Lecture 8

Reversible and Irreversible Processes

Actual processes that occur in nature happens in one direction and it cannot be reversed without changing the surroundings. For example if water flows from a height, to reverse the process we have to expend work to pump it back to the same height. By doing work the surroundings is changed.

Such processes are said to be **irreversible**.

A **reversible process** is an idealised process where both the system and surroundings are brought back to the initial state at the end of the reverse process. Reversible process is a process that can be reversed without leaving a trace in the surroundings.

A process is called **irreversible** if the system and all parts of its surroundings cannot be exactly restored to their respective initial states after the process has occurred.

A system can be restored to its initial state following a process, regardless of whether the process is reversible or irreversible. But for reversible processes, both system and surroundings has to be restored to the initial state.

Reversible processes actually do not occur in nature. They are merely idealizations of actual processes.

Uses of reversible process

1. They are easy to analyse
2. actual processes can be compared with this idealised process
3. work-producing devices such as car deliver the most work if reversible processes are used
4. work-consuming devices such as compressors, pumps etc. consume the least work when reversible processes are used

Irreversibilities

The factors that render a process to be irreversible are called irreversibilities. Irreversible processes normally include one or more of the following irreversibilities

- Friction
- Heat transfer through a finite temperature difference
- Unrestrained expansion of a gas
- Spontaneous chemical reaction
- Spontaneous mixing of matter at different compositions or states
- Electric current flow through a resistance
- Inelastic deformation

The term **irreversibility** is used to identify any of these effects. A reversible process involves none of these irreversibilities

Friction renders a process irreversible

Consider sliding a book on top of a desk in one direction. Because of friction extra work has to be done to overcome it. This extra work heats up the interface as we can sense an increase in temperature. Now when it is slid back to the original position again temperature rises. For the system (book) to reach initial state heat has to transfer to the surroundings so that initial temperature is reached. But the surroundings has changed because heat transfer increases the internal energy of the surroundings. To restore the surroundings to initial state this internal energy has to be converted to work completely which is impossible without violating the second law. Both system and surroundings has to reach the initial state for a reversible process. Here only system reaches the initial state. Hence friction causes this to be an irreversible process.

Heat transfer through a finite temperature difference causes a process to be irreversible

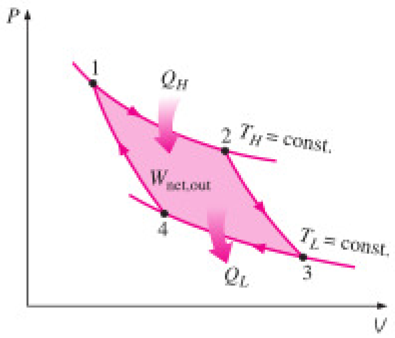
If a cup of cold water is kept in a room heat transfers the surroundings to the water. If this process has to be reversed this heat has to be transferred back to the surrounding so that the initial temperature of the system (water) is reached. Here heat has to be transferred from water(at a lower temperature) to the room (at a higher temperature). This does not happen spontaneously. So we have to use a refrigerator to transfer this heat back from the water. Even though the system (water) reaches its initial state, the surroundings has changed because of the work input to the refrigerator. The internal energy of the surroundings will increase by an amount equal in magnitude to the work supplied to the refrigerator. The restoration of the surroundings to the initial state can be done only by converting this excess internal energy completely to work, which is impossible to do without violating the second law. Hence this process is irreversible.

THE CARNOT CYCLE

If it is impossible to have 100% efficiency for a heat engine, what is the maximum efficiency it can have?

A heat engine operates in a thermodynamic cycle. A thermodynamic cycle consists of processes. If all the processes in a cycle are free of irreversibilities then the cycle will have maximum efficiency. A heat engine that operates in a cycle that consists of only reversible processes will have maximum efficiency.

Carnot cycle is one such cycle where all the processes are reversible. Therefore the maximum efficiency a heat engine can have is the Carnot efficiency.



Carnot cycle consists of four processes

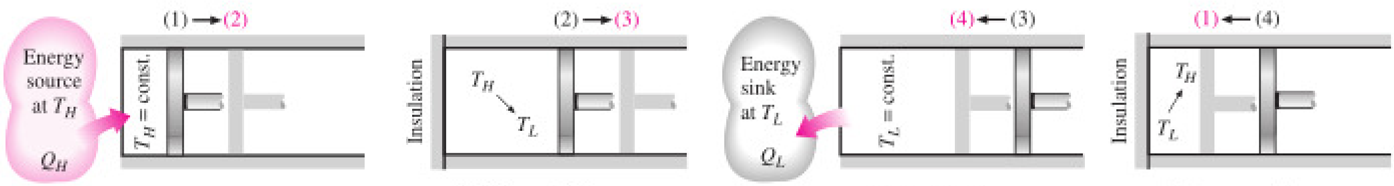
1-2 Reversible Isothermal Expansion

2-3 Reversible Adiabatic Expansion

3-4 Reversible Isothermal Compression

4-1 Reversible Adiabatic Compression

Consider a system that consists of a gas contained in a piston–cylinder device



(*a*) Process 1-2 (*b*) Process 2-3 (*c*) Process 3-4 (*d*) Process 4-1

Process 1-2 The initial gas temperature is T_H and it is in contact with a source of temperature T_H. The gas is allowed to expand. As it expands the temperature drops to an amount dT (a very very small change in temperature). The heat is transferred from the source so that temperature becomes T_H. This slow expansion and heat transfer happens till state 2 during which temperature is maintained at a **constant temperature T_H**. The heat transfer is only through an infinitesimal temperature difference dT, therefore a reversible heat transfer. The amount of heat transfer is Q_H. Process from 1-2 is a **reversible isothermal expansion**.

Process 2-3 The source is removed and the cylinder is provided with insulation. The gas is allowed to expand adiabatically from T_H to T_L. During the process it does work to the surroundings. Piston is considered frictionless and the process is assumed to be quasi equilibrium. The process is therefore a **reversible adiabatic expansion**.

Process 3-4 The insulation is removed and the system is in contact with a sink at temperature T_L. The gas is slowly compressed. As it is compressed the temperature increases by an amount dT. Heat transfers from the gas to the sink so that the temperature drops to T_L. This is continued till state 4 is reached at the **constant temperature T_L**. The amount of heat transfer during the process is Q_L. It is a reversible heat transfer since the temperature difference is infinitesimal. The process is a **reversible isothermal compression**.

Process 4-1 The sink is removed and the cylinder is insulated. The gas is compressed adiabatically from T_L to T_H. The gas returns to the initial state and the cycle is completed. The process is therefore a **reversible adiabatic compression**.

Being a reversible cycle, the Carnot cycle is the most efficient cycle operating between two specified temperature limits. Even though the Carnot cycle cannot be achieved in reality, the efficiency of actual cycles can be improved by attempting to approximate the Carnot cycle more closely.

$$\eta_{carnot} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H}$$

Q. An inventor claims to have developed a power cycle capable of delivering a net work output of 410 kJ for an energy input by heat transfer of 1000 kJ. The system undergoing the cycle receives the heat transfer from hot gases at a temperature of 500 K and discharges energy by heat transfer to the atmosphere at 300 K. Evaluate this claim.

Efficiency of the cycle,

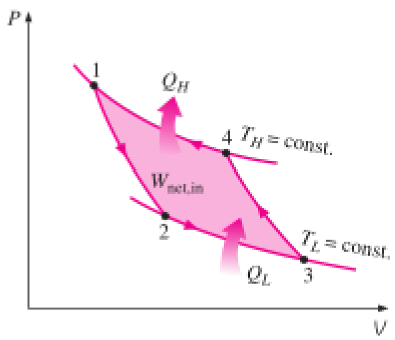
$$\eta = \frac{W_{net}}{Q_H} = \frac{410}{1000} = 41\%$$

Theoretically attainable maximum efficiency of an engine operating between a source temperature of 500K and a sink temperature of 300K is given by Carnot efficiency

$$\eta_{carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{300}{500} = 40\%$$

Since the thermal efficiency of the actual cycle exceeds the maximum theoretical value, the claim cannot be valid.

The Reversed Carnot Cycle



Carnot cycle is a reversible cycle so all the processes in Carnot cycle can be reversed. When the processes are reversed we get the **reversed Carnot cycle** or the **Carnot refrigeration cycle.** The directions of heat and work interactions are also reversed: Heat, Q_L is absorbed from the low-temperature reservoir, heat Q_H is rejected to a high-temperature reservoir, and a work input of Wnet, is required to run the cycle.

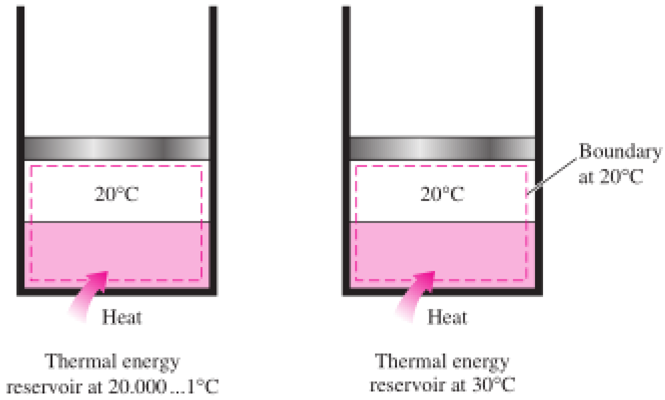
Internally and Externally Reversible Processes

In an irreversible process, irreversibilities are present within the system, its surroundings, or both.

An **internally reversible process** is one in which there are no irreversibilities within the system. During an internally reversible process, a system proceeds through a series of equilibrium states, and when the process is reversed, the system passes through exactly the same equilibrium states while returning to its initial state. The quasi-equilibrium process is an example of an internally reversible process.

A process is called **externally reversible** if no irreversibilities occur outside the system boundaries during the process.

A process is called **totally reversible**, or simply reversible, if it involves no irreversibilities within the system or its surroundings.



(*a*) Totally reversible (*b*) Internally reversible

Consider the transfer of heat to two identical systems that are undergoing a constant-pressure (thus constant-temperature) phase change process. Both processes are internally reversible, since both take place isothermally and both pass through exactly the same equilibrium states. The first process shown is externally reversible also, since heat transfer for this process takes place through an infinitesimal temperature difference dT.

The second process is externally irreversible, since it involves heat transfer through a finite temperature difference ΔT.