CHE 260 Lecture Notes

Hei Shing Cheung

Thermodynamics and Heat Transfer, Fall 2025 CHE260

The up-to-date version of this document can be found at `https://github.com/HaysonC/skulenotes`

"If there is one word that describes this class it would be ***energy****."*

Chapter 1

Thermodynamics

1.1 Systems and Properties in Thermodynamics

Definiton 1.1.0.1 (Energy)**.** You should have learned that energy is the ability to do work.

Definiton 1.1.0.2 (Work)**.** You also learned that work is the transfer of energy.

We have a problem. The above two definitions are in terms of each other. This touches on the theory of fundamental concepts:

Fundamental Concepts For example, the following are fundamental concepts in physics:

- Time
- **Mass** Interestingly, we don't measure mass directly; instead, we measure weight, which is the force exerted by gravity on an object, and from that we deduce mass.
- Space

In this course, we are going to explore two:

- **Energy** Energy is pretty familiar to us.

- **Entropy** Entropy is what gives students the most trouble; you can't show someone a picture of entropy, it is abstract.

These fundamental concepts are in arbitrary units and form the foundation 'axioms' in science.

1.1.1 Energy

Energy An understanding of energy is its ability to **lift weights**. This is a way we could test if there is energy.

Example 1.1.1.1 (Potential Energy)**.** A 1 kg mass lifted 1 meter has a potential energy of about 10 J. Imagine that it is attached to a balance, with a small mass on the other side, then, it is able to lift that weight.

Example 1.1.1.2 (Kinetic Energy)**.** Given a flying ball that hits a lever with a mass rested on it, given the appropriate angle, the ball can transfer its kinetic energy to the mass, causing it to lift.

Example 1.1.1.3 (Heat)**.** Given a gas in a container, if we heat the gas, it expands and lifts objects on top of it.

Example 1.1.1.4 (Newcomen Engine)**.** The above example is actually a simplified representation of how the Newcomen engine operates. In the Newcomen engine, steam is used to create a vacuum that lifts a piston, demonstrating the conversion of thermal energy into mechanical work.

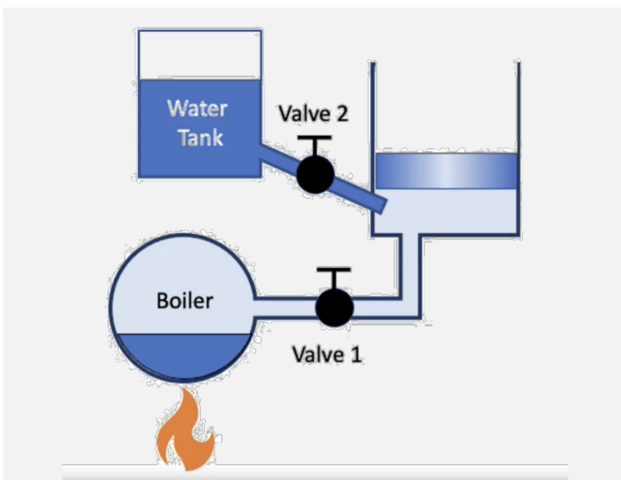

Figure 1.1: A Newcomen Engine

When Valve 1 opens, steam fills the chamber and lifts up the piston. When Valve 2 opens (with valve 1 closes), water gets sprayed, evaporates, and condenses, causing the piston to lower.

However, the Newcomen engine is not the most efficient steam engine, most heat is lost in the heating and cooling process. Solution? A external condenser was added to improve efficiency by cooling the steam and creating a vacuum, allowing the piston to be pulled down more effectively. This is the **Watt Engine**.

Steam Cycle The steam cycle is a thermodynamic cycle that converts heat energy into mechanical work. It consists of four main processes:

1. **Heating** - The working fluid (steam) is heated in the boiler, converting water into steam and increasing its energy.
2. **Expansion** - The high-pressure steam expands in the piston, doing work on the piston and converting thermal energy into mechanical work.
3. **Cooling** - The steam is cooled in the condenser, releasing heat to the surroundings and condensing back into water.
4. **Compression** - The water is pumped back into the boiler, completing the cycle.

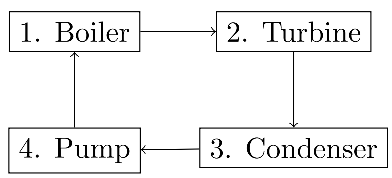

Figure 1.2: Steam Cycle Diagram

Definiton 1.1.1.5 (Heat Engine)**.** A heat engine is a device that converts thermal energy into mechanical work. It operates by taking in heat from a high-temperature source, performing work using that heat, and then releasing some waste heat to a low-temperature sink. The steam engine is a classical instance of a heat engine.

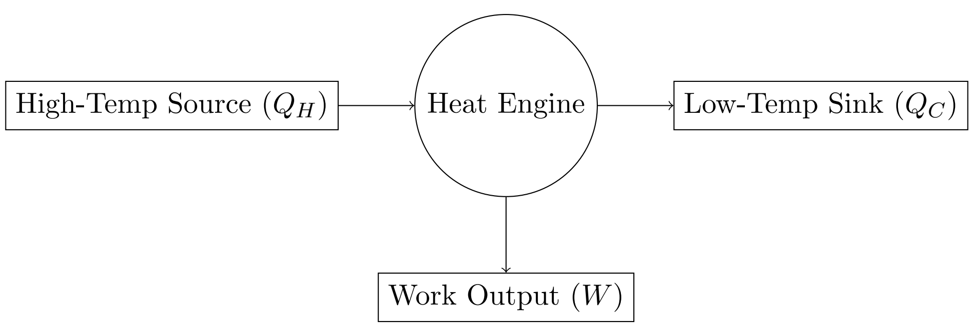

Figure 1.3: A Heat Engine

Efficiency of a Heat Engine The efficiency of a heat engine is defined as the ratio of the work output to the heat input:

$$\eta = \frac{W}{Q_H} \tag{1.1}$$

Obviously, the best engine is when η is maximized (W is maximized, and Q_H is minimized). For example, a Newcomen engine has a low efficiency ($\eta \approx 0.34\%$), while a classic watt engine has a higher efficiency ($\eta \approx 4\%$). The modern powerplant is optimized such that it has $\eta \approx 30\%$.

This begs the question, can we create a heat engine with 100% efficiency (i.e., $Q_C = 0$)? The answer is no, due to the second law of thermodynamics [Sadi Carnot (1830)]. For now, consider the wasted energy Q_c.

Irreversibility and Spontaneity The process of losing heat is spontaneous and irreversible. Once heat is lost to the cooler surroundings, it cannot be completely recovered and converted back into work, however, the process of bringing heat from a cooler body to a hotter body is non-spontaneous and requires external work (e.g., a refrigerator). These give rise to the concept of irreversibility in thermodynamic processes, from the laws of thermodynamics.

The first law of thermodynamics is simple and easy to understand:

Definiton 1.1.1.6 (First Law of Thermodynamics)**.** The first law of thermodynamics states that energy cannot be created or destroyed, only transformed from one form to another. In the context of a heat engine, this means that the work output (W) is equal to the heat input (Q_H) minus the heat rejected (Q_C):

$$W = Q_H - Q_C \tag{1.2}$$

The second law formalizes the concept of the directionality of thermodynamic processes, stating that heat cannot spontaneously flow from a colder body to a hotter body. This law introduces the idea of entropy, a measure of the disorder or randomness in a system, which tends to increase over time in isolated systems.

Definiton 1.1.1.7 (Second Law of Thermodynamics)**.** The second law of thermodynamics states that the total entropy of an isolated system can never decrease over time. We consdier entropy as:

$$S = \frac{Q}{T} \tag{1.3}$$

In the above example, we can see that entropy increases as heat is transferred from the hot reservoir to the cold reservoir:

$$\Delta S = S_{\text{final}} - S_{\text{initial}} = \frac{Q_C}{T_C} - \frac{Q_H}{T_H} > 0$$

Since $Q_C = Q_H$ in a closed system and $T_H > T_C$, we have $\Delta S > 0$.

1.1.2 Modeling Ideal Gas

Definiton 1.1.2.1 (Ideal Gas)**.** We consider ideal gas conditions as those where the gas particles do not interact with each other except during elastic collisions, and the volume of the gas particles themselves is negligible compared to the volume of the container. In this course, we consider 1 atm as the threshold for ideal gas behavior. Of course, ideal gas obey the ideal gas law:

$$PV = nRT \tag{1.4}$$

1.1.3 Systems and States

Definiton 1.1.3.1 (System)**.** Any piece of matter or a region of space.

Chapter 2

Heat Transfer