

### 3.8: The First Law of Thermodynamics (Summary)

#### Key Terms

<b>adiabatic process</b>	process during which no heat is transferred to or from the system
<b>boundary</b>	imagined walls that separate the system and its surroundings
<b>closed system</b>	system that is mechanically and thermally isolated from its environment
<b>cyclic process</b>	process in which the state of the system at the end is same as the state at the beginning
<b>environment</b>	outside of the system being studied
<b>equation of state</b>	describes properties of matter under given physical conditions
<b>equilibrium</b>	thermal balance established between two objects or parts within a system
<b>extensive variable</b>	variable that is proportional to the amount of matter in the system
<b>first law of thermodynamics</b>	the change in internal energy for any transition between two equilibrium states is $\Delta E_{int} = Q - W$
<b>intensive variable</b>	variable that is independent of the amount of matter in the system
<b>internal energy</b>	average of the total mechanical energy of all the molecules or entities in the system
<b>isobaric process</b>	process during which the system's pressure does not change
<b>isochoric process</b>	process during which the system's volume does not change
<b>isothermal process</b>	process during which the system's temperature remains constant
<b>molar heat capacity at constant pressure</b>	quantifies the ratio of the amount of heat added removed to the temperature while measuring at constant pressure
<b>molar heat capacity at constant volume</b>	quantifies the ratio of the amount of heat added removed to the temperature while measuring at constant volume
<b>open system</b>	system that can exchange energy and/or matter with its surroundings
<b>quasi-static process</b>	evolution of a system that goes so slowly that the system involved is always in thermodynamic equilibrium
<b>reversible process</b>	process that can be reverted to restore both the system and its environment back to their original states together
<b>surroundings</b>	environment that interacts with an open system
<b>thermodynamic process</b>	manner in which a state of a system can change from initial state to final state
<b>thermodynamic system</b>	object and focus of thermodynamic study

#### Key Equations

Equation of state for a closed system	$f(p, V, T) = 0$
Net work for a finite change in volume	$W = \int_{V_1}^{V_2} p dV$
Internal energy of a system (average total energy)	$E_{int} = \sum_i (\bar{K}_i + \bar{U}_i) ,$

Internal energy of a monatomic ideal gas	$E_{int} = nN_A(\frac{3}{2}k_B T) = \frac{3}{2}nRT$
First law of thermodynamics	$\Delta E_{int} = Q - W$
Molar heat capacity at constant pressure	$C_p = C_V + R$
Ratio of molar heat capacities	$\gamma = C_p/C_V$
Condition for an ideal gas in a quasi-static adiabatic process	$pV^\gamma = \text{constant}$

## Summary

### 3.2 Thermodynamic Systems

- A thermodynamic system, its boundary, and its surroundings must be defined with all the roles of the components fully explained before we can analyze a situation.
- Thermal equilibrium is reached with two objects if a third object is in thermal equilibrium with the other two separately.
- A general equation of state for a closed system has the form  $f(p, V, T) = 0$ , with an ideal gas as an illustrative example.

### 3.3 Work, Heat, and Internal Energy

- Positive (negative) work is done by a thermodynamic system when it expands (contracts) under an external pressure.
- Heat is the energy transferred between two objects (or two parts of a system) because of a temperature difference.
- Internal energy of a thermodynamic system is its total mechanical energy.

### 3.4 First Law of Thermodynamics

- The internal energy of a thermodynamic system is a function of state and thus is unique for every equilibrium state of the system.
- The increase in the internal energy of the thermodynamic system is given by the heat added to the system less the work done by the system in any thermodynamics process.

### 3.5 Thermodynamic Processes

- The thermal behavior of a system is described in terms of thermodynamic variables. For an ideal gas, these variables are pressure, volume, temperature, and number of molecules or moles of the gas.
- For systems in thermodynamic equilibrium, the thermodynamic variables are related by an equation of state.
- A heat reservoir is so large that when it exchanges heat with other systems, its temperature does not change.
- A quasi-static process takes place so slowly that the system involved is always in thermodynamic equilibrium.
- A reversible process is one that can be made to retrace its path and both the temperature and pressure are uniform throughout the system.
- There are several types of thermodynamic processes, including (a) isothermal, where the system's temperature is constant; (b) adiabatic, where no heat is exchanged by the system; (c) isobaric, where the system's pressure is constant; and (d) isochoric, where the system's volume is constant.
- As a consequence of the first law of thermodynamics, here is a summary of the thermodynamic processes:
  - (a) isothermal:  $\Delta E_{int} = 0, Q = W$ ;
  - (b) adiabatic:  $Q = 0, \Delta E_{int} = -W$ ;
  - (c) isobaric:  $\Delta E_{int} = Q - W$ ; and
  - (d) isochoric:  $W = 0, \Delta E_{int} = Q$ .

### 3.6 Heat Capacities of an Ideal Gas

- For an ideal gas, the molar capacity at constant pressure  $C_p$  is given by  $C_p = C_V + R = dR/2 + R$ , where  $d$  is the number of degrees of freedom of each molecule/entity in the system.
- A real gas has a specific heat close to but a little bit higher than that of the corresponding ideal gas with  $C_p \simeq C_V + R$ .

### 3.7 Adiabatic Processes for an Ideal Gas

- A quasi-static adiabatic expansion of an ideal gas produces a steeper  $pV$  curve than that of the corresponding isotherm.
- A realistic expansion can be adiabatic but rarely quasi-static.

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