Homework Assignment 8

PHYSICS 314 - THERMODYNAMICS & STATISTICAL PHYSICS (Spring 2018)

Due Friday, April 13th, by noon, Noyce 1135

I cannot award full credit for work that I am unable to read or follow. For my benefit and for yours, please:

- *Write neatly*
- *Show and EXPLAIN all steps*
- *Make diagrams large and clearly-labeled*

You are welcome to collaborate with others on this assignment. However, the work you turn in should be your own. Please cite collaborators and outside sources. See the syllabus for details.

Regardless of the number of parts, all homework problems are weighted equally. Regardless of the number of questions, all homework assignments are weighted equally.

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1) State whether the following quantities are *extensive* or *intensive*. Explain your answer both in words and using the mathematics of extensive and intensive variables discussed on pages 163-164 of Schroeder.
   a) Heat capacity, C_V
   b) Specific heat, c_V

2) Four new thermodynamic potentials can be obtained by subtracting μN from the four thermodynamic potentials that we have been discussing in class, U, H, F, and G. Probably the most useful of the four is the *grand free energy* (also known as the *grand potential*), Φ.

$$\Phi \equiv F - \mu N$$

   a) Derive the thermodynamic identity for the grand free energy. From this identity, find the related formulas for the partial derivatives of grand free energy with respect to T, V, and μ.
   b) Is grand free energy *extensive* or *intensive*? Explain your answer both in words and using the mathematics of extensive and intensive variables discussed on pages 163-164 of Schroeder.

3) Examine the following partial derivative relationships for chemical potential that we derived in class.

$$\mu = \left.\frac{\partial G}{\partial N}\right|_{T,P} \qquad \mu = \left.\frac{\partial F}{\partial N}\right|_{T,V}$$

   Carefully explain *in your own words* why the first equality implies that the chemical potential is equal to the Gibbs free energy per particle: $G = N\mu$, yet the second does **NOT** imply that the chemical potential is equal to the Helmholtz free energy per particle: $F = N\mu$. (Remember that we are free to define $F = 0$ and $G = 0$ wherever we choose.)

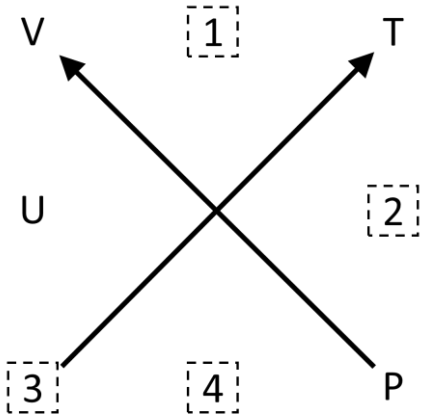
4) Work is produced by muscle when glucose is metabolized through the reaction below.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O_{(l)}$$

   a) Use the tables in the back of Schroeder to calculate ΔH and ΔG for this reaction. Assume that there is one mole of glucose ($C_6H_{12}O_6$) and that the reaction takes place at room temperature and atmospheric pressure.

b) What is the maximum amount of work that the muscle can perform for each mole of glucose consumed?
c) Assuming maximum work output, is heat absorbed or expelled by the chemicals during the metabolism? For one mole of glucose, calculate the amount of heat absorbed or expelled during the metabolism.
d) Explain your answer about the direction of heat flow using the concept of entropy. The table at the back of Schroder has the entropy values needed.
e) Now suppose that the operation of the muscle is not ideal. Assume that there are inefficiencies, and the work output is less than the maximum possible work found in part b). Explain *qualitatively* how this changes your answers to parts a), c), and d).

5) Figure 5.2 on page 151 of Schroeder is one way to visualize the connections between thermodynamic quantities. Another way to visualize the connections is shown below. Your task is to fill in the four numbered squares with the correct thermodynamic quantities.



To understand how the chart works, consider an example. On the left side of the square is the energy, U. The chart indicates the connections between energy and the two adjacent quantities, the one on the top left and the one on the bottom left. The top left position is volume, V, which is connected *against the direction of the arrow* on the diagonal to pressure, P. The bottom left position is the unknown quantity 3, which is connected *with the direction of the arrow* to temperature, T. These connections are to be interpreted as follows:

$$P = -\left.\frac{\partial U}{\partial V}\right|_{(3)} \quad \text{and} \quad T = +\left.\frac{\partial U}{\partial (3)}\right|_{V}, \quad or$$

$$dU = -P\, dV + T\, d(3).$$

The direction of the arrow determines the sign. *The number of particles is assumed to be held constant.*

Redraw the chart with the numbered squares replaced with the proper thermodynamic quantities. Provide partial differential formulas like the ones above to justify your answers.

6) Sketch a *qualitatively* accurate graph of Gibbs free energy as a function of temperature for a pure substance as it changes from a solid to a liquid to a gas *at fixed pressure*. Assume the number of molecules is also fixed. On your plot, be sure to label the phases and the phase transition points. Briefly explain the main features of your plot. *Hint: Consider the relative entropies of the three phases.*

7) Read the following material discussing recent topics from class.

Hydrogen-powered vehicles: A chicken and egg problem
https://physicstoday.scitation.org/doi/full/10.1063/PT.3.3690
What separates a liquid from a gas?
https://physicstoday.scitation.org/doi/full/10.1063/PT.3.1796

Write a short response to the two articles. One paragraph per article is sufficient.

- Summarize the main points of each article in a sentence or two.
- For each article, discuss in a few sentences the connections between the science discussed in the article and the material covered in this course.
- Which article did you feel better conveyed the relevant science? Why? (Keep in mind the intended audience of each piece.)
- Fulfilling the above requirements will earn you a $^{3.25}/_{4}$. The rest of the points will be awarded based on the depth and quality of your explanations of the connections. (For example, a response that discusses the energy flow of a negative temperature system will earn more points than a response that simply states that negative temperature is something we saw in class.)

8) List *three* main ideas from this homework assignment. For example, you could write a few-sentence explanation of a concept, or list an equation and explain the variables and in what circumstances the equation applies.
The goal is for you to review and to reflect on the big picture. Think about what you might want to remember when you look back at this homework before the test. I hope that this will be useful for your studying. I am not looking for anything specific here; you will be graded on effort and completion.