Thermodynamic Cycles

Introduction

A **thermodynamic cycle** is a sequence of processes that return a system to its initial state, while producing work or transferring heat. Cycles are the backbone of engines, refrigerators, and power plants.

Key Concepts

- State Functions and Cycles
- Refrigeration Cycles
- Efficiency

Definitions

- **Cycle:** A process or set of processes that brings a system back to its starting point.
- **Heat Engine:** Converts heat into work by operating between two temperature reservoirs.
- **Refrigerator/Heat Pump:** Uses work to move heat from low temperature to high temperature.

The First Law for Cycles

As we know, state functions do not depend on the path taken, but rather the starting and ending point. The definition of a cycle is a process that starts and ends at the same spot. This tells us that any state function (Internal Energy) will have no change. Path functions however, will have an assoicated change.

$$\Delta U_{cycle} = 0 \quad \Rightarrow \quad W_{net} = -Q_{net}$$

This means the net work out of a cycle equals the net heat transferred in.

The Carnot Cycle

The **Carnot cycle** is the idealized, reversible cycle operating between T_H and T_C ($T_H > T_C$). It consists of:

(i) Isothermal expansion at T_H

(ii) Adiabatic expansion (temperature drops from T_H to T_C)

(iii) Isothermal compression at T_C

(iv) Adiabatic compression (temperature rises from T_C to T_H)

Efficiency

We will learn later that no process is able to achieve 100% efficiency. This is due to both the 2nd and 3rd laws. However, the Carnot cycle is the closest we are able to get to that point. For Carnot cycles the efficiency is:

$$\eta = 1 - \frac{Q_c}{Q_h} = 1 - \frac{T_c}{T_h}$$

For real cycles:

$$\eta = \frac{W_{net}}{Q_{in}} \quad \leq \quad \eta_{Carnot}$$

Carnot cycles set the upper bound on performance.

Recap

Thermodynamic cycles allow for repeated work extraction or heat transfer. The Carnot cycle defines the ideal limit, showing efficiency depends only on the two reservoir temperatures. Every real engine is a worse version of Carnot.