3.3: Heat Engines

The emphasis of this course is on the properties of matter. This section is independent of the properties of matter! It is included because:

1. historically important

2. expected coverage (e.g. for GRE)

3. important from an applications and engineering standpoint (See, for example, "Hurricane heat engines" by H.E. Willoughby, *Nature* **401** (14 October 1999) 649–650. Or "A thermoacoustic Stirling heat engine" by S. Backhaus and G.W. Swift, *Nature* **399** (27 May 1999) 335–338, and "Traveling-wave thermoacoustic electric generator," by S. Backhaus, E. Tward, and M. Petach, *Applied Physics Letters* **85** (9 August 2004) 1085–1087, concerning an engine that might replace nuclear thermal power sources in deep space missions.)

4. fascinating

This section follows Reif sections 3.1 and 5.11.

Heat engines do not include electrical and chemical engines (such as muscles). The Carnot theorems don't apply to them. The name Carnot is French, so it is pronounced "Car-no" rather than "Car-not".

Problems

3.6 (I) The Carnot cycle*

Describe the Carnot cycle. Always means quasistatic. Take this order:

1. Expand at constant $T = T_1$ from A to B, decreasing pressure. Absorb heat q_1 from high-temperature heat bath.

2. Expand even more, adibatically, from B to C, decreasing pressure still more.

3. Contract at constant $T = T_2$ from C to D, increasing pressure. Expel heat q_2 into low-temperature heat bath.

4. Contract even more, adibatically, increasing pressure still more, until system comes back to original state A.

3.7 (E) The Carnot cycle

(This problem is stolen from a GRE Physics test.)

The p-V diagram for a quasistatic Carnot cycle is shown in Reif page 189. Legs bc and da represent isotherms, while ab and cd represent adiabats. A system is carried through the cycle abcd, taking in heat q_1 from the hot reservoir at temperature T_1 and releasing heat q_2 to the cold reservoir at temperature T_2. Which of the following statements is false?

a. $q_1/T_1 = q_2/T_2$.

b. The entropy of the hot reservoir decreases.

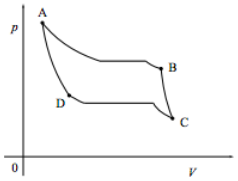
c. The entropy of the system increases.

d. The work w is equal to the net heat absorbed, $q_1 - q_2$.

e. The efficiency of the cycle is independent of the working substance.

3.8 (D) The liquifying Carnot cycle

Suppose a quasistatic Carnot cycle is executed with a working substance of steam rather than ideal gas. Furthermore, suppose that the cycle straddles the liquid-vapor coexistence curve, so that when the working substance is at a high volume and low pressure it is steam, but when it is at a low volume and high pressure it is liquid water. Then the (p, V) diagram of the cycle resembles the following:



a. Explain the significance of the flat portions of the isotherms.

b. Of the four points A, B, C, and D, which represent liquid and which represent gas?

c. Below is a list of properties of the Carnot cycle executed with an ideal gas. Which of these properties remain true for our liquifying Carnot cycle?

i. The efficiency is $1 - T_1/T_2$.

ii. The adiabats BC and DA are described by pV^γ = constant.

iii. The work done is the area enclosed by the cycle.

iv. More.
