Homework Assignment 7

PHYSICS 314 - THERMODYNAMICS & STATISTICAL PHYSICS (Spring 2018)

Due Friday, April 6th, 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.

***OPTIONAL** Opportunity:*

I realize that it can be difficult to arrive at 8 a.m. to do the daily summaries and to remember to send in the weekly reading questions. Therefore, you have the opportunity to make up some of those points. The following assignment can be used to make up the points for one week of daily summaries or for one weekly e-mail questions (both of which are worth the same number of points). If you have not missed any points, you may still do the assignment to add to your point total.

When she found out I was teaching thermodynamics, Prof. Laura Sivert in the Art History Department sent me the following article. It is an article that argues for the interpretation of artist Winslow Homer's works through the lens of thermodynamics.

Winslow Homer and the Drama of Thermodynamics
http://www.jstor.org/stable/3109370

To earn back missed points, read the article, and write a ½-page response. In your response, use your knowledge of thermodynamics to focus on the author's explanations and applications of thermodynamics. Are the scientific principles explained accurately? Does the author use them appropriately to explain Homer's work? Cite specific examples to support your argument.

The grading of this will be similar to the other article response homework questions. Roughly 80% of the credit is for completion, with the remaining portion from depth and quality of your response. I will grade primarily on content rather than style.

1) Derive the following equation for the efficiency of the Otto cycle. *Hint: We worked on this in class.*

$$e = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma - 1}$$

2) Instead of electrical energy, some refrigerators use heat from burning fuel (frequently propane). Such refrigerators, known as *absorption refrigerators*, can be used where electricity is unavailable. Define a set of parameters for an absorption refrigerator, with all of them defined to be positive.

$Q_f =$ heat input from burning fuel
$Q_c =$ heat extracted from inside refrigerator
$Q_r =$ waste heat pumped into room
$T_f =$ temperature of burning fuel
$T_c =$ temperature inside refrigerator
$T_r =$ room temperature

a) Sketch an energy-flow diagram for this process (like the one drawn in class for a heat engine – see Figure 4.1 in Schroeder).
b) How should the coefficient of performance for an absorption refrigerator be defined? Briefly explain.
c) Does the *conservation of energy* set a limit for coefficient of performance? If so, find the limit.
d) Use the second law of thermodynamics to set a limit on coefficient of performance in terms of only the three temperatures defined above.

3) A *heat pump* is the same thing as a conventional refrigerator, but the purpose is to warm the hot reservoir rather than to cool the cold reservoir. (Like a refrigerator, regardless of its purpose, it actually does both.) For example, a heat pump could be used to heat a building by pumping heat in from the cold outdoors. Define a set of parameters for a heat pump, with all of them defined to be positive.

$T_h =$ temperature indoors
$T_c =$ temperature outdoors
$Q_h =$ heat pumped into the building
$Q_c =$ heat taken from outdoors
$W =$ electrical energy used by the pump

a) How should the coefficient of performance for a heat pump be defined? Briefly explain.
b) Does the *conservation of energy* set a limit for coefficient of performance? If so, find the limit.
c) Use the second law of thermodynamics to set a limit on coefficient of performance in terms of only the indoor and outdoor temperatures.
d) An *electric furnace* is a heating device that converts electrical work directly into heat. Compare the coefficient of performance of a heat pump with that of an electric furnace.

4) In class, we found an expression for the maximum efficiency for a heat engine with set hot and cold reservoir temperatures.

$$e_{max} = 1 - \frac{T_c}{T_h}$$

Suppose that someone claims to have a heat engine with an efficiency greater than this. Prove that this is impossible. Do so by showing that if this were the case, you could use the work from such a heat engine to power an ordinary Carnot refrigerator with zero *work* input to the overall system.

5) For one mole of argon gas is at room temperature and atmospheric pressure, calculate *in SI units*:
   a) thermal energy,
   b) entropy,
   c) enthalpy,
   d) Helmholtz free energy, and
   e) Gibbs free energy.

6) Ammonia is sometimes used as a refrigerant. (The *U.S. Emergency Planning and Community Right-to-Know Act* identifies it as an "extremely hazardous substance"; it is way worse for you than Freon!) It is produced from nitrogen and hydrogen in the reaction shown below.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

   Suppose this reaction occurs at 298 K and 1 bar. Calculate the change in Gibbs free energy of this reaction in two different ways.
   a) Use the values of ΔH and S in the table on page 405 of Schroeder.
   b) Find the value directly in the table on page 405 of Schroeder.

7) Read (or listen to) the following material discussing recent topics from class.

   Nobel Prize press release: Award for development of methods to cool and trap atoms with laser light
   https://www.nobelprize.org/nobel_prizes/physics/laureates/1997/press.html
   Two stories on diesel cars in the United States
   https://www.npr.org/2018/02/27/589279432/why-diesel-powered-cars-are-bigger-in-europe-than-in-the-u-s
   https://www.npr.org/2015/09/25/443489259/the-shaky-future-of-diesel-fuel-in-america

   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.