Physics 4C
Chapter 20: Entropy and the Second Law of Thermodynamics

“The answers you receive depend upon the questions you ask.” – Thomas Kuhn

"*Your own mind is a sacred enclosure into which nothing harmful can enter except by your promotion.*" – Ralph Waldo Emerson

“*Nobody made a greater mistake than he who did nothing because he could only do a little*.”
Edmund Burke

Reading: pages 536 – 555

Outline:

⇒ direction of thermodynamic processes
    reversible and irreversible processes
⇒ heat engines
    efficiency
    Carnot engine
    efficiency of a Carnot engine
⇒ refrigerators
    coefficient of performance
    Carnot refrigerator
⇒ entropy and the second law of thermodynamics
    definition of entropy
    examples of entropy change
    second law of thermodynamics
    statistical view of entropy

Problem Solving Techniques

Many problems deal with heat engines and refrigerators. In each case, energy is absorbed as heat over part of the cycle, energy is rejected as heat over another part, and work is done on or by the working substance. Given any one of these quantities and the efficiency or coefficient of performance, you should be able to calculate the others. The relevant equations are the first law of thermodynamics and the definition of either the efficiency or the coefficient of performance. Other problems give you two of the energy terms and ask for the efficiency or coefficient of performance.

Some problems ask you to test data for heat engines or refrigerators to see if they violate the first or second laws of thermodynamics. Remember that the second law places upper limits on the efficiency of an engine and the coefficient of performance of a refrigerator.

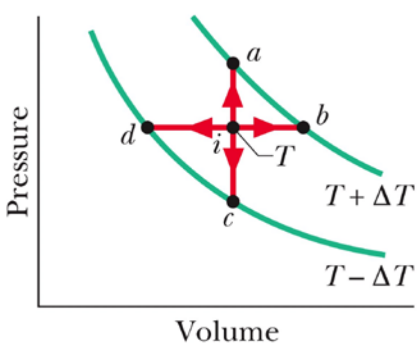
You should also practice calculating the heat and work for various processes (isothermal, adiabatic, constant volume, and constant pressure). Use the heat capacity or specific heat to compute the heat, use $\int p\,dV$ to compute the work.

You should know how to calculate changes in entropy for various processes. Remember that $\Delta S = \int (1/T)\,dQ$ for a reversible process between the initial and final state. To evaluate the integral you need to substitute for dQ and what you substitute depends on the process involved. In most cases you will use a heat capacity or specific heat to determine dQ in terms of the temperature change dT. In some cases you will need the first law of thermodynamics to determine dQ in terms of the work dW and the change dE_{int} in the internal energy. The change in the internal energy can always be written in terms of the heat capacity or specific heat at constant volume and the change in temperature.

Some problems deal with the microscopic view of entropy. You must calculate the number W of microstates for a given configuration and use S = -klnW.

Questions and Example Problems from Chapter 20

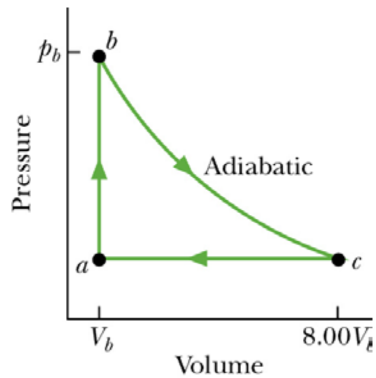
Question 1
Point i in the figure below represents the initial state of an ideal gas at temperature T. Taking algebraic signs into account, rank the entropy changes that the gas undergoes as it moves successively and reversibly, from point i to points a, b, c, and d, greatest first.



Question 2
A box contains 100 atoms in a configuration, with 50 atoms in each half of the box. Suppose that you could count the different microstates associated with this configuration at the rate of 100 billion states per second, using a supercomputer. Without written calculation, guess how much computing time you would need: a day, a year, or much more than a year.

Problem 1

The figure below shows a reversible cycle through which one mole of a monatomic ideal gas is taken. Process bc is an adiabatic expansion, with $p_b = 10.0$ atm and $V_b = 1.00 \times 10^{-3}$ m^3. Find (a) the energy added to the gas as heat, (b) the energy leaving the gas as heat, (c) the net work done by the gas, and (d) the efficiency of the cycle.



Problem 2
A Carnot engine has an efficiency of 22.0%. It operates between constant-temperature reservoirs differing in temperature by 75.0 C°. What are the temperatures of the two reservoirs?

Problem 3
A Carnot engine operates between 235°C and 115°C, absorbing 6.30×10^4 J per cycle at the higher temperature. (a) What is the efficiency of the engine? (b) How much work per cycle is this engine capable of performing?

Problem 4
A Carnot air conditioner takes energy from the thermal energy of a room at 70°F and transfers it to the outdoors, which is at 96°F. For each joule of electric energy required to operate the air conditioner, how many joules are removed from the room?

Problem 5
The electric motor of a heat pump transfers energy as heat from the outdoors, which is at -5.0°C, to a room, which is at 17°C. If the heat pump were a Carnot heat pump (a Carnot engine working in reverse), how many joules of heat would be transferred to the thermal energy of the room for each joule of electric energy consumed?

Problem 6
Suppose 4.00 mol of an ideal gas undergo a reversible isothermal expansion from volume V_1 to volume $V_2 = 2.00V_1$ at temperature $T = 400$ K. Find (a) the work done by the gas and (b) the entropy change of the gas. (c) If the expansion is reversible and adiabatic instead of isothermal, what is the entropy change of the gas?

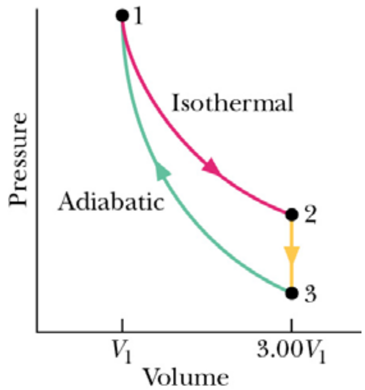
Problem 7
In an experiment, 200 g of aluminum (with a specific heat of 900 J/kg·K) at 100°C is mixed with 50.0 g of water at 20.0°C, with the mixture thermally isolated. (a) What is the equilibrium temperature? What are the entropy changes of (b) the aluminum, (c) the water, and (d) the aluminum–water system?

Problem 8

A 10 g ice cube at -10°C is placed in a lake whose temperature is 15°C. Calculate the change in entropy of the cube–lake system as the ice cube comes to thermal equilibrium with the lake. The specific heat of ice is 2220 J/kg·K. (Hint: Will the ice cube affect the temperature of the lake?)

Problem 9

An ideal diatomic gas, whose molecules are rotating but not oscillating, is taken through the cycle in the figure below. Determine for all three processes, in terms of p_1, V_1, T_1, and R: (a) p_2, p_3, and T_3 and (b) W, Q, ΔE_{int}, and ΔS per mole.



Problem 10

A box contains N gas molecules, equally divided between its two halves. For N = 50: (a) What is the multiplicity of this central configuration? (b) What is the total number of microstates for the system? (c) What percentage of the time does the system spend in its central configuration? (d) Repeat (a) through (c) for N = 100. (e) Repeat (a) through (c) for N = 200. (f) As N increases, you will find that the system spends less time (not more) in its central configuration. Explain why this is so.