work. The maximum possible fraction that can be converted is given by the Carnot efficiency:

$$\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H}, \qquad [4.35]$$

where T_L is a lower temperature. The Carnot efficiency refers specifically to a *cycle* operating between two temperatures, T_H and T_L.

4.12 Problems

Problem 4.1: Calculate the entropy change of steam between states $P_1 = 36$ bar, $T_1 = 250$ °C, and $P_2 = 22$ bar, $T_2 = 400$ °C by direct application of the definition of entropy. *Hint:* devise a path of constant pressure followed by a path of constant volume that connects the two states; use tabulated values of U and H to calculate the required heat capacities.

Problem 4.2: A 2 kg piece of copper at 200 °C is taken out of a furnace and is let stand to cool in air with ambient temperature 25 °C. Calculate the entropy generation as a result of this process. *Additional data:* The C_P of copper is 0.38 kJ/kg K.

Problem 4.3: A bucket that contains 1 kg of ice at -5 °C is placed inside a bath that is maintained at 40 °C and is allowed to reach thermal equilibrium. Determine the entropy change of the ice and of the bath. Additional information: $C_{P,\text{liq}} = 4.18$ kJ/kgK, $C_{P,\text{ice}} = 2.05$ kJ/kgK, $\Delta H_{\text{fusion}} = 334$ kJ/kg.

Problem 4.4: To convince yourself that the entropy of a bath changes even though its temperature remains unchanged, consider the following case: A tub that contains water at 40 °C receives 100 kJ of heat. Calculate the final temperature of the water and its entropy change if the mass of the water in the tub is:
a) 1 kg.
b) 10 kg.
c) 1000 kg.
d) Compare your results to the calculation $\Delta S = Q_{\text{bath}}/T_{\text{bath}}$. What do you conclude? (For water use $C_P = 4.18$ kJ/kg K.)
e) Prove that when the mass of the bath approaches infinity the entropy change of the bath is

-Q

$$\Delta S_{\text{bath}} = \frac{\cancel{-C_P(T_2 - T_1)}}{T_2}.$$

Hint: Recall that $\ln x \approx x - 1$ when $x \approx 1$.

numerator should be -Q

Problem 4.5: Ethanol vapor at 0.5 bar and 78 °C is compressed isothermally to 2 bar in a reversible process in a closed system.
a) Draw a qualitative PV graph and show the path of the process. Mark all the relevant pressures and isotherms.
b) Calculate the enthalpy change of the ethanol.
c) Calculate the entropy change of the ethanol.
d) What amount of heat is exchanged between the ethanol and the surroundings during the compression?
remove slash to read: J/K mol.
Assume that ethanol vapor is an ideal gas with $C_P = 45$ J/K/mol. The saturation pressure of ethanol at 78 °C is 1 bar.

Problem 4.6: One mol of methanol vapor is cooled under constant pressure in a closed system by removing 25000 J of heat. Initially, the system is at 2 bar, 200 °C.
a) Determine the final temperature.
b) Calculate the entropy change of methanol.
Additional data: boiling point of methanol at 2 bar: 83 °C; heat capacity of vapor: 60 J/mol K; heat capacity of liquid: 80 J/mol K; heat of vaporization at 2 bar: 36740 J/mol.

Problem 4.7: Calculate the entropy of toluene in the following states:
a) 10 bar, 300 °C
b) Vapor-liquid mixture at 10 bar with quality 25%.
c) 10 bar, 20 °C.
d) 15 bar, 20 °C.
The following data are available:

Saturation temperature at 10 bar:	216.80	°C
Enthalpy of saturated liquid at 10 bar:	21.757	kJ/mol
Entropy of saturated liquid at 10 bar:	49.582	kJ/kg K
Enthalpy of vaporization at 10 bar:	25.36	kJ/mol
C_P of liquid:	227.49	J/mol K
C_P of vapor:	189.37	J/mol K

Problem 4.8: Steam is compressed by reversible isothermal process from 15 bar, 250 °C, to a final state that consists of a vapor-liquid mixture with a quality of 32%.
a) Calculate the amount of work.
b) Calculate the amount of heat that is required to maintain isothermal conditions. Is this heat added or removed from the system?

Problem 4.9: Steam in a closed system is compressed by reversible isothermal process in a heat bath at 250 °C, starting from an initial pressure of 15 bar. During the process, the steam transfers 2000 kJ/kg of heat to the bath. Determine the final state and the amount of work involved.

Problem 4.10: Steam in a closed system is compressed by reversible isothermal process in a heat bath at 250 °C, starting from an initial pressure of 15 bar. During the process, the steam receives 400 kJ/kg of work. Determine the final state and the amount of heat exchanged with the bath.

Problem 4.11: Steam at 1 bar, 150 °C, is compressed in a closed system by reversible isothermal process to final pressure of 20 bar. Determine the ~~final temperature,~~ amount of work~~,~~ and the entropy change of the steam and of the heat bath that is used to maintain the process isothermal.

Problem 4.12: Steam at 1 bar, 150 °C is compressed in a closed system by reversible adiabatic process to final pressure of 20 bar. Determine the final temperature and the amount of work.

Problem 4.13: Nitrogen is compressed adiabatically in a closed system from initial pressure $P_1 = 1$ bar, $T_1 = 5$ °C to $P_2 = 5$ bar. Due to irreversibilities there is an entropy generation equal to 4.5 J/mol K.
a) Calculate the temperature at the end of the compression.
b) Calculate the amount of work. How does it compare to the reversible adiabatic work?
Assume nitrogen to be an ideal gas under the conditions of the problem. Is this a reasonable assumption?

Problem 4.14: Methanol vapor at 2 bar and 65 °C expands isothermally to 0.2 bar through a reversible process.
a) Draw a qualitative PV graph and show the path of the process. Mark all the relevant pressures and isotherms. The process is conducted in a closed system.
b) Calculate the enthalpy change of the methanol.
c) Calculate the entropy change of the methanol.
d) What amount of heat is exchanged between the ethanol and the surroundings during the compression?
remove slash to read: J/mol K
Assume that the vapor phase is an ideal gas with $C_P = 45$ J/K/ mol. The boiling point of methanol at 1 bar is 65 °C.

Problem 4.15: Calculate ΔS for steam from 250 °C, 0.05 bar to 250 °C, 6 bar assuming steam to be an ideal gas. Compare to the value in the steam tables.

Problem 4.16: a) Calculate the amount of work necessary for the reversible isothermal expansion of 1 kg of steam from 10 bar to 5 bar at 400 °C.
b) Calculate the amount of heat associated with this process.