Problem 1

Kittel & Kroemer, Chapter 8, problem 1 [Heat Pump.]

(a): 1 point

Show that for a reversible heat pump the energy required per unit of heat delivered inside the building is given by the Carnot efficiency (6):

$$\frac{W}{Q_h} = \eta_C = \frac{\tau_h - \tau_l}{\tau_h}.$$

What happens if the heat pump is not reversible?

(b): 1 point

Assume that the electricity consumed by a reversible heat pump must itself be generated by a Carnot engine operating between the temperatures τ_{hh} and τ_l. What is the ratio Q_{hh}/Q_h, of the heat consumed at τ_{hh}, to the heat delivered at τ_h? Give numerical values for $T_{hh} = 600$ K; $T_h = 300$ K; $T_l = 270$ K.

(c): 1 point

Draw an energy-entropy flow diagram for the combination heat engine-heat pump, similar to Figures 8.1, 8.2 and 8.4, but involving no external work at all, only energy and entropy flows at three temperatures.

Problem 2

Kittel & Kroemer, Chapter 8, problem 2 [Absorption Refrigerator.]

In absorption refrigerators the energy driving the process is supplied not as work, but as heat from a gas flame at a temperature $\tau_{hh} > \tau_h$. Mobile home and cabin refrigerators may be of this type, with propane fuel.

(a): 1 point

Give an energy-entropy flow diagram similar to Figures 8.2 and 8.4 for such a refrigerator, involving no work at all, but with energy and entropy flows at the three temperatures $\tau_{hh} > \tau_h > \tau_l$.

(b): 1 point

Calculate the ratio Q_l/Q_{hh}, for the heat extracted at $\tau = \tau_l$, where Q_{hh} is the heat input at $\tau = \tau_{hh}$. Assume reversible operation.

Problem 3

Kittel & Kroemer, Chapter 8, problem 3 [Photon Carnot engine.] Consider a Carnot engine that uses as the working substance a photon gas.

(a): 1 point

Given t_h and τ_l as well as V_1 and V_2, determine V_3 and V_4.

(b): 1 point

What is the heat Qh taken up and the work done by the gas during the first isothermal expansion? Are they equal to each other, as for the ideal gas?

(c): 1 point

Do the two isentropic stages cancel each other, as for the ideal gas?

(d): 1 point

Calculate the total work done by the gas during one cycle. Compare it with the heat taken up at τ_h and show that the energy conversion efficiency is the Carnot efficiency.

Problem 4

Kittel & Kroemer, Chapter 8, problem 4 [Heat engine-refrigerator cascade]: 2 points

The efficiency of a heat engine is to be improved by lowering the temperature of its low-temperature reservoir to a value τ_r, below the environmental temperature τ_l, by means of a refrigerator. The refrigerator consumes part of the work produced by the heat engine. Assume that both the heat engine and the refrigerator operate reversibly. Calculate the ratio of the net (available) work to the heat Q_h supplied to the heat engine at temperature τ_h. ls it possible to obtain a higher net energy conversion efficiency in this way?

Problem 5

Kittel & Kroemer, Chapter 8, problem 5 [Thermal pollution]: 2 points

A river with a water temperature $T_l = 20^\circ$ C is to be used as the low temperature reservoir of a large power plant, with a steam temperature of $T_h = 500^\circ$ C. If ecological considerations limit the amount of heat that can be dumped into the river to 1500 MW, what is the largest electrical output that the plant can deliver? If improvements in hot-steam technology would permit raising T_h by 100° C, what effect would this have on the plant capacity?

Problem 6

Kittel & Kroemer, Chapter 8, problem 6 [Room air conditioner.]

A room air conditioner operates as a Carnot cycle refrigerator between an outside temperature T_h and a room at a lower temperature T_l. The room gains heat from the outdoors at a rate $A(T_h - T_l)$: this heat is removed by the air conditioner. The power supplied to the cooling unit is P.

(a): 1 point

Show that the steady state temperature of the room is

$$T_l = (T_h + P/2A) - [(T_h + P/2A)^2 - T_h^2]^{1/2}.$$

(b): 1 point

If the outdoors is at 37° C and the room is maintained at 17° C by a cooling power of 2 kW, find the heat loss coefficient A of the room in W K^{-1}.