Physics 467/667: Thermal Physics **Spring 2019**

Lecture 13: Engines and Refrigerators

Lecturer: Qiang Zhu *Scribes: scribe-name1,2,3*

13.1 Heat Engines and Refrigerators

A heat engine is any device that absorbs heat and converts part of that energy into work. Unfortunately, only part of the energy absorbed as heat can be converted to work. The reason is that the heat, as it flows in, brings along entropy, which must somehow be disposed as waste.

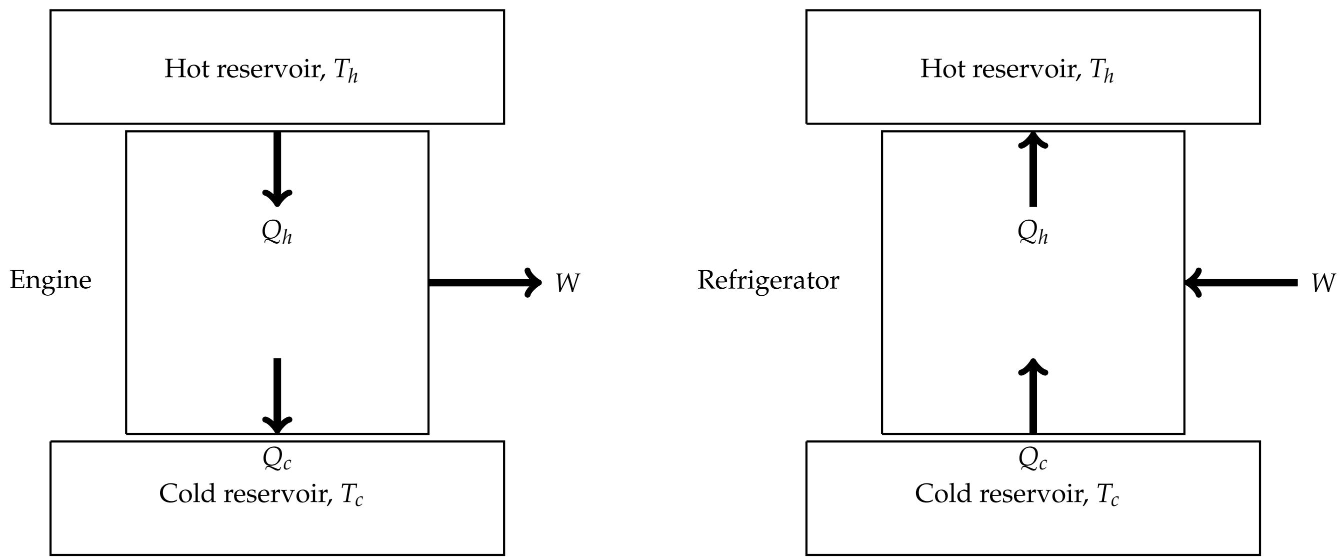


Figure 13.1: The schemes of cold and heat engines.

The benefit of a heat engine is the work produced, W. Let's define the efficiency e,

$$e = \frac{W}{Q_h} \tag{13.1}$$

Because of the 1st law,

$$Q_h = Q_c + W \tag{13.2}$$

$$e = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h} \tag{13.3}$$

According to the definition of entropy,

$$S2 \geq S1 \qquad \rightarrow \qquad \frac{Q_c}{T_c} \geq \frac{Q_h}{T_h} \qquad \rightarrow \qquad \frac{Q_c}{Q_h} \geq \frac{T_c}{T_h} \tag{13.4}$$

Therefore, we conclude

$$e \leq 1 - \frac{T_c}{T_h} \tag{13.5}$$

13.2 Refrigerator

The benefit of a refrigerator is Q_c. Let's define the efficiency e,

$$e = \frac{Q_c}{W} \tag{13.6}$$

Because of the 1st law,

$$Q_h = Q_c + W \tag{13.7}$$

$$e = \frac{Q_c}{Q_h - Q_c} = \frac{1}{Q_h/Q_c - 1} \tag{13.8}$$

According to the entropy relation,

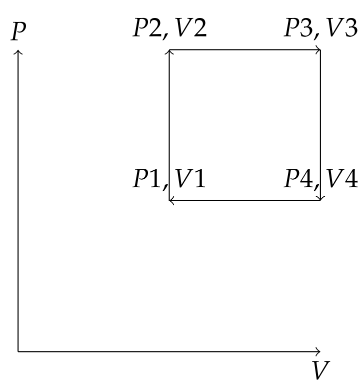
$$S2 \geq S1 \quad \rightarrow \quad \frac{Q_h}{T_h} \geq \frac{Q_c}{T_c} \quad \rightarrow \quad \frac{Q_h}{Q_c} \geq \frac{T_h}{T_c} \tag{13.9}$$

Therefore, we conclude

$$e \leq \frac{1}{T_h/T_c - 1} \tag{13.10}$$

13.3 To calculate the efficiency

Suppose 1 mol He undergoes the following cycles, in which $P_2 = 2P_1$, V_4=$2V_1$. Calculate the heat transfer (Q) for each step, and the efficiency of the engine.



13.4 The Carnot Cycle

How to avoid an increase in entropy?
In order to avoid entropy's increase, we need to

1. keep $T_h = T_{\text{gas}}$ and $T_c = T_{\text{gas}}$ during heat transfer;
2. In the course of temperature dropping from T_h and T_c, we use adiabatic conditions to avoid heat waste.

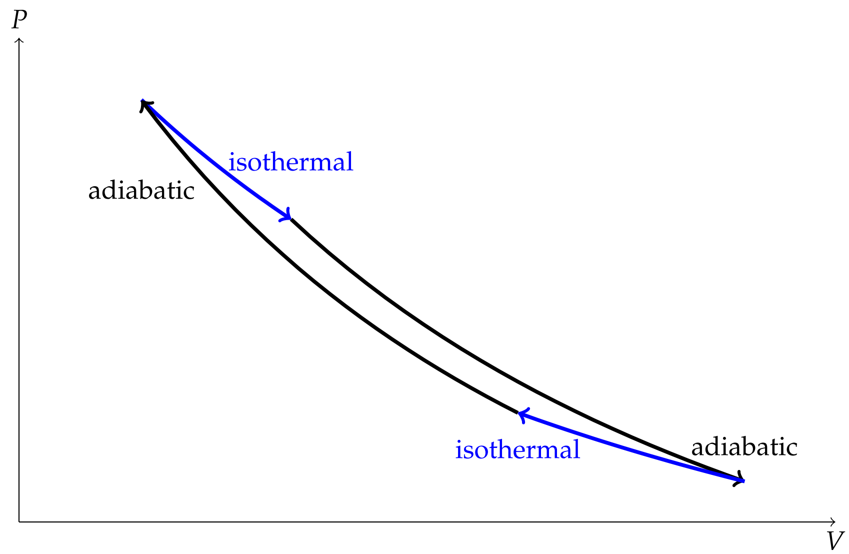


Figure 13.2: The Carnot cycle.

Exercises

1. Why must you put an air conditioner in the window of a building, rather than in the middle of a room?
2. Can you cool off your kitchen by leaving the refrigerator door open?
3. Prove that the efficiency of a Carnot engine is 1-$\frac{T_c}{T_h}$

13.5 Homework

Problem 4.2, 4.3, 4.11