PHYS2060 – Thermal Physics
Session 2 - 2007
Tutorial Problems – Set 5 (Weeks 12-14)

These problems are intended to illustrate and reinforce the course material. It is important to work through these problems, or attempt to. Some will be done in class as examples. Problems marked (*) are more difficult and are included as a challenge, but should be attempted if possible as they will best test your knowledge/skills.

1. A liter of air, initially at room temperature and atmospheric pressure, is heated at constant pressure until it doubles in volume. Calculate the increase in its entropy during this process.

2. Sketch a qualitatively accurate graph of the entropy of a substance (perhaps H_2O) as a function of temperature, at fixed pressure. Indicate where the substance is solid, liquid and gas. Explain each feature of the graph briefly.

3. A cylinder contains one liter of air at room temperature and atmospheric pressure. At one end of the cylinder is a massless piston, whose surface area is 0.01 m^2. Suppose that you push the piston in very suddenly, exerting a force of 2000N. The piston moves only one millimetre, before it is stopped by an immovable barrier of some sort.

   (a) How much work have you done on this system?

   (b) How much heat has been added to the gas?

   (c) Assuming that all the energy added goes into the gas (not the piston or cylinder walls), by how much does the internal energy of the gas increase?

   (d) Use $dU = TdS - PdV$ to calculate the change in the entropy of the gas (once it has reached equilibrium).

4. Suppose we have one mole of argon gas at room temperature and atmospheric pressure. Compute the internal energy, entropy (using the Sackur-Tetrode equation below), enthalpy, Helmholtz free energy and Gibbs free energy. Express all answers in SI units.

$$S = Nk_B\left[\ln\left(\frac{V}{N}\left(\frac{4\pi mU}{3Nh^2}\right)^{3/2}\right)+\frac{5}{2}\right]$$

5. (*) The phase diagram for ^{3}He (helium comes in two isotopes one with one neutron ^{3}He and one with two neutrons ^{4}He) is shown below.

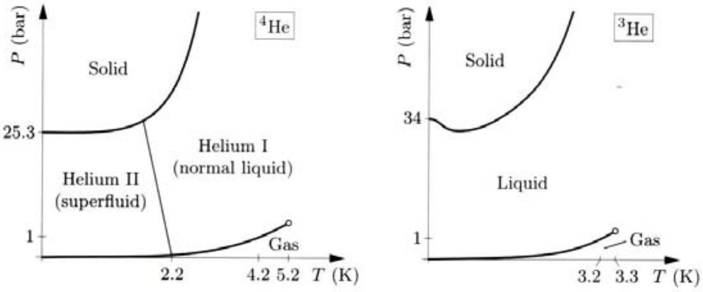

Figure 5.13. Phase diagrams of ^{4}He (left) and ^{3}He (right). Neither diagram is to scale, but qualitative relations between the diagrams are shown correctly. Not shown are the three different solid phases (crystal structures) of each isotope, or the superfluid phases of ^{3}He below 3 mK.

Below 0.3K, the slope of the ^{3}He solid-liquid phase boundary is negative.

   (a) Which phase, solid or liquid, is more dense? Which phase has more entropy per mole?

(b) Suppose that you compress liquid ^3He adiabatically until it becomes a solid. If the temperature just before the phase change is 0.1K, will the temperature after the phase change be higher or lower?

In each case, explain your reasoning carefully.

6. Sketch qualitatively accurate graphs of G vs. T for all three phases of H_2O (ice, water and steam) at atmospheric pressure. Put all three graphs on the same set of axes, and label the temperatures 0°C and 100°C. How would the graphs differ at a pressure of 0.001 bar? (n.b., you should have done Q2 before attempting this.)

7. Sketch qualitatively accurate graphs of G vs P for the three phases of H_2O (ice, water and steam) at 0°C. Put all three graphs on the same set of axes, and label the point corresponding to atmospheric pressure. How would the graphs differ at slightly higher temperatures?