



IDX G10 Physics H
Study Guide Issue S1M2
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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:** $\Delta U = Q + W_{on}$, 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.

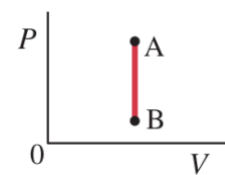
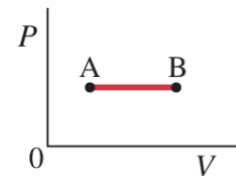
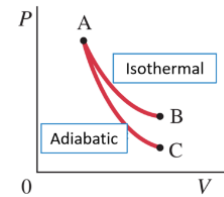
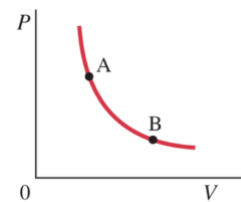
15.2 Thermodynamic Processes and the First Law

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).



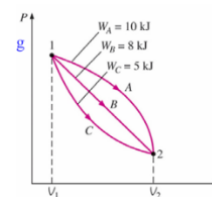
3. Specific Heats of Gases

- 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.



between

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).

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 \rightarrow 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.

