University of Al-Mustaqbal
College of Science
Department of Medical Physics

Thermodynamics and Heat

Second stage

Thermal machines

Lecture Seven

Name of lecturer

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Thermal machines

The thermal machine is a sentence that takes energy in the form of heat and gives part of this energy in the form of work, using a medium. This is done periodically.

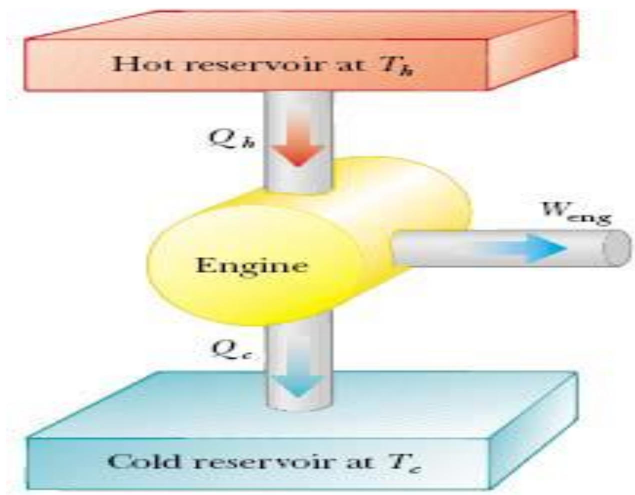
Steam engine where the medium is water vapor, and the cycle is as follows:

1. boiling water

2. the steam extend then motor piston moves

3. Re-cool and condense the vapor and return to the steam boiler

The thermal machine can be represented as follows:



Heat Engine:

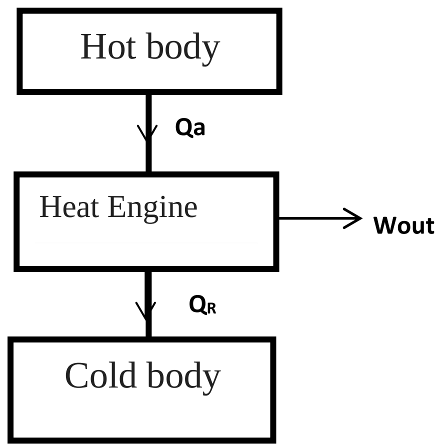
A thermodynamic system that works in a cycle and produces a work when the heat is added to it from the hot body, expelled from the hot body and partially expelled from the heat to the cold body. The thermal motor performance is expressed in thermal efficiency (η).

$$\eta = \frac{Wout}{Qh} = \frac{Qh - Qc}{Qh} \qquad \eta = 1 - \frac{Q_c}{Qh}$$

Q_h= The amount of heat added to the engine by the hot body.

Q_c = Amount of heat discharged from the engine to the cold body.

W_{out} = the work produced by the thermal engine.



Heat pumps:

Heat pumps are defined as transferring heat from the cold source to the hot source by taking mechanical action from the outside.

Figure blew shows the thermal pump, which is a thermodynamic system operating in the role and transfer heat from the cold body to the hot body. To accomplish this, the heat pump takes up a work from the surrounding medium.

The performance of the thermal pump is expressed by the Coefficient of Performance

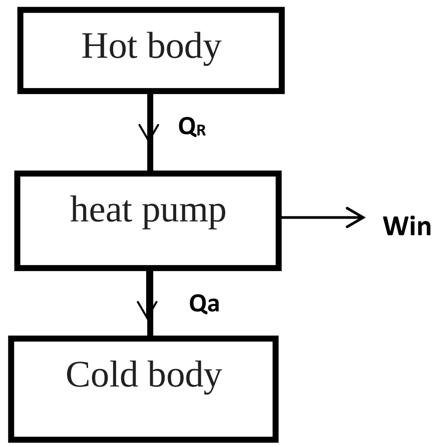
$$\textbf{C.O.P} = \frac{Qc}{Win} = \frac{Qc}{Q_h - Qc}$$

Where :

Q_c = Amount of heat absorbed by the heat pump from the cold body.

Q_h = Amount of heat expelled by the heat pump to the hot body.

W_{in}= The work required for the heat pump



Example: Household fridge, air conditioner

Carnot cycle

Carnot's cycle in physics and thermodynamics is one of the most famous dynamic reflex courses named after the French engineer Sadi Carnot (1796-1832).

Carnot's cycle is a theoretical thermocouple cycle that has a significant reflection in thermodynamics as it gives the maximum to get the work through a thermal cycle between two different degrees of heat. Through the Carnot cycle, the thermal efficiency of a particular machine can be calculated. That is, it gives us the part of the total thermal that we put into the machine to get them to work.

Through periodic reflections (Carnot cycle) the heat can be converted into a work because the amount of transformation in the state functions (internal energy - the entropy) is equal to zero.

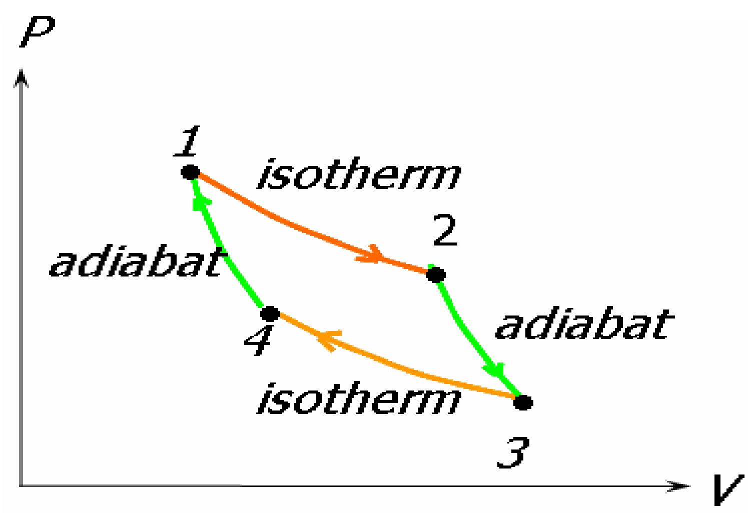
This cycle includes four steps that are reflective:

- 1 The process of extend by temperature stability.

2 - The process of extension adipatic.

- 3 compression by of temperature stability.

4 - The process of compression adipatic .



1- Process No. (1)

The gas expands at a When temperature is confirmed at high temperature of V_1 to V_2 and therefore performs a work .The heat escapes from the hot reservoir to the gas.

2 - Process No. (2)

The cylinder is isolated and the gas is allowed to expand adipatic from V_2 to V_3 (q = 0) and its temperature drops from T_2 to T_1 and the gas performs a work .

Since the gas is isolated, there is no heat exchange between it and the tank.

3 - process No. (3)

When the temperature is confirmed, the volume of the gas is reduced from V_3 to V_1 and thus the ocean performs a work at the expense of the gas and therefore a quantity of heat is transferred from the gas to the tank.

4- Process No. (4)

The gas is compressed backwards (in a large process) from V_4 to V_1 and the piston performs a work on the gas during the compression process.

Since steps 2 and 4 are numerically equal and different by signal , therefore they are equal and cancel each other and thus the work done at the cycle is:

$$W = W1 + W3$$

$$W2 = - Cv\ dT$$

$$W4 = Cv\ dT$$

$$W2 + W4 = - Cv\ dT + Cv\ dT = 0$$

$$\Delta E = q + W$$

$$- q = W$$

$$- q = - P\ dV$$

$$W1 = n\ RT \ln V2 / V1$$

$$W3 = n\ RT \ln V2 / V1$$

Questions

1. What is the primary function of a thermal machine?

a) To convert chemical energy into mechanical energy

b) To convert heat energy into work

c) To transfer heat from a cold source to a hot source

d) To store thermal energy

e) To heat a cold body without work output

2. What is the coefficient of performance (C.O.P) of a heat pump defined as?

a) The ratio of heat absorbed by the heat pump to the heat discharged by it

b) The ratio of work done by the pump to the heat absorbed

c) The ratio of heat absorbed from the cold body to the work input

d) The ratio of work input to the heat discharged to the hot body

e) The ratio of heat discharged to the work input

3. In the Carnot cycle, which of the following processes is characterized by an adiabatic expansion where no heat is exchanged?

a) Process 1 b) Process 2 c) Process 3 d) Process 4 e) None of the above

4. In a heat engine, which of the following represents the heat added from the hot body?

a) Qh b) Qc c) Wout d) Win e) Cv

5. During the Carnot cycle, the work produced is the result of the heat difference between which two bodies?

a) Two hot bodies

b) Two cold bodies

c) A hot body and a cold body

d) A hot body and the engine itself

e) A cold body and the surrounding environment

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Maxwell's equations and Thermodynamic Potentials

Lecture Eight

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Maxwell's equations and there application

The Maxwell relations are derived from Euler's reciprocity relation. The relations are expressed in partial differential form. The Maxwell relations consists of the characteristic functions: internal energy U, enthalpy H, Helmholtz free energy F, and Gibbs free energy G and thermodynamic parameters: entropy S, pressure P, volume V, and temperature T. Following is the table of Maxwell relations for secondary derivatives:

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_V$$

$$\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T$$

$$\left(\frac{\partial V}{\partial T}\right)_P = -\left(\frac{\partial S}{\partial P}\right)_T$$

Thermodynamic Potentials

Before we continue with Maxwell's relations we will briefly explain all the four thermodynamic potentials which are also known as the characteristic functions that form the base of Maxwell's relations.

Some quantity that is used to represent some thermodynamic state in a system is known as thermodynamic potential. Each thermodynamic potential gives a different measure of the “type” of the energy system. Here we will discuss four types of potentials that help derive the Maxwell thermodynamic relation.

Internal energy- the energy contained in a system is the internal energy of a system. This energy excludes any outside energy that comes due to external forces. It also excludes the kinetic energy of a system as a whole. Internal energy includes only the energy of the system, which is due to the motion, and interactions of the particles that make up the system.

Making use of the first law of thermodynamics, you can seek the differential form of the said internal energy:

$$dU = \delta Q + \delta W$$

$$dU = TdS - PdV$$

Enthalpy- the summation of internal energy and the product of volume and pressure gives enthalpy. The equation of enthalpy represents that the total heat content of a system is always the preferred potential to use when many chemical reactions are under study when such chemical reactions take place at a constant pressure. When the pressure here is constant, the change in the said internal energy is equal to the change in enthalpy of the system. The letter H represents the enthalpy.

$$H = U + PV$$

You can seek dH with the help of the above stated expression:

$$dH = dU + d(PV) =$$

$$dU + PdV + VdP$$

$$dH = TdS - PdV + PdV + VdP$$

$$dH = TdS + VdP$$

Helmholtz free energy- Helmholtz free energy is the difference between the internal energy of the system and the product of entropy and temperature. This equation represents the amount of useful work that can be easily obtained from a close system when the temperature and the volume are constant. The letter F in this equation represents the said Helmholtz free energy.

$$\mathbf{F = U - TS}$$

From which you can find the differential form of the said equation above

$$\mathbf{dF = dU - d(TS) = dU - TdS - SdT}$$

Substituting the differential form of the said internal energy (dU = TdS - PdV)

$$\mathbf{dF = TdS - PdV - TdS - SdT}$$

$$\mathbf{dF = -PdV - SdT}$$

Gibbs Free Energy - This thermodynamic potential is the last potential that helps to calculate the quantity of work a system can do at constant pressure and temperature. It is a very useful concept while studying phase transitions that happen during such conditions. Gibbs can be defined as the said difference between the enthalpy of a system as well as the product of entropy and temperature of the system. The letter G here given in the equation represents the said Gibbs free energy.

Thus**,** $\mathbf{G = H - TS}$

From which you can find the differential form of the said equation above:

$$\mathbf{dG = dH - d(TS) = dH - TdS - SdT}$$

Now, you need to substitute in the said differential form of the enthalpy (dH = TdS + VdP)

$$\mathbf{dG = TdS + VdP - TdS - SdT}$$

$$\mathbf{dG = VdP - SdT}$$

This Table Summarizes the Differential Forms of the Four Types of Thermodynamic Potentials:

Thermodynamic Potentials	The Derived Derivational Form	The Natural Variables
Internal Energy depicted by U	dU = TdS − PdV	S and V
Enthalpy depicted by H	dH = TdS + VdP	S and P
Helmholtz Free Energy as depicted by F	dF = −PdV − SdT	V and T
Gibbs Free Energy as depicted by Gd	G = VdP − SdT	P and T

Thermodynamic cycle Rule

A thermodynamic cycle consists of a linked sequence of thermodynamic processes that involve transfer of heat and work into and out of the system, while varying pressure, temperature, and other state variables within the system, and that eventually returns the system to its initial state.[1] In the process of passing through a cycle, the working fluid (system) may convert heat from a warm source into useful work, and dispose of the remaining heat to a cold sink, thereby acting as a **heat engine.** Conversely, the cycle may be reversed and use work to move heat from a cold source and transfer it to a warm sink thereby acting as a **heat pump**. If at every point in the cycle the system is in thermodynamic equilibrium, the cycle is reversible. Whether carried out reversible or irreversibly, the net entropy change of the system is zero, as entropy is a state function.

During a closed cycle, the system returns to its original thermodynamic state of temperature and pressure. Process quantities (or path quantities), such as heat and work are process dependent. For a cycle for which the system returns to its initial state the first law of thermodynamics applies:

$$\Delta U = E_{in} - E_{out} = 0$$

The above states that there is no change of the internal energy (U) of the system over the cycle. E in represents the total work and heat input during the cycle and E out would be the total work and heat output during the cycle. The repeating nature of the process path allows for continuous operation, making the cycle an important concept in thermodynamics. Thermodynamic cycles are often represented mathematically as quasistatic processes in the modeling of the workings of an actual device

Questions

1. Which thermodynamic potential represents the total heat content of a system at constant pressure?
a) Internal energy b) Helmholtz free energy c) Gibbs free energy
d) Enthalpy e) Temperature

Answer: d) Enthalpy

2. The differential form of internal energy (dU) is given by:
a) TdS + PdV b) TdS – PdV c) -PdV + VdP
d) TdS + VdP e) -PdV + SdT

Answer: b) TdS - PdV

3. What does Helmholtz free energy (F) represent in a system?
a) Heat released in a system at constant temperature
b) Work that can be obtained from a system at constant volume and temperature
c) Energy stored in a system d) Total heat content of a system
e) Energy released in a system at constant pressure

Answer: b) Work that can be obtained from a system at constant volume and temperature

4. Which thermodynamic potential is useful for studying phase transitions at constant pressure and temperature?
a) Enthalpy b) Helmholtz free energy c) Gibbs free energy
d) Internal energy e) Temperature

Answer: c) Gibbs free energy

5. What is the formula for Gibbs free energy (G)?
a) $G = U – TS$ b) $G = H – TS$ c) $G = H + TS$
d) $G = U + PV$ e) $G = TS - U$

Answer: b) $G = H - TS$

6. In a thermodynamic cycle, what is the net change in internal energy (ΔU)?
a) Zero b) positive c) Negative d) Undefine e) Equal to the work done

Answer: a) Zero

7. What is the Maxwell relation derived from the Helmholtz free energy?
a) $(\partial S/\partial V)_T = (\partial P/\partial T)_V$ b) $(\partial T/\partial V)_S = (\partial P/\partial S)_V$ c) $(\partial P/\partial T)_S = (\partial V/\partial T)_P$
d) $(\partial S/\partial T)_P = - (\partial V/\partial P)_T$ e) $(\partial T/\partial S)_P = - (\partial V/\partial P)_T$

Answer: d) $(\partial S/\partial T)_P = - (\partial V/\partial P)_T$

8. What is the differential form of the Gibbs free energy (dG)?
a) $dG = VdP - SdT$
b) $dG = TdS + PdV$
c) $dG = - PdV + SdT$
d) $dG = VdP + SdT$
e) $dG = - VdP - TdS$

Answer: a) $dG = VdP - SdT$

9. A thermodynamic cycle in which the system returns to its initial state after completing the cycle is known as:
a) Reversible cycle b) Irreversible cycle c) Heat engine
d) Heat pump e) Ideal cycle

Answer: a) Reversible cycle

10. The change in internal energy (ΔU) over a thermodynamic cycle is:
a) Equal to the heat added to the system b) Equal to the work done by the system
c) Zero d) Equal to the total work done in the cycle
e) The sum of all the heat inputs

Answer: c) Zero