Thermodynamics

Lecture : The First Law of Thermodynamics

th Class1Grade:

Dr.Haleemah Jaber Mohmmed

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The First Law of Thermodynamics

The change in internal energy of a closed system will be equal to the energy added to the system minus the work done by the system on its surroundings.

$$\Delta U = Q - W \quad (15\text{-}1)$$

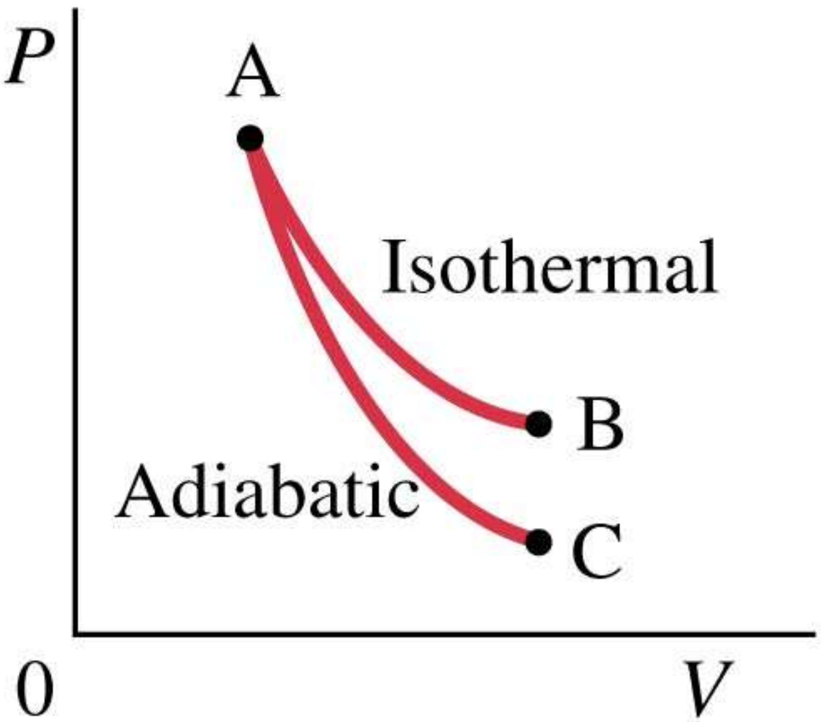
This is the law of conservation of energy, written in a form useful to systems involving heat transfer.

Thermodynamic Processes and the First Law

- **Adiabatic** – no heat transferred
- **Isothermal** – constant temperature
- **Isobaric** – constant pressure
- **Isochoric** – constant volume

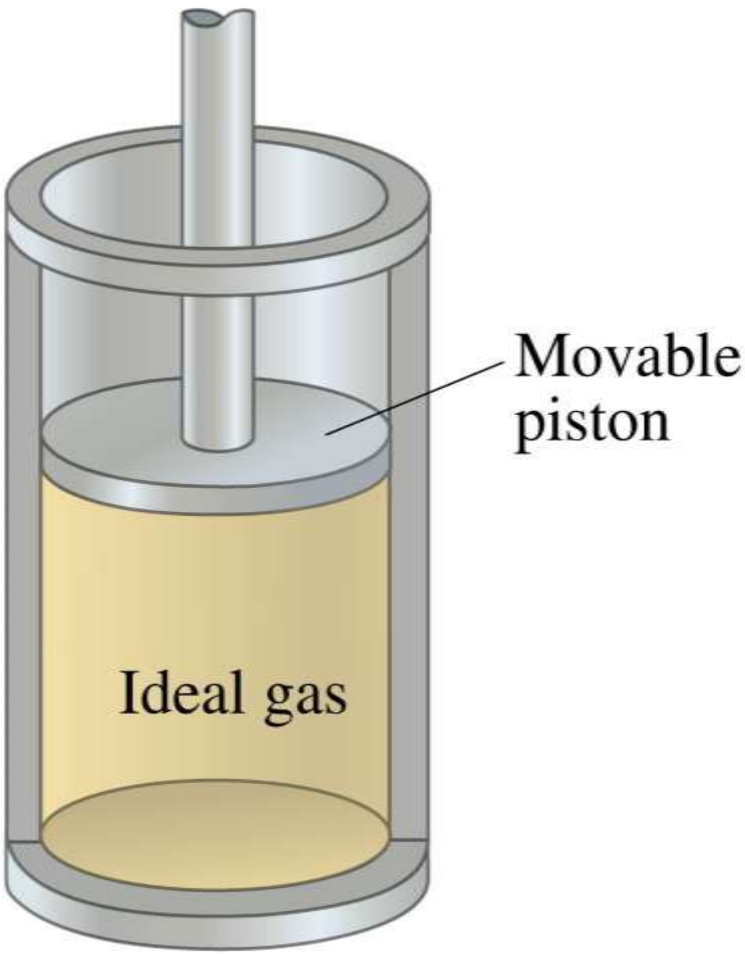
1- Adiabatic Process

An adiabatic process is one where there is no heat flow into or out of the system.

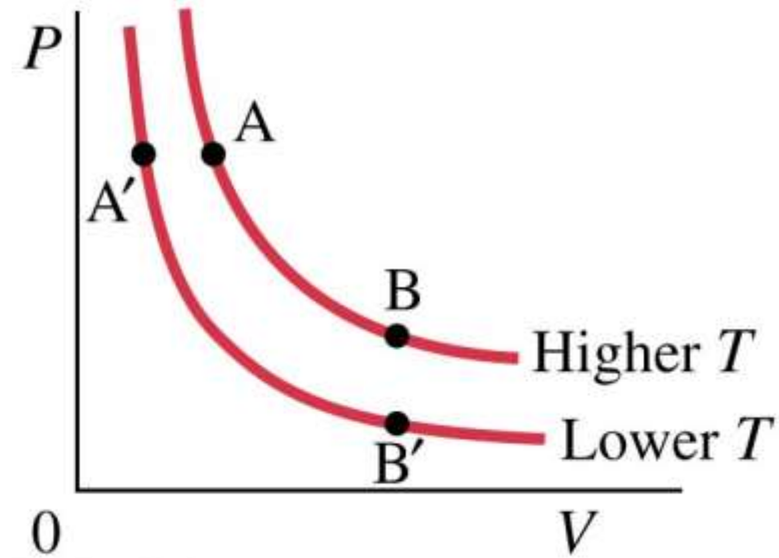


- An adiabatic process transfers no heat
  - therefore $Q = 0$
- $\Delta U = Q - W$
- When a system expands adiabatically, W is positive (the system does work) so ΔU is negative.
- When a system compresses adiabatically, W is negative (work is done on the system) so ΔU is positive.

2- An isothermal process



An isothermal process is one where the temperature does not change.



- An isothermal process is

a constant temperature process. Any heat flow into or out of the system must be slow enough to maintain thermal equilibrium

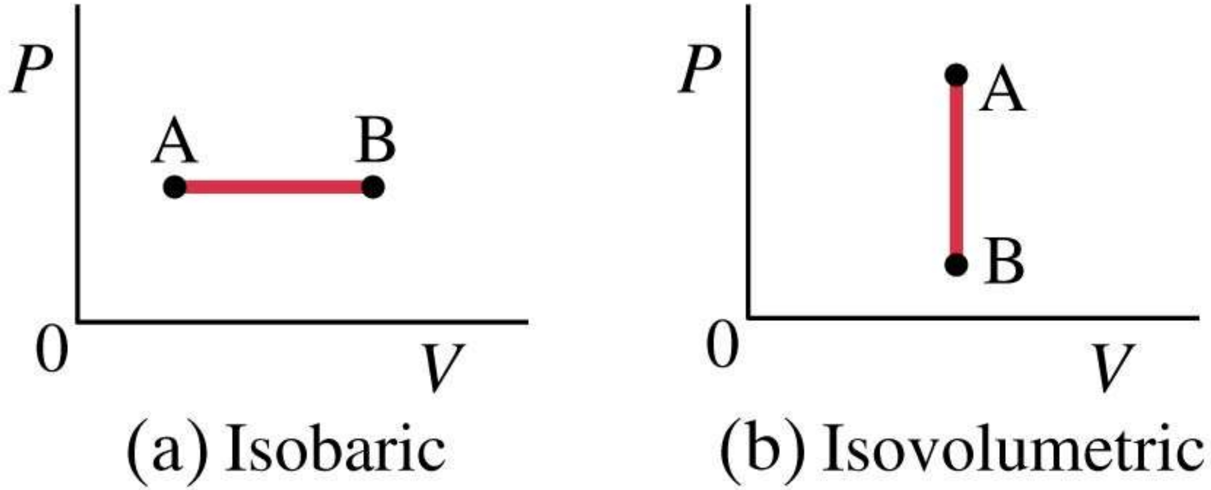
- For ideal gases, if ΔT is zero, $\Delta U = 0$
- Therefore, $Q = W$
  - Any energy entering the system (Q) must leave as work (W)

In order for an isothermal proces
to take place, we assume the system is in contact with a heat reservoir.

In general, we assume that the system remains in equilibrium throughout all processes.

3- An isobaric process (a)

An isobaric process (a) occurs at constant pressure; an isovolumetric one (b) at constant volume.



If the pressure is constant, the work done is the pressure multiplied by the change in volume:

$$W = P\,\Delta V. \qquad \text{[constant pressure]}$$

In an isometric process, the volume does not change, so the work done is zero.

- An isobaric process is a constant pressure process. ΔU, W, and Q are generally non-zero, but calculating the work done by an ideal gas is straightforward

$$W = P \cdot \Delta V$$

- Water boiling in a saucepan is an example of an isobar process

4- Isochoric Process

- An isochoric process is a constant volume process. When the volume of a system doesn’t change, it will do no work on its surroundings. $W = 0$

$$\Delta U = Q$$

- Heating gas in a closed container is an isochoric process

Thermodynamic Processes and the First Law

TABLE 15–1 Simple Thermodynamic Processes and the First Law

Process	What is constant:	The first law, $\Delta U = Q - W$, predicts:
Isothermal	T = constant	$\Delta T = 0$ makes $\Delta U = 0$, so $Q = W$
Isobaric	P = constant	$Q = \Delta U + W = \Delta U + P\,\Delta V$
Isovolumetric	V = constant	$\Delta V = 0$ makes $W = 0$, so $Q = \Delta U$
Adiabatic	$Q = 0$	$\Delta U = -W$

Human Metabolism and the First Law

If we apply the first law of thermodynamics to the human body:

$$\Delta U = Q - W \qquad (15\text{-}1)$$

we know that the body can do work. If the internal energy is not to drop, there must be energy coming in. It isn't in the form of heat; the body loses heat rather than absorbing it. Rather, it is the chemical potential energy stored in foods.

Heat Capacity

- The amount of heat required to raise a certain mass of a material by a certain temperature is called heat capacity

$$Q = mc_x\Delta T$$

- The constant c_x is called the specific heat of substance x, (SI units of J/kg·K)

Heat Capacity of Ideal Gas

- C_V = heat capacity at constant volume

$$C_V = 3/2\ R$$

- C_P = heat capacity at constant pressure

$$C_P = 5/2\ R$$

- For constant volume

$$Q = nC_V\Delta T = \Delta U$$

- **Example problems on the first law of thermodynamics**

Q1/ What is the name of an ideal-gas process in which no heat is transferred?

A. Isochoric
B. Isentropic
C. Isothermal
D. Isobaric
✔ **E. Adiabatic**

Q2/ Heat is

A. the amount of thermal energy in an object.

B. the energy that moves from a hotter object to a colder object. ✓

C. a fluid-like substance that flows from a hotter object to a colder object.

D. both A and B.

E. both B and C.

Q3/ The thermal behavior of water is characterized by the value of its

A. heat density.
B. heat constant.
✔ **C. specific heat.**
D. thermal index.

Q / 5000 J of heat are added to two moles of an ideal monatomic gas initially at a temperature of 500 K, while the gas performs 7500 J of work. What is the final temperature of the gas?

- <u>Solution</u>

$$\Delta U = Q - W = 5000\,J - 7500\,J = -2500\,J$$

$$\Delta U = -2500\,J = (3\ \ 2)\,nR\Delta T = (3\ \ 2)(2)(8.31)\Delta T$$

$$\rightarrow \Delta T = -100\,K$$

$$\rightarrow T_f = 500\,K - 100\,K - 400\,K$$

- *comment*: the gas does more work than it takes in as heat, so it must use 2500 J of its internal energy.

Q / Compute the internal energy change and temperature change for the two processes i mole of an ideal monatomic gas.

A- 1500 J of heat are added to the gas and the gas does no work and no work is done on the gas

B- 1500 J of work are done on the gas and the gas does no work and no heat is added or taken away from the gas

- Solution

- A

$$\Delta U = Q - W = 1500\,J - 0 = 1500\,J$$

$$\Delta U = 1500\,J = \left(3\ 2\right) nR\Delta T = \left(3\ 2\right)\left(1\right)\left(8.31\right)\Delta T$$

$$\rightarrow \Delta T = 120\,K$$

B

$$\Delta U = Q - W = 0 - \left(-1500\,J\right) = +1500\,J$$

$$\Delta U = 1500\,J = \left(3\ 2\right) nR\Delta T = \left(3\ 2\right)\left(1\right)\left(8.31\right)\Delta T$$

$$\rightarrow \Delta T = 120\,K$$

- Notice that in both processes, the change in internal energy is the same. We say that the internal energy is a “state function”. A state function depends only on the state of the system and not on the process that brings the system to that particular state.

Do You Have Any Questions?