Physics 4C: Collected Homework 2

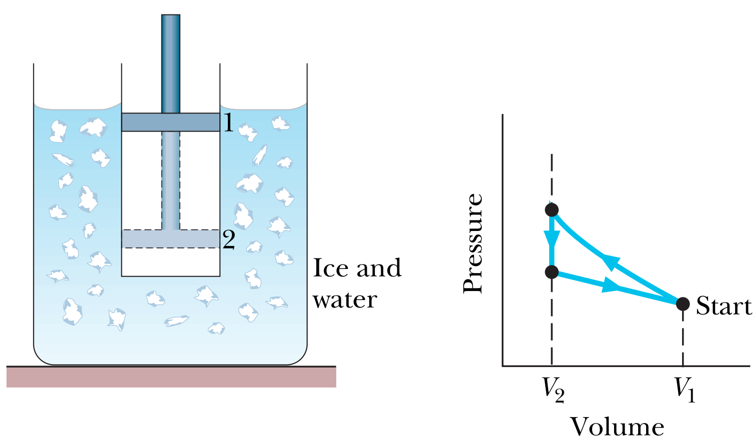
Solutions are not considered complete without the logical argument and/or full calculation.

1. Figure (a) shows a cylinder containing 5.00 moles of an ideal gas and closed by a movable piston. The cylinder is kept submerged in an ice-water mixture. A cycle of 3 steps is completed: (A) the piston is *very quickly* pushed down from position 1 to position 2, and then (B) held at position 2 until the gas is again at the temperature of the ice-water mixture, then (C) it is *slowly* raised back to position 1. Figure (b) is a P-V diagram for the process. The volume of the cylinder with the piston in position 1 is 4 times the volume with the piston in position 2 ($V_1 = 4V_2$ in figure (b)).

   (a) If 100 g of ice is melted during the cycle, how much work has been done on the gas?

   (b) What is the work done on the gas in step (A)? (Hint: Think about the other steps.)

   (c) What is the heat transferred to the gas in step (B)?

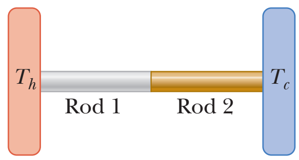


(a) (b)

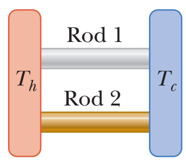
2. Consider two rods of metal with the same cross sectional area, and the same length.

   (a) Suppose the two rods are welded end to end, as shown in figure a, with a temperature of T_c on the right side and T_h on the left side. Let the thermal conductivity of the first rod be k_1 and the second be k_2, the length of the rods be L, and the cross sectional areas be A. Derive an expression (don't just write it down!) for the total heat transfer rate (power transfer) between two surfaces at temperatures T_h and T_c, ($T_h > T_c$) across the two rods in series.

   (b) Suppose $T_c = 0°\text{C}$ and $T_h = 100°\text{C}$, and for this part of the question, suppose $k_1 = k_2$. When the rods are in the configuration shown in figure a, 10 J is conducted at a constant rate from the left side to the right side in 2.0 min. How much time would be required to conduct 10 J if the rods were welded side to side between the same reservoirs, as in figure b?



a



b

3. Newton's law of cooling applies for heat transfer by thermal conductivity and not (in general) for heat transfer by radiation. However, if the temperature difference between an object and its surroundings is small compared to the temperatures involved, Newton's law of cooling does apply approximately. Let T be the temperature of the hot object and T_0 be the temperature of the surroundings. Let $\delta = T - T_0$ be a positive number and $\delta \ll T_0$. Starting from Stefan's law:

$$P_{\text{net}} = \sigma A e (T^4 - T_0^4)$$

where P_{net} is the rate of energy loss from the hot object and σ (the Stefan-Boltzmann constant), A (the surface area of the hot object), and e (the emissivity) are constants, show that to first order in δ the rate of energy loss $P_{\text{net}} = \frac{\text{dQ}}{\text{dt}}$ obeys Newton's law of cooling:

$$\frac{\text{dQ}}{\text{dt}} = k(T - T_0)$$

where k is a constant, and find the value of k in terms of the other constants given in this question.

4. **Kinetic theory.** An ideal gas is expanded isobarically. During this process, heat is added to the gas. Some fraction of the heat added goes to increasing the internal energy of the gas, and the rest goes to the work of expansion (in other words, it is energy transferred from the gas to the environment as work). What fraction of heat transferred to the gas in this process is spent to perform the work of expansion if

   (a) the gas is monatomic?

   (b) the gas is a diatomic gas at room temperature (only translational and rotational degrees of freedom are excited)?

   (c) the gas is a diatomic gas at high temperature, so that all degrees of freedom (translational, rotational, and vibrational) of the molecules are excited?

   (d) In which case is the largest fraction of the heat added going to the work?