



IDX G10 Physics H

Study Guide Issue S1M2

By Hayley & Ziyu, Edited by Edward

NOTE: This is an official document by Indexademics. Unless otherwise stated, this document may not be accredited to individuals or groups other than the club IDX, nor should this document be distributed, sold, or modified for personal use in any way.

Contents:

1. 15.1 The First Law of Thermodynamics
2. 15.2 Thermodynamic Processes and the First Law
3. 15.4 + 15.7-9 Second Law of Thermodynamics and Entropy

15.1 The First Law of Thermodynamics

Key Concepts

- **Thermodynamics:** The branch of physics that studies the relationships between heat, work, and energy.
- **Heat (Q):** Energy transfer due to a temperature difference.
- **Work (W):** Energy transfer by mechanical means, not due to temperature difference.
- Internal Energy (U): The sum of all kinetic and potential energies of the molecules within a system (we assume PE = 0 for ideal gas).

The Zeroth Law

- **Statement:** If two systems are in thermal equilibrium with a third system, they are also in thermal equilibrium with each other.
- **Significance:** Establishes the concept of temperature and allows for temperature measurement.



By Ralph H Fowler in 1935

The First Law of Thermodynamics

- **Core Idea:** A generalization of the law of conservation of energy applied to thermodynamic systems.
- **Formula:** $\Delta U = Q - W$
 - ΔU = Change in the system's internal energy.
 - Q = Net heat added to the system.
 - W (or W_{by}) = Work done **by the system** on its surroundings.
- Sign Conventions:
 - $Q > 0$: Heat is added to the system (gains energy).
 - $Q < 0$: Heat is lost by the system (loses energy).
 - $W > 0$: The system does work on the surroundings (expends energy).
 - $W < 0$: Work is done on the system (gains energy).
- Alternative Form: $\Delta U = Q + W_{\text{on}}$, where W_{on} is work done **on the system**.

Extended Form (For Non-Stationary Systems)

- If the system is moving we consider kinetic (KE) and potential energy (PE):
- **Formula:** $\Delta KE + \Delta PE + \Delta U = Q - W$
- This accounts for changes in all forms of the system's energy.

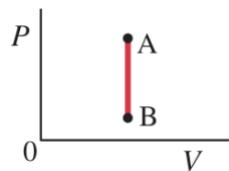
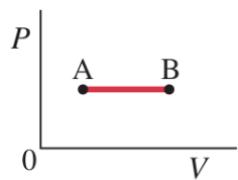
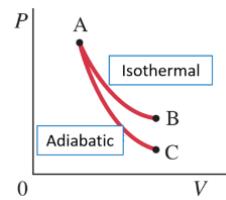
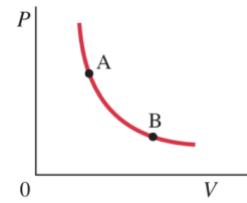
15.2 Thermodynamic Processes and the First Law

1. Work Done by/on a Gas

- Expansion (Gas increases volume):
 - $W_{\text{by}} > 0$ (Gas does positive work on the piston/surroundings).
 - $W_{\text{on}} < 0$ (Negative work done on the gas).
- Compression (Gas decreases volume):
 - $W_{\text{by}} < 0$ (Gas does negative work).
 - $W_{\text{on}} > 0$ (Positive work is done on the gas).

2. Types of Thermodynamic Processes

- Isothermal ($\Delta T = 0$):
 - Temperature constant.
 - For an ideal gas, $\Delta U = \frac{3}{2}nR\Delta T = 0$.
 - Therefore, $Q = W$ (All heat added becomes work done).
- Adiabatic ($Q = 0$):
 - No heat exchange with surroundings.
 - $\Delta U = -W$.
 - If gas expands adiabatically ($W > 0$), $\Delta U < 0$ and temperature decreases.
- Isobaric ($\Delta P = 0$):
 - Pressure constant.
 - Work done: $W = P\Delta V$.
 - Both Q and ΔU are generally non-zero.
- Isovolumetric/Isochoric ($\Delta V = 0$):
 - Volume constant.
 - $W = 0$ (No work done in volume change).
 - $\Delta U = Q$ (All heat change goes to internal energy).



3. Specific Heats of Gases

- c_v : Molar specific heat at constant volume.
- c_p : Molar specific heat at constant pressure.
- Why $c_p > c_v$?
 - At constant pressure, added heat (Q) must both increase internal energy (ΔU) and do work of expansion (W).

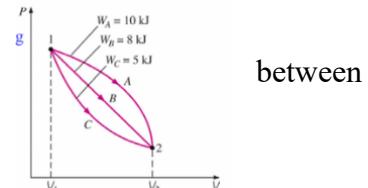
- At constant volume, no work is done, so all heat goes into increasing U. Therefore, less heat is required to raise the temperature by the same amount.

4. Work Done in Volume Changes (PV Diagrams)

- Work (W) for any process is the area under the curve on a PV diagram.
- Sign of Work:
 - Expansion (Volume increases): $W > 0$.
 - Compression (Volume decreases): $W < 0$.
- Closed Cycle (Loop):
 - Net work done = Area enclosed by the loop.
 - $\Delta U_{\text{cycle}} = 0$ (Returns to initial state).
 - Therefore, $Q_{\text{net}} = W_{\text{net}}$ for the entire cycle.
- Path Dependence: Work done depends on the path taken between two states, not just the endpoints.

5. Key Problem-Solving Steps

- (1) Identify the Process: Is it isothermal, adiabatic, isobaric, or isovolumetric? This determines Q, W, ΔU relationships.
- (2) Determine Known Variables: Note given P, V, T, n, Q, W, or ΔU .
- (3) Apply the First Law: $\Delta U = Q - W$.
- (4) Use Ideal Gas Law and Other Relations:
 - Ideal Gas Law: $PV = nRT$.
 - For monatomic ideal gas: $\Delta U = \frac{3}{2}nR\Delta T$ (or use $\Delta U = nc_v\Delta T$).
 - Work for constant pressure: $W = P\Delta V$.
- (5) For PV Diagrams: Calculate work as area under the curve (or enclosed area for cycles).



between

6. Common Example Types

- Boiling/Condensation: Use latent heat ($Q = mL$), calculate work $W = P\Delta V$, then find $\Delta U = Q - W$. Most heat goes into internal energy.
- Adiabatic Expansion/Compression: Use $Q = 0$ and $\Delta U = -W$ to link temperature change to work.
- Engine Cycles: Calculate net work from enclosed PV diagram area; net heat transfer equals net work.

15.4 + 15.7-9 Second Law of Thermodynamics

Statements of Second Law (all equivalent)

1. **Clausius statement:** No device is possible whose sole effect is to transfer heat from one system at a temperature T_L into a second system at a higher temperature T_H .
2. **Kelvin-Planck statement:** No device is possible whose sole effect is to transform a given amount of heat completely into work.
3. **Entropy:** A measure of the order or disorder of the system.

$$\Delta S = \frac{Q}{T}$$

- ΔS : the change in entropy S of a system
- T : absolute temperature in Kelvin (If the temperature varies → use average value of the temperature.)
- Q : the heat added to it by a reversible process at constant temperature
- The total entropy of an isolated system can never decrease. Only idealized (reversible) processes can have $\Delta S = 0$.
 - Real processes always have $\Delta S > 0$
- **The general statement of the second law of thermodynamics**
 - The total entropy of any system plus that of its environment increases as a result of any natural process.

4. **The second law of thermodynamics in terms of disorder:** Natural processes tend to move toward a state of greater disorder.

5. Unavailability of Energy

- As entropy increases, the energy in a system becomes less available to do useful work.
 - Because some of the energy is "trapped" in the increased disorder of the system, and it cannot be fully recovered or converted back into a more ordered state without external input of energy.
- **The second law of thermodynamics in terms of unavailability of energy:** In any natural process, some energy becomes unavailable to do useful work.

Heat Death of the Universe

- As time goes on, energy is degraded. It goes from more orderly forms (such as mechanical) eventually to the **least orderly form: internal, or thermal energy**.

- Heat death of the universe (热寂) could happen when all the energy of the universe would have **degraded to thermal energy**
 - Because thermal equilibrium is reached and doing useful work is no longer possible.

