Kelvin-Planck statement.

The other one is called the Clausius statement. So, the Kelvin-Planck statement refers to a heat engine, and the Clausius statement refers to a refrigerator and heat pump.

Heat Engines

Heat Engines:

- Heat engine is a cyclic device, used to convert heat to work.
- Heat engine can be characterized by the following points:
- They receive heat from a high temperature source (solar energy, oil-furnace etc.)
- They convert part of this heat to work (usually in the form of a rotating shaft)
- They reject the remaining waste heat to a low temperature sink (the atmosphere, rivers, etc)
- They operate on a cycle.



Now, let us understand what a heat engine is. A heat engine is a cyclic device used to convert heat into work. So, there is heat.

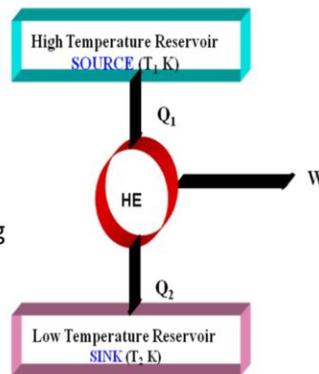
So, you see here source. There is a sink, Q_1 , Q_2 . So, you can see the direction which it comes. And, in the heat engine, you try to get the work done. The heat engine can be characterized by the following points.

They receive heat from a higher temperature. They get converted the heat into work usually in the form of rotating of shaft turbine engine. The rejected whatever is residue air which is with heat which is called as waste is sent to the lower sink. They operate on a cycle.

Heat Engines



- Heat engines are fundamental to many energy conversion systems, including **internal combustion engines, steam turbines, gas turbines, and jet engines**.
- The basic working of a heat engine involves four steps:
 - (1) **Heat input (Q_{in})** is absorbed from a high-temperature reservoir,
 - (2) part of this energy is converted into **work (W)** by expanding a working fluid (such as gas or steam)
 - (3) the working fluid is then cooled, and
 - (4) **heat is rejected (Q_{out})** to a low-temperature reservoir. The engine then returns to its original state to repeat the cycle.



https://res.cloudinary.com/dpzn3dkw/image/upload/v1724754465/SEOContent/Physics/Heat_Engine_Diagram_idygv.jpg

The heat engines are fundamental to many heat conversion systems which include internal combustion engine, steam turbines, gas turbines and jet engines.

The basic working of a heat engine involves four steps. Basically, the first step is heat input, which is called as Q_{in} , is absorbed from the higher temperature reservoir. Part of the energy is converted into work by expanding a working fluid. So, it can be steam, it can be gas, whatever it is. Then, the next one is the working fluid of the system. The last one is heat is rejected which is called as Q_{out} to a lower temperature reservoir. The engine then returns to its original state to repeat the cycle. So, it can go repeatedly to form a cycle.

Heat Engines



- The **thermal efficiency** (η) of a heat engine is defined as the ratio of useful work output to the heat input:

$$\eta = \frac{W_{\text{net}}}{Q_{\text{in}}} = 1 - \left(\frac{Q_{\text{out}}}{Q_{\text{in}}}\right)$$

- This equation shows that **some heat must always be rejected**, which means **no heat engine can be 100% efficient**, as per the **Second Law of Thermodynamics**.
- The theoretical maximum efficiency of a heat engine operating between two temperature reservoirs is given by the **Carnot efficiency**:

$$\eta_{\text{Carnot}} = 1 - \left(\frac{T_{\text{cold}}}{T_{\text{hot}}}\right)$$

- T_{hot} , T_{cold} are the absolute temperatures (in Kelvin) of the sink and source, respectively. The Carnot cycle sets the upper limit for heat engine performance and serves as a benchmark for evaluating real engines.



So, if you want to calculate the thermal efficiency of a heat engine, which is obtained by this efficiency term, η of a heat engine is defined as the ratio of useful work output to the heat input. So,

$$\eta = \frac{W_{\text{net}}}{Q_{\text{in}}} = 1 - \left(\frac{Q_{\text{out}}}{Q_{\text{in}}}\right)$$

Through this, we always try to get the efficiency of the system. This equation shows that there is always heat that must be rejected, which means that no heat engine can have 100% efficiency as per the second law of thermodynamics, which is also true in reality. The theoretical maximum efficiency, the first one we did for HE (heat engine).

Next, we are trying to take Carnot. So, the efficiency of a heat engine operating between two temperature reservoirs is given by Carnot efficiency. So,

$$\eta_{\text{Carnot}} = 1 - \left(\frac{T_{\text{cold}}}{T_{\text{hot}}}\right)$$

T_{hot} and T_{cold} are the absolute temperatures of the sink and source. The Carnot efficiency sets the upper limit of the heat engine performance and serves as a benchmark for evaluating real engines. That is why we always talk about the Carnot cycle.

Heat Engines



Components of a Heat Engine:

- **Heat Source:** Supplies thermal energy at high temperature.
- **Working Substance:** Typically a gas or vapor that undergoes expansion and compression.
- **Engine Mechanism:** Converts the expansion of the working substance into mechanical work (e.g., piston, turbine blades).
- **Heat Sink:** Absorbs the rejected heat at a lower temperature.
- **Cycle Controller:** Manages the cyclic process and controls timing (in practical engines).



What are the components? Heat source: It supplies thermal energy at a higher temperature. The working substance is typically a gas or a vapour that undergoes expansion or compression.

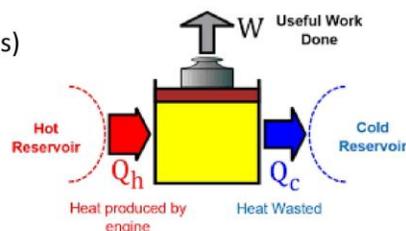
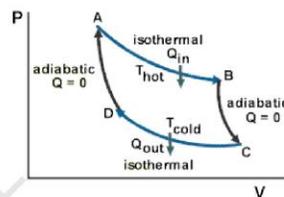
Then, the engine mechanism converts the expansion of the working substance into mechanical work, like in a heat engine. Then, the heat sink is also the same. We have added one more term, which is called a cycle controller. It manages the cyclic process and controls timing.

Heat Engines



Common Heat Engine Cycles:

- **Carnot Cycle** (ideal, reversible)
- **Otto Cycle** (used in petrol engines)
- **Diesel Cycle** (used in diesel engines)
- **Rankine Cycle** (used in steam turbines)
- **Brayton Cycle** (used in gas turbines and jet engines)



There are common heat engines. One is the Carnot cycle, which is ideal and reversible. Then, there is the Otto cycle, used in petrol engines. The Diesel cycle is used in diesel engines. The Rankine cycle is used in steam turbines. The Brayton cycle is used in gas turbines and jet engines. So, the Carnot cycle is ideal and reversible.

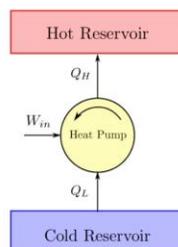
So, when we try to draw a PV diagram, we can see from A to B it is isothermal, and from B to C it is adiabatic. So, A to B is isothermal expansion, B to C is adiabatic expansion, C to D is isothermal compression, and D to A is adiabatic compression again. So, isothermal Q in occurs between A to B and C to D. There is always a rejection at B to C and A to D. The adiabatic $Q = 0$. So, you can see here schematically a hot reservoir where Q is pushed into an engine, and then you try to get a Q out where it is a cold reservoir. You have a weight; when the heat is applied, the gas expands and the weight increases or moves higher, or the weight is pushed to a higher level.

Heat Pumps



Heat Pumps:

- Heat pumps are another cyclic devices, used to transfer heat from a low temperature medium to a high temperature medium.
- The objective of a heat pump is to maintain a heated space at a high temperature. This is accomplished by absorbing heat from a low temperature source, such as cold outside air in winter and supplying this heat to the high temperature medium such as a house.



<https://www.yacrealstate.com>

Let us now try to understand the concept of a heat pump. A heat pump is another cyclic device. A heat engine is a cyclic device. Heat pumps are also cyclic devices. They are used to transfer heat from a lower temperature to a higher temperature.

So, the objective of a heat pump is to maintain a heated space at a high temperature. This is accomplished by absorbing heat from a lower temperature source, such as cold outside air in winter, and supplying this to a high-temperature medium, such as a house. So, there we use a heat pump. So, a heat pump and a heat engine are used to transfer heat from a

lower-temperature medium to a higher-temperature medium. So, the objective of a heat pump is to maintain a heated space at a high temperature. So, here the work is done such that the heat pump operates from a lower temperature to a higher temperature.

Heat Pumps



- Unlike heat engines that convert heat into work, or refrigerators that cool a space by removing heat, a **heat pump is primarily used for heating purposes**—delivering heat to a warmer space by extracting it from a colder environment.
- This is especially useful for **space heating in winter**, where ambient outdoor air, soil, or water serves as the cold source, and the heated indoor space is the hot sink.
- Heat pumps operate on the **reversed Carnot cycle** or more practically, on the **vapor-compression refrigeration cycle**, much like a refrigerator or air conditioner.
- The system includes four major components: a **compressor**, **condenser**, **expansion valve**, and **evaporator**.



Unlike a heat engine, which converts heat into work, or a refrigerator, which cools a space by removing heat, a heat pump is primarily used for heating purposes. It delivers heat to a warmer space by extracting it from a colder environment. So, you can see that a heat pump and a heat engine are different. This is especially used for space heating in winter, where ambient outside air, soil, or water serves as a cold source, and the heated indoor space is a hot sink.

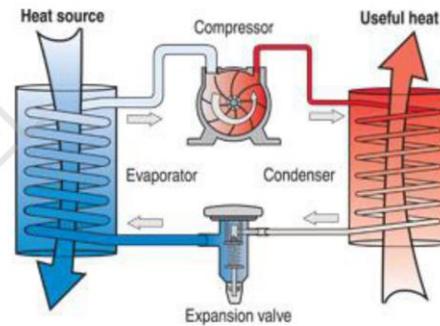
So, the heat pumps operate on a reversed Carnot cycle or, more practically, on the vapor compression refrigeration cycle, much like a refrigerator or an air conditioner. So, a vapor compression refrigeration cycle. The system includes four components: a compressor, a condenser, an expansion valve, and an evaporator.

Heat Pumps



In heating mode:

- The **evaporator** absorbs heat from the cold outdoor environment.
- The **compressor** raises the pressure and temperature of the refrigerant.
- The **condenser** releases the absorbed heat into the indoor space.
- The **expansion valve** reduces the pressure before the refrigerant returns to the evaporator.



<https://heatpumpingtechnologies.org/market-technology/heat-pump-work/>

So, you will see the schematic diagram of a heat pump. So, you have a compressor which compresses air, raising the pressure and temperature of the refrigerant. Then, subsequently, you have a condenser. The condenser releases the absorbed heat into the indoor space. So, this part will be inside the building. So, this is indoor. So, once it has done its job, it passes through the expansion valve and goes to the evaporator. The evaporator absorbs heat from the cold outdoor environment.

So, the system starts this way. So, from the blue, the heat source is going away. So, you will have a compressor here. So, the compressor gets its input from an evaporator. The evaporator absorbs heat from the outdoor environment.

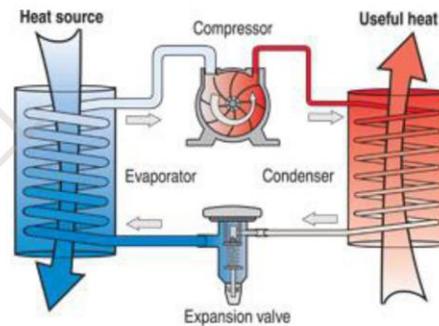
The compressor increases the pressure and the temperature. Then, the condenser releases the heat absorbed indoors, and then it goes to an expansion valve. From the expansion valve, it goes to the evaporator.

Heat Pumps



In heating mode:

- The **evaporator** absorbs heat from the cold outdoor environment.
- The **compressor** raises the pressure and temperature of the refrigerant.
- The **condenser** releases the absorbed heat into the indoor space.
- The **expansion valve** reduces the pressure before the refrigerant returns to the evaporator.



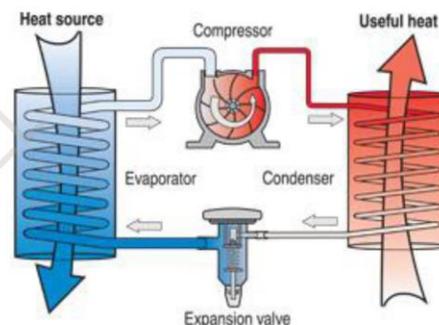
<https://heatpumpingtechnologies.org/market-technology/heat-pump-work/>

So, in heating mode, the evaporator absorbs heat from the cold outdoor environment. The compressor raises the pressure and temperature. The condenser releases the absorbed heat into the indoor space. The expansion valve reduces the pressure. So, if you go by it, the expansion valve reduces the pressure. The compressor increases the pressure, right? The expansion valve reduces the pressure before the refrigerant enters the evaporator.

Heat Pumps



- Heat pumps are widely used in residential and commercial heating, water heaters, and industrial drying or dehumidifying systems.
- They are energy-efficient, reduce dependence on fossil fuels, and can often reverse operation to act as air conditioners in summer, making them dual-purpose.



<https://heatpumpingtechnologies.org/market-technology/heat-pump-work/>

So, heat pumps are widely used in residential and commercial heating, water heaters, and industrial drying or dehumidifying systems. Everywhere, we use heat pumps. Heat pumps are slightly less energy efficient compared to heat engines. They are energy efficient, reduce dependency on fossil fuels, and can often reverse operation to act as an air conditioner in summer, making it a dual-purpose system. Today, we have air conditioners that are available for both hot and cold. So, it works on this principle. So, we have a heat pump. This is called a heat pump, and these are the four components.

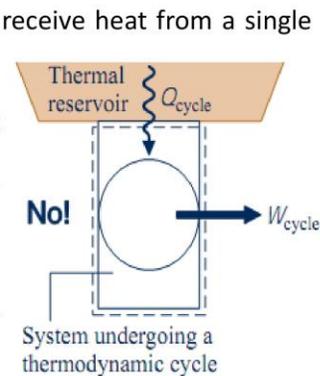
Kelvin-Planck Statement



Kelvin-Planck Statement of the Second law

It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work.

- The Kelvin-Planck statement asserts that no heat engine can operate in a cyclic process and convert all the heat it absorbs from a high-temperature reservoir entirely into work without rejecting some heat to a lower temperature reservoir.
- In other words, it is **impossible to achieve 100% thermal efficiency** in any cyclic heat engine. This sets a fundamental limit on the performance of all engines, no matter how perfectly designed.
- A heat engine that violates the Kelvin-Planck statement.



<https://media.cheggcdn.com/media/e0c/e0ce26dc-f90d-43be-8f4b-73772b9c83a7/phpyIMHM4>

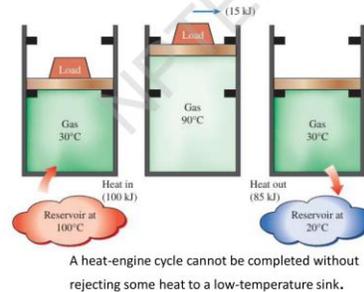
Now, let us go back to the Kelvin-Planck statement of the second law. It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work. So, this is what the Kelvin-Planck statement crudely states.

It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work. So, you can see a thermal reservoir where there is a work cycle being done. The system undergoes a thermodynamic cycle here. So, it is not there. So, the Kelvin-Planck statement asserts that no heat engine can operate in a cyclic process and convert all the heat it absorbs from a higher-temperature reservoir entirely into work without rejecting some heat to a lower-temperature reservoir.

So, you can never convert all the heat grabbed from a heat source and get it back into the system without undergoing a certain amount of loss. In other words, it is impossible to achieve a 100 percent thermally efficient cyclic heat engine.

Kelvin-Planck Statement

- In below Figure that, even under ideal conditions, a heat engine must reject some heat to a low temperature reservoir in order to complete the cycle. That is, no heat engine can convert all the heat it receives to useful work. This limitation on the thermal efficiency of heat engines forms the basis for the Kelvin–Planck statement of the second law of thermodynamics.



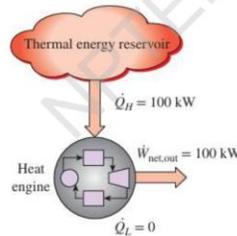
In the figure below, even under ideal conditions, the heat engine must reject some heat to a lower-temperature reservoir to complete the cycle. That is, no heat engine can convert all the heat it receives into useful work. For example, the reservoir is at 100 degrees, there is a gas at 30 degrees, and there is a load.

So, when the gas expands, the reservoir you try to inject it into, the heat is about 100 kilojoules. So, when it is given to the gas, the gas expands, the weight is lifted, and they are setting the upper and lower limits. So, you can see that the weight is lifting, and it is around about 15 kilograms or kilojoules, right? So, it expands and reaches this point, and because of the load, whatever you apply, it compresses the gas. Once the gas is compressed, the gas temperature is brought to 30 degrees. It rejects heat to the reservoir back at 20 degrees. The heat out will be 85 kilojoules. So, this limitation on the thermal efficiency of a heat engine forms the basis of the Kelvin-Planck statement of the second law of thermodynamics.

Kelvin-Planck Statement



- A heat engine must exchange heat with a low-temperature sink as well as a high-temperature source to keep operating. The Kelvin–Planck statement can also be expressed as no heat engine can have a thermal efficiency of 100 percent, or as for a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace.



A heat engine that violates the Kelvin–Planck statement of the second law



Yunus A. Çengel, Michael A. Boles, Mehmet Kanoğlu - Thermodynamics: An Engineering Approach-McGraw-Hill Education (2019) Pg : 279

The heat engine must exchange heat with a lower-temperature sink as well as a higher-temperature source to keep operating. So, the Kelvin-Planck statement can also be expressed as: no heat engine can have a thermal efficiency of 100%, or for a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace. So, this is a repeat of the previous one. So, here we see a thermal energy source where 100 kilowatts is given.

So, there is a heat engine. So, the heat engine is there. So, Q_L and work out is 100 kilojoules. The heat engine that violates the Kelvin-Planck statement of the second law is described here.

Kelvin-Planck Statement



- Note that the impossibility of having a 100 percent efficient heat engine is not due to friction or other dissipative effects. It is a limitation that applies to both the idealized and the actual heat engines.

Application:

- **Internal Combustion Engine** : Used in cars, trucks, and motorcycles. These engines cannot convert all the heat from fuel combustion into mechanical work; some energy is always lost as waste heat to the environment.
- **External Combustion Engine** : Such as steam engines in thermal power plants, where heat from burning fuel is used to produce steam, which then drives turbines. Not all the input heat can be converted to work—some must be released to a condenser or cooling system.



<https://www.vedantu.com/physics/kelvin-planck-statement>

So, the application of the Kelvin-Planck statement includes internal combustion engines and external combustion engines. Internal combustion engines are found in cars, trucks, and motorcycles, as you know. External combustion engines, such as steam engines in thermal power plants, use heat from burning fuel to produce steam, which then drives a turbine. Not all the input heat is converted into work. Some of it is released to a condenser or a cooling system.

Kelvin-Planck Statement



Application:

- **Gas Turbine** :Utilized in jet aircraft and power generation, where the principle limits the efficiency of converting fuel heat into mechanical or electrical work.
- **Power Plants** : Including thermal, nuclear, and geothermal plants, which use heat to generate electricity. The Kelvin-Planck statement explains why these plants always have less than 100% efficiency, as some heat must be discharged to the environment.
- **Refrigeration and Heat Pump Analysis** : The statement is used to compare and calculate the efficiencies of engines, refrigerators, and heat pumps, emphasizing the necessity of a heat sink for continuous operation.



<https://www.vedantu.com/physics/kelvin-planck-statement>

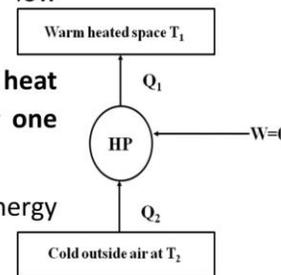
Gas turbines are another application. Power plants. Power plants include thermal, nuclear, and geothermal plants, which use heat to generate electricity. So, here also, these plants do not operate at 100 percent efficiency. The refrigeration and heat pump analysis: The statement is used to compare and calculate the efficiency of engines, refrigerators, and heat pumps, emphasizing the necessity of a heat sink for continuous operation.

Clausius Statement



Clausius Statement:

- It is impossible to construct a device that operates in a cycle and produce no effect other than the transfer of heat from a low temperature body to a high temperature body.
- The Clausius statement, on the other hand, emphasizes that **heat cannot flow spontaneously from a colder body to a hotter one** without external work being done on the system.
- This explains why **refrigerators and heat pumps** require energy input to move heat against its natural direction.
- A refrigerator that violates the Clausius statement of the second law.



Now, let us move to the Clausius Statement. It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body.

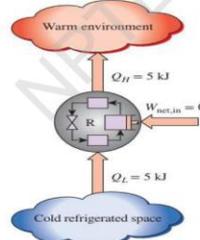
The Clausius statement, on the other hand, emphasizes that heat cannot flow spontaneously from a colder body to a hotter one without external work being done on the system. So, for heat to move from cold to hot, some work must be done. The Clausius statement emphasizes that heat cannot flow spontaneously from a colder body to a hotter one without external work being done on the system. This explains why refrigerators and heat pumps require energy input to move heat against its natural direction. This is a point that is often asked about in interviews.

This explains why refrigerators and heat pumps require energy input to move heat against the direction. So, this is the reason. So, here in Clausius statement from a cold air system, at T_2 you try to move to T_1 where in which you try to apply a work on top of the system HP and get it transferred. This explains why refrigerator and heat pumps require energy input to move heat against its natural direction. A refrigerator that violates the Clausius statement of the second law.

So, a refrigerator that violates a Clausius statement of second law is given here.

Clausius Statement

- The Clausius statement does not imply that a cyclic device that transfers heat from a cold medium to a warmer one is impossible to construct. In fact, this is precisely what a common household refrigerator does. It simply states that a refrigerator cannot operate unless its compressor is driven by an external power source, such as an electric motor.



A refrigerator that violates the Clausius statement of the second law.

So, this is the refrigerator that violates the Clausius statement of second law.

Clausius Statement

- This way, the net effect on the surroundings involves the consumption of some energy in the form of work, in addition to the transfer of heat from a colder body to a warmer one.
- That is, it leaves a trace in the surroundings. Therefore, a household refrigerator is in complete compliance with the Clausius statement of the second law.
- Both the Kelvin–Planck and the Clausius statements of the second law are negative statements, and a negative statement cannot be proved. Like any other physical law, the second law of thermodynamics is based on experimental observations.
- To date, no experiment has been conducted that contradicts the second law, and this should be taken as sufficient proof of its validity.

So, this way, the net effect on the surrounding involves a consumption of some energy in the form of work, in addition to the transfer of heat from colder body to a warmer work. That is, it leaves a trace in the surrounding. Both Kelvin-Planck and Clausius statement of the second law are negative statements.

And, the negative statements cannot be proved. Like any other physical law, the second law of thermodynamics is based on experimental observation. To date, no experiments have been conducted that contradicts the second law. And, this should be taken as sufficient proof of its validity. So, these two statements are only to say how is this law still getting accepted in reality.

Clausius Statement



Application:

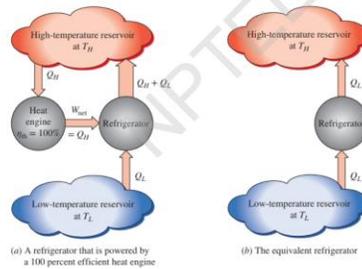
- **Refrigerators and Heat Pumps** : These devices transfer heat from a cold region (inside the fridge or a cooled room) to a warmer region (the surrounding environment). According to the Clausius statement, this process cannot occur spontaneously and requires external work input, typically provided by a compressor.
- **Air Conditioner** : Similar to refrigerators, air conditioners move heat from the cooler indoor environment to the warmer outdoors, requiring electrical energy to drive the process.
- **Thermodynamics Analysis** : The Clausius statement is fundamental in analyzing and designing thermodynamic cycles, such as the Carnot cycle, and in determining the theoretical limits of efficiency for heat engines and refrigerators.



So, applications: Refrigerator and heat pumps are part of Clausius statement. Air condition is an example. Thermodynamic analysis: The Clausius statement is fundamental in analyzing and designing thermodynamic cycles such as Carnot cycle. And in determining the thermodynamic limit of the efficiency of the heat engines and refrigerator.

Clausius Statement

- Equivalence of the Two Statements The Kelvin–Planck and the Clausius statements are equivalent in their consequences, and either statement can be used as the expression of the second law of thermodynamics. Any device that violates the Kelvin–Planck statement also violates the Clausius statement, and vice versa.



Proof that the violation of the Kelvin–Planck statement leads to the violation of the Clausius statement

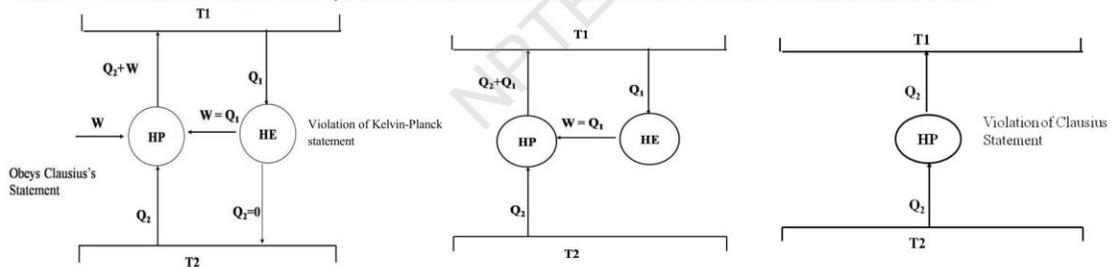
So, now there is a possibility of Clausius statement. So, Clausius statement equivalency of two statements. Kelvin-Planck and Clausius statements are equivalent in their consequences. And either statements can be used as an expression of the second law of thermodynamics. Any device that violates Kelvin-Planck statement also violates Clausius statement. So, if it violates Kelvin-Planck, Clausius statement is also violated and vice versa. That is what is explained here.

Second Law of Thermodynamics

Equivalence of Kelvin Planck and Clausius Statements:

- The equivalence of the statement is demonstrated by showing that the violation of each statement implies the violation of other.

CASE-1: Violation of Kelvin-planck statement leads to violation of Clausius statement



So, the equivalence of Kelvin-Planck and Clausius statement: The equivalency of a statement is demonstrated by showing that violation of each statement implies the violation of the other. So, from here you can see from Q2 the Clausius is obeyed here in this first one and the Kelvin statement is violated here. So, you can see T1, HE is there and it gives you W. This W comes to HP and here it goes from Q2 go plus W here and then it goes to T1. So, this is violation of Kelvin-Planck statement.

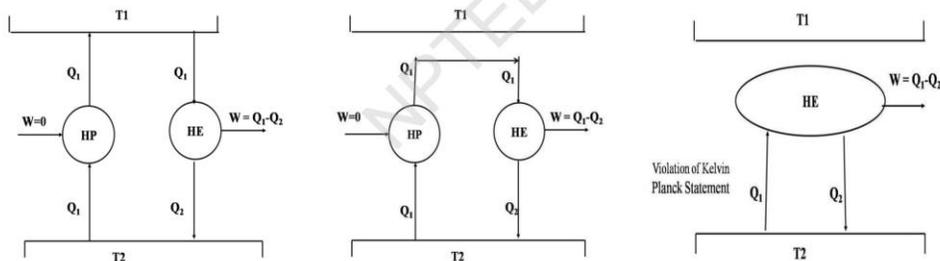
So, the heat engine Q1 goes to Q2, where $Q2 = 0$. So, it is a violation. So, you can take it from here: T1 goes to HE, where $W = Q1$, and then this HP is operating. So, from here, $Q1 + Q2$ is there. So, the last one is: violation of Clausius statement is Q2, Q1, and there is no work done at all.

Second Law of Thermodynamics



- Thus violation Kelvin Planck Statement has lead to the violation of Clausius Statement.

CASE-2: Violation of Clausius statement leads to violation of Kelvin-planck statement



<https://i.sstatic.net/Fxhjo.png>

The second, thus violating the Kelvin-Planck statement, has led to the violation of Clausius statement. Violation of Clausius statement leads to the violation of Kelvin statement. In the previous one, it is violation of Kelvin-Planck leading to Clausius. So, here it is violation of Clausius statement leading to the violation of Kelvin-Planck. So, you can see here T1, T2.

So, there is HP, pump. The work done is 0. So, the $Q1$ leads to $Q1$. So, in the second case, $Q1, Q2$, we have HE, where $W = Q1 - Q2$. The next thing is T1, T2.

So, where HP, you can see the heat pump work is 0 here. So, and then, it has taken Q_1 from Q_1 , you tap it and give it to HE. And then, this is Q_2 where $W = Q_1 - Q_2$. So, here it is the closest statement that is getting invalid. So, where violation of Kelvin statement is HE, you give a Q_1 , and then you draw Q_2 $W = Q_1 - Q_2$. So, all these equivalent circuits are drawn to show you that one statement leads to the violation of the other.

Second Law of Thermodynamics



- Thus violation Kelvin Planck Statement has led to the violation of Clausius Statement.
- At first sight, Kelvin-Planck's and Clausius statements may appear to be unconnected, but it can easily be shown that they are virtually two parallel statements of the second law and are equivalent in all respects.
- The equivalence of the two statements will be proved if it can be shown that the violation of one statement implies the violation of the second, and vice versa.



So, thus the violation of Kelvin-Planck statement has led to the violation of Clausius statement. At first sight, Kelvin-Planck's and Clausius statements may appear unconnected, but it can be easily shown that they are virtually two parallel statements of the second law and are equivalent in all aspects. So, that is why we always take these two laws and go. The equivalence of the two statements will be proved if it can be shown that the violation of one statement implies the violation of the other. The last part of this lecture, we will try to discuss reversibility and irreversibility.

Second Law of Thermodynamics



The irreversibility of a process may be due to either one or both of the following:

(a) Lack of equilibrium during the process:

The lack of equilibrium (mechanical, thermal or chemical) between the system and its surroundings, or between two systems, or two parts of the same system, causes a spontaneous change which is irreversible.

(b) Involvement of dissipative effects:

The irreversibility of a process may be due to the dissipative effects in which work is done without producing an equivalent increase in the kinetic or potential energy of any system.



The second law of thermodynamics enables us to divide all processes into two classes: reversible and irreversible, ideal process and natural process. A reversible process is one which is performed in such a way that at the conclusion of the process, both the system and the surroundings may be restored to the initial state without producing any change in the rest of the universe.

The reversible process is carried out infinitely slowly with an infinitesimally small gradient so that every state passed through by the system is an equilibrium state. The irreversibility of the process may be due to either one of these two states. One is the lack of equilibrium during the process. There can be mechanical non-equilibrium, thermal non-equilibrium, or chemical non-equilibrium between the system and the surroundings, between two systems, or between two parts of the same system, causing a spontaneous change which is irreversible. Involvement of dissipative effects is; the irreversibility of a process may be due to the dissipative effect in which work is done without producing an equivalent increase in the kinetic or potential energy.

So, the irreversibility of the process may be due to the lack of a dissipative effect, in which work is done without producing an equivalent increase in the kinetic and potential energy of any system. So, this is the dissipative effect. So, there can be two effects, right, that an irreversible process can have.

To Recapitulate



- State and Explain the First Law of Thermodynamics
- Energy is a property of the System
- First Law of Thermodynamics - Limitations
- Second Law of Thermodynamics
- Kelvin-Planck's Statement
- Clausius' Statement
- Reversibility and Irreversibility



Thus, to conclude, we have seen in this lecture the state and explained the first law. Energy is a property of a system.

The first law of thermodynamics and its limitations. The second law of thermodynamics, in which we have seen the Kelvin-Planck statement and the Clausius statement. Then, we tried to see reversibility and irreversibility. Friends, as I told you, the numerical problems will be solved during the tutorials.

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These are the references which we have used for making these slides.

Thank you very much.