Subjective Question Bank

Chapter 1: History of Thermodynamics

Based on Course Notes

Preparation Strategy:
This document covers Short (2-3 Marks) and Long (5 Marks) answer type questions extracted from the history of thermodynamics. It covers the evolution from Galileo's thermoscope to Caratheodory's rigorous mathematical formulation.

Quick Revision: Key Timeline

- **1600s: Galileo** invents the thermoscope (limited by atmospheric pressure).
- **1770s: Joseph Black** distinguishes Heat vs. Temperature; Caloric Theory proposed.
- **1798: Count Rumford** challenges Caloric theory (Cannon boring experiment).
- **1824: Sadi Carnot** introduces the concept of the "Cycle" and reversibility.
- **1840s: Joule** & **Mayer** establish the First Law (Work-Heat Equivalence).
- **1850s: Clausius** & **Kelvin** formulate the Second Law.
- **1909: Caratheodory** provides a rigorous mathematical structure (Adiabatic walls).

1 Short Answer Type Questions (2–3 Marks)

Q1. Describe Galileo's Thermoscope and its primary limitation. [2–3 Marks]

Solution:

- **Construction:** In roughly 1600, Galileo took a glass vessel (size of a hen's egg) fitted with a long narrow tube. He heated the bulb and inverted it into a vessel of water. As the bulb cooled, water rose in the tube.
- **Operation:** It measured "degrees of heat and cold" based on the height of the water column.
- **Limitation:** The instrument was essentially a barometer as well as a thermometer. Because the water level depended on **atmospheric pressure** variations, it could only be used to compare temperatures within very short intervals of time.

Q2. Differentiate between the physiological sensation of heat and the concept of thermal equilibrium. [2–3 Marks]

Solution:

- **Physiological Sensation:** Human touch is inadequate for measuring temperature. For example, a block of copper feels colder than a block of wood in winter, even if both are at the same temperature, due to differences in thermal conductivity.
- **Equilibrium Concept:** This is the principle that all bodies exposed to the same environment (e.g., severe winter cold) will ultimately attain a **uniform degree of coldness** (temperature), regardless of how they feel to the touch.

Q3. Who was Joseph Black, and what was his major contribution to Thermodynamics? [2–3 Marks]

Solution: Joseph Black (University of Glasgow, 1770) was a pioneer who:

1. Made a sharp distinction between **Temperature** (intensity) and the **"Influence"** transferred (Heat).
2. Showed that mixing equal masses of different liquids resulted in varying final temperatures (concept of specific heat).
3. Discovered that temperature is not conserved during phase changes (ice to water), leading to the concept of **Latent Heat**.

Q4. Define the "Caloric Theory" and list two of its postulates. [2–3 Marks]

Solution: The Caloric Theory was a conservation principle assuming heat was a material substance called "Caloric." **Postulates (Any two):**

- Caloric is an **elastic fluid** whose particles repel each other strongly.

- Caloric is **indestructible** and cannot be created (Conservation of Caloric).
- Caloric has weight (assumed from calcination experiments).

Q5. What is a Thermodynamic Cycle and why is it important in engineering? [2–3 Marks]

Solution:

- **Definition:** Introduced by Sadi Carnot in 1824, a cycle is a process or series of processes that leaves no net change in the condition of the system (the system returns to its initial state).
- **Importance:** It is critical for engineering because, unlike acyclic processes, cycles allow for the construction of **compact machines** that can operate continuously for long hours.

Q6. What was the "gap in the armor" of the Caloric Theory? [2–3 Marks]

Solution: The major flaw in the Caloric Theory was its inability to explain the **heating effect of friction**.

- Caloric proponents argued friction merely squeezed caloric out of material.
- Experiments (Rumford) showed the heat generated by friction was **inexhaustible**, contradicting the idea that caloric was a finite material substance stored in a body.

Q7. State Caratheodory's version of the Second Law of Thermodynamics. [2–3 Marks]

Solution: In 1909, Constantin Caratheodory presented a rigorous mathematical structure for thermodynamics. His statement of the Second Law is:
"In the neighborhood of any prescribed initial state, there are states which cannot be reached by an adiabatic process."

2 Long Answer Type Questions (5 Marks)

Q1. Explain the "Theory of Caloric" in detail. How did it account for observed physical phenomena? [5 Marks]

Solution: The "Theory of Caloric" was the dominant theory of heat in the 18th century, formally postulated by William Cleghorn. It treated heat as a material fluid.
The Five Postulates:

1. **Elastic Fluid:** Caloric is a fluid where particles repel one another strongly (explains gas expansion).
2. **Attraction to Matter:** Caloric particles are attracted to ordinary matter in different degrees (explains different specific heats).
3. **Conservation:** Caloric is indestructible and cannot be created.
4. **States:** Caloric is either *Sensible* (detectable by temperature) or *Latent* (combined chemically during phase change).
5. **Weight:** Caloric has weight.

Explanation of Phenomena: These postulates were ingeniously used to explain:

- **Expansion:** The self-repulsion of caloric pushed matter apart when heated (Postulate 1).
- **Latent Heat:** Black's discovery of constant temperature during melting was explained by caloric combining chemically with solids to form liquids (Postulate 4).
- **Calcination:** The gain in weight of metals when heated was attributed to the weight of the added caloric (Postulate 5).

Q2. Discuss Count Rumford's Cannon-Boring experiments and how they disproved the Caloric Theory. [5 Marks]

Solution: Context: The Caloric Theory stated that heat was a conserved material fluid. Friction was explained by saying that rubbing "squeezed" caloric out of a body, much like water from a sponge.
Rumford's Experiments: Count Rumford (Benjamin Thompson) conducted experiments while boring cannons at the arsenal in Munich.

- **Observation 1 (Weight):** He showed that caloric appeared to be weightless, contradicting the postulate that caloric had mass.
- **Observation 2 (Specific Heat):** He showed that the metal shavings (chips) produced by friction had the *same* heat capacity as the solid native metal. If caloric had been "squeezed out," the shavings should have had a different capacity.
- **Observation 3 (The Crucial Proof):** He submerged the cannon bore in water and used a blunt borer. The water eventually boiled. Rumford noted that the source of heat generated by friction was **inexhaustible**. As long as work was put in (rubbing), heat was produced.

Conclusion: Rumford concluded: *"Anything which any insulated body... can continue* *to furnish without limitation cannot possibly be a material substance."* This paved the way for the concept of heat as a form of motion/energy.

Q3. Trace the development of the First and Second Laws of Thermodynamics from Carnot to Clausius. [5 Marks]

Solution: The classical laws evolved through the conflict between the Caloric theory and the Mechanical theory of heat.

1. Sadi Carnot (1824):

- Introduced the **Cycle** and the concept of **Reversibility**.
- Proposed that a reversible engine is the most efficient.
- *Flaw:* He based his arguments on the conservation of Caloric (heat is not consumed, merely dropped from high to low temp).

2. Joule and Mayer (1840s - First Law):

- **Mayer** suggested the convertibility of heat to work.
- **Joule** experimentally proved that Work and Heat are equivalent. He showed that the work required to change a state is independent of the path (Mechanical, Electrical, etc.). This contradicted Caloric conservation.

3. The Conflict & Resolution (Clausius - 1850):

- Kelvin pointed out the conflict: Carnot said heat is conserved (Caloric); Joule said heat is converted to work.
- **Rudolf Clausius** reconciled them. He kept Carnot's principle (Reversibility/Efficiency) but abandoned Caloric theory.
- **Outcome:** Clausius formulated that in a cycle, heat *is* converted to work (agreeing with Joule), but not all heat can be converted. This established the **First Law** (Energy Conservation) and laid the foundation for the **Second Law** (Entropy/Efficiency limits) as independent principles.

Q4. Write a note on the contributions of Maxwell, Planck, and Caratheodory to the structure of Thermodynamics. [5 Marks]

Solution: James Clerk Maxwell (1860s):

- Clarified the definition of Temperature.
- Stated the principle of mutual equilibrium between bodies, which we now recognize as the **Zeroth Law of Thermodynamics**.
- *Note:* He had some confusion regarding "stored heat" vs "stored energy," which later scientists corrected.

Max Planck (1897):

- Solidified the Second Law by connecting it to **reversibility**.

- Stated the Second Law as the impossibility of a cyclic device that produces positive work while exchanging heat with a single reservoir (Perpetual Motion Machine of the Second Kind).

Constantin Caratheodory (1909):

- Moved away from "Heat engines" and "Cycles" to a purely mathematical axiomatic approach.
- Defined the laws using the concept of the **Adiabatic Wall**.
- His First Law focuses on the increment of an extensive property (Energy) equal to work in an adiabatic process.
- His work removed "Heat" as a primary undefined quantity, treating it as a derived concept from Work and Energy.