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:

- o *Write neatly*
- o *Show and EXPLAIN all steps*
- o *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 <u>Opportunity:</u>

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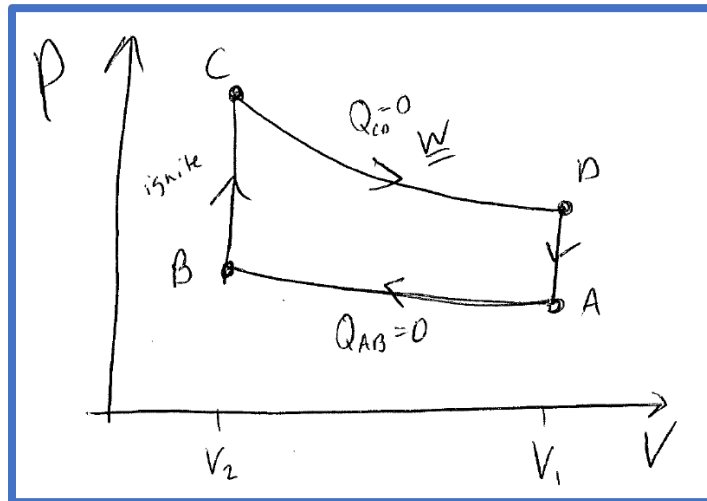
1) Derive the following equation for the efficiency of the Otto cycle. *Hint: We worked on this in class.*

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

Start with the general expression for efficiency.

$$e = \frac{W}{Q_{in}}$$

First find the heat, which comes from the ignition step, $B \to C$.

Because the volume change is zero during this step, work is zero. By the First Law, then, the heat is equal to the change in energy.

$$Q_{BC} = \Delta U$$

Use the Equipartition Theorem to write the energy in terms of temperature.

$$Q_{BC} = \frac{f}{2} nR\Delta T$$

$$Q_{BC} = \frac{f}{2} nR(T_C - T_B)$$

$$Q_{BC} = \frac{f}{2} (nRT_C - nRT_B)$$

Use the Ideal Gas Law to replace rewrite this in terms of pressure and volume.

$$Q_{BC} = \frac{f}{2} (P_C V_C - P_B V_B)$$

Rewrite the factor out front in terms of the adiabatic constant.

$$\gamma \equiv \frac{f+2}{f}$$

$$\gamma = 1 + \frac{2}{f}$$

$$\gamma - 1 = \frac{2}{f}$$

$$\frac{1}{\gamma - 1} = \frac{f}{2}$$

Plug this into the expression for heat.

$$Q_{BC} = \frac{1}{\gamma - 1}(P_C V_C - P_B V_B)$$

Note that the volume is constant for this step, and the value is V_2.

$$Q_{BC} = \frac{1}{\gamma - 1}(P_C V_2 - P_B V_2)$$

$$Q_{BC} = \frac{V_2}{\gamma - 1}(P_C - P_B)$$

Next find the net work done by the system. Because we are looking for the work done by the system (rather than on the system), the sign is the opposite of the usual convention.

$$W = +PdV$$

Because the volume change is zero during steps $B \to C$ and $D \to A$, work is zero during those steps. Thus, only the adiabatic steps ($C \to D$ and A$\to$ B) need to be considered.

$$W_{net} = + \int_{V_C}^{V_D} PdV + \int_{V_A}^{V_D} PdV$$

Rewrite pressure in terms of volume to integrate. Use the fact that for an adiabat, PV^γ is constant. Call this constant K.

$$PV^\gamma = K$$

$$P = KV^{-\gamma}$$

Use this fact for each adiabat. Note that the constants are different.

$$W_{net} = + \int_{V_C}^{V_D} K_{CD}V^{-\gamma}dV + \int_{V_A}^{V_B} K_{AB}V^{-\gamma}dV$$

Pull the constants out of the integrals.

$$W_{net} = K_{CD} \int_{V_C}^{V_D} V^{-\gamma}dV + K_{AB} \int_{V_A}^{V_B} V^{-\gamma}dV$$

Note that the volumes at these points are known. See the diagram.

$$V_A = V_D = V_1$$

$$V_B = V_C = V_2$$

$$W_{net} = K_{CD} \int_{V_2}^{V_1} V^{-\gamma} dV + K_{AB} \int_{V_1}^{V_2} V^{-\gamma} dV$$

In order to combine the integrals, flip the bounds on the second integral and add a negative sign.

$$W_{net} = K_{CD} \int_{V_2}^{V_1} V^{-\gamma} dV - K_{AB} \int_{V_2}^{V_1} V^{-\gamma} dV$$

$$W_{net} = (K_{CD} - K_{AB}) \int_{V_2}^{V_1} V^{-\gamma} dV$$

Evaluate the integral.

$$W_{net} = (K_{CD} - K_{AB}) \frac{1}{-\gamma + 1} V^{-\gamma+1} \Big|_{V_2}^{V_1}$$

$$W_{net} = (K_{CD} - K_{AB}) \frac{1}{-\gamma + 1} \left(V_1^{-\gamma+1} - V_2^{-\gamma+1} \right)$$

Now rewrite the constants in terms of the known pressures and volumes. Note either subscript could be chosen for the pressure and the volume.

$$K_{CD} = P_C V_C^{\gamma}$$

$$K_{AB} = P_B V_B^{\gamma}$$

Substitute in the known volumes. $V_B = V_C = V_2$

$$K_{CD} = P_C V_2^{\gamma}$$

$$K_{AB} = P_B V_2^{\gamma}$$

$$W_{net} = \left(P_C V_2^{\gamma} - P_B V_2^{\gamma} \right) \frac{1}{-\gamma + 1} \left(V_1^{-\gamma+1} - V_2^{-\gamma+1} \right)$$

$$W_{net} = \frac{V_2^{\gamma} (P_C - P_B) \left(V_1^{-\gamma+1} - V_2^{-\gamma+1} \right)}{-\gamma + 1}$$

Now plug the calculated heat and work expressions into the efficiency expression.

$$e = \frac{W}{Q_{in}}$$

$$e = \cfrac{\cfrac{V_2^{\gamma}(P_C - P_B)\left(V_1^{-\gamma+1} - V_2^{-\gamma+1}\right)}{-\gamma + 1}}{\cfrac{V_2}{\gamma - 1}(P_C - P_B)}$$

Simplify.

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

Cancel pressure terms.

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

Combine V_2 terms.

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

Note that $(-\gamma + 1) = -(\gamma - 1)$.

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

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

Distribute the negative sign.

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

Distribute the term out front.

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

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

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.
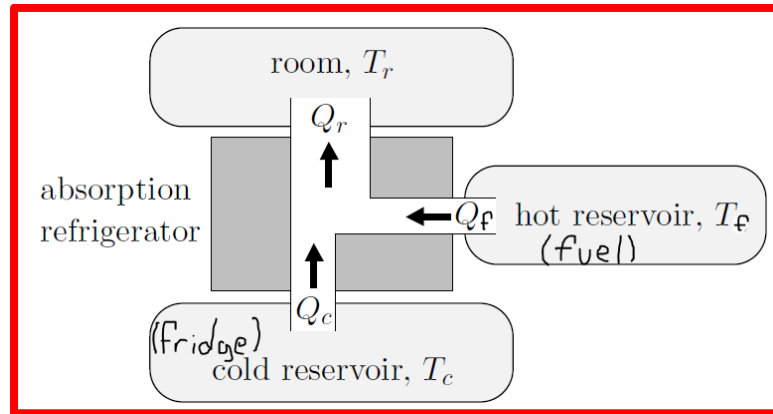
Q_f = heat input from burning fuel
Q_c = heat extracted from inside refrigerator
Q_r = waste heat pumped into room

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.

The coefficient of performance should be the benefit divided by the cost. In this case, the benefit is the heat pulled out of the refrigerator, Q_c. The cost is the heat input from the burning fuel, Q_f.

$$COP = \frac{Q_c}{Q_f}$$

c) Does the _conservation of energy_ set a limit for coefficient of performance? If so, find the limit.

Conservation of energy requires that the heat going in equals the heat going out. (There is no work being done.)

$$Q_c + Q_f = Q_r$$

Rearrange and plug into COP expression.

$$Q_f = Q_r - Q_c$$

$$COP = \frac{Q_c}{Q_r - Q_c}$$

$$COP = \frac{1}{\frac{Q_r}{Q_c} - 1}$$

This relationship does not set a limit on the COP. This function has no upper bound.

d) Use the second law of thermodynamics to set a limit on coefficient of performance in terms of only the three temperatures defined above.

The second law requires that overall entropy stay the same or increase. The refrigerator itself cannot gain or lose entropy because it the process must be cyclic. Thus, the second law requires that the entropy expelled must be greater than or equal to the amount absorbed.

$$\Delta S_r \geq \Delta S_C + \Delta S_f$$

Express the entropies in terms of heat and temperature.

$$\frac{Q_r}{T_r} \geq \frac{Q_C}{T_C} + \frac{Q_f}{T_f}$$

The COP does not involve the waste heat to the room. Replace this heat with the others using the conservation of energy mentioned in part c).

$$\frac{Q_C + Q_f}{T_r} \geq \frac{Q_C}{T_C} + \frac{Q_f}{T_f}$$

$$\frac{Q_C}{T_r} + \frac{Q_f}{T_r} \geq \frac{Q_C}{T_C} + \frac{Q_f}{T_f}$$

Rearrange to get expressions with the same heat on the same side.

$$\frac{Q_C}{T_r} - \frac{Q_C}{T_C} \geq \frac{Q_f}{T_f} - \frac{Q_f}{T_r}$$

$$Q_C \left(\frac{1}{T_r} - \frac{1}{T_C} \right) \geq Q_f \left(\frac{1}{T_f} - \frac{1}{T_r} \right)$$

Solve for the ratio that appears in the COP.

$$\frac{Q_C}{Q_f} \left(\frac{1}{T_r} - \frac{1}{T_C} \right) \geq \left(\frac{1}{T_f} - \frac{1}{T_r} \right)$$

Divide by the term in parentheses. Note that since $T_r > T_C$, this term is negative. Dividing by a negative number flips the inequality.

$$COP = \frac{Q_C}{Q_f} \leq \frac{\frac{1}{T_f} - \frac{1}{T_r}}{\frac{1}{T_r} - \frac{1}{T_C}}$$

Simplify by getting common denominators.

$$COP \leq \frac{\dfrac{T_r - T_f}{T_f T_r}}{\dfrac{T_C - T_r}{T_r T_C}}$$

$$COP \leq \frac{\dfrac{T_r - T_f}{T_f}}{\dfrac{T_C - T_r}{T_C}}$$

$$COP \leq \frac{T_C}{T_f}\left(\frac{T_r - T_f}{T_C - T_r}\right)$$

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.

The coefficient of performance should be the benefit divided by the cost. In this case, the benefit is the heat that enters the building, Q_h. The cost is the electrical energy input required, W.

$$COP = \frac{Q_h}{W}$$

b) Does the *conservation of energy* set a limit for coefficient of performance? If so, find the limit.

Conservation of energy requires that the energy going in equals the energy going out.

$$Q_h = Q_c + W$$

$$Q_h - Q_c = W$$

Use this to replace work in the coefficient of performance expression.

$$COP = \frac{Q_h}{Q_h - Q_c}$$

$$COP = \frac{1}{1 - \dfrac{Q_c}{Q_h}}$$

Since work is positive, the heat to the hot reservoir is larger in magnitude than the heat coming from the cold reservoir. Thus, the numerator is larger than the denominator.

$$Q_h > Q_h - Q_c$$

Therefore, the COP is always greater than 1.

c) Use the second law of thermodynamics to set a limit on coefficient of performance in terms of only the indoor and outdoor temperatures.

The second law requires that overall entropy stay the same or increase. The pump itself cannot gain or lose entropy because it the process must be cyclic. Thus, the second law requires that the entropy expelled must be greater than or equal to the amount absorbed.

$$\Delta S_h \geq \Delta S_c$$

Express the entropies in terms of heat and temperature.

$$\frac{Q_h}{T_h} \geq \frac{Q_c}{T_c}$$

Note that the COP can be written in terms of the ratio of these heats by dividing by the heat from the hot reservoir.

$$COP = \frac{Q_h}{Q_h - Q_c} = \frac{1}{1 - Q_c/Q_h}$$

Rearrange the above inequality to get this same ratio.

$$\frac{T_c}{T_h} \geq \frac{Q_c}{Q_h}$$

Subtract each side from one. This flips the inequality.

$$1 - T_c/T_h \leq 1 - Q_c/Q_h$$

Invert both sides, which flips the inequality *again*.

$$\frac{1}{1 - T_c/T_h} \geq \frac{1}{1 - Q_c/Q_h}$$

This is the expression for COP.

$$\frac{1}{1 - T_c/T_h} \geq COP$$

$$COP \leq \frac{1}{1 - {T_c}/{T_h}}$$

Eliminate the fraction in the denominator by multiplying by the temperature of the hot reservoir.

$$COP \leq \frac{T_h}{T_h - T_c}$$

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.

For an electric furnace, define coefficient of performance in the same way as for the heat pump.

$$COP = \frac{Q_h}{W}$$

In the case of the electric furnace, because the conversion is direct, these two quantities are equal.

$$COP = \frac{Q_h}{Q_h} = 1$$

In part b), the COP of the heat pump was found to always be greater than one.

$$COP_{heat\ pump} > COP_{electric\ furnace}$$

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.

The energy-flow diagram for the hypothetical engine connected to a Carnot refrigerator is shown below. The work from the engine powers the refrigerator. Note that the engine and refrigerator share the same hot and cold reservoirs.
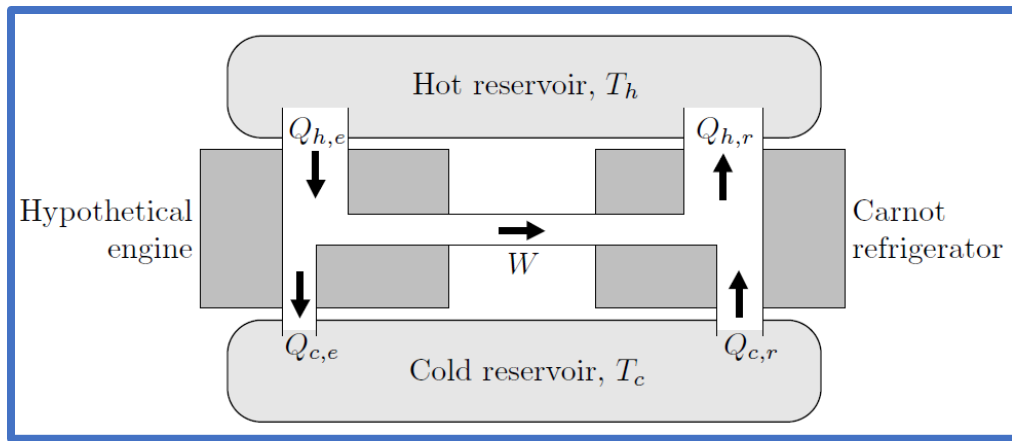
Write down the conservation of energy equations for both the engine and the refrigerator.

$$Q_{h,e} = Q_{c,e} + W$$

$$Q_{h,r} = Q_{c,r} + W$$

The work is the same in both cases.

$$W = Q_{h,e} - Q_{c,e} = Q_{h,r} - Q_{c,r}$$

For the refrigerator, replace the heat from the cold reservoir with the heat from the hot reservoir and the temperatures. (See Schroeder (4.8), and use the equality for the ideal case.)

$$\frac{Q_h}{Q_c} = \frac{T_h}{T_c} \rightarrow Q_c = Q_h \frac{T_c}{T_h}$$

$$W = Q_{h,e} - Q_{c,e} = Q_{h,r} - Q_{h,r} \frac{T_c}{T_h}$$

$$Q_{h,e} - Q_{c,e} = Q_{h,r} \left(1 - \frac{T_c}{T_h} \right)$$

Make a similar replacement for the engine case using Schroeder (4.4). In this case, however, assume greater than maximum efficiency, so change the inequality from $\geq$ to $<$.

$$\frac{Q_c}{Q_h} < \frac{T_c}{T_h} \rightarrow Q_c < Q_h \frac{T_c}{T_h}$$

$$Q_{h,e} - Q_{h,e} \frac{T_c}{T_h} < Q_{h,e} - Q_{c,e} = Q_{h,r} \left(1 - \frac{T_c}{T_h} \right)$$

$$Q_{h,e} - Q_{h,e} \frac{T_c}{T_h} < Q_{h,r} \left(1 - \frac{T_c}{T_h} \right)$$

$$Q_{h,e} \left(1 - \frac{T_c}{T_h} \right) < Q_{h,r} \left(1 - \frac{T_c}{T_h} \right)$$

$$Q_{h,e} < Q_{h,r}$$

Apply the First Law equation above to rewrite this in terms of the cold reservoir heats.

$$Q_{c,e} + W < Q_{c,r} + W$$

$$Q_{c,e} < Q_{c,r}$$

In light of these inequalities for heat, examine the net heat for the reservoirs.

$$Q_{out\ of\ cold\ reservoir} = Q_{c,r} - Q_{c,e} > 0$$

$$Q_{into\ hot\ reservoir} = Q_{h,r} - Q_{h,e} > 0$$

Thus, the net effect is to transfer heat from the hot reservoir to the cold reservoir. The system is a refrigerator without any work input, which is impossible. Thus, the engine that breaks the efficiency limit that we used must not exist.

5) For one mole of argon gas is at room temperature and atmospheric pressure, calculate _in SI units_:
   a) thermal energy,

   Use the equipartition theorem. Argon is monatomic, so $f = 3$.

$$U = \frac{f}{2} nRT$$

$$U \approx \frac{3}{2} (1\ mol) \left(8.314\ {}^{J}/_{mol\ K}\right) 300\ K$$

$$U \approx 3741.3\ J$$

$$U \approx 3740\ J$$

   b) entropy,

   Use the Sackur Tetrode equation to calculate the entropy. (Schroeder 2.49)

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

   Use the equipartition theorem to replace U.

$$S \approx Nk \left[\ln \left[\frac{V}{N} \left(\frac{4\pi m \left(\frac{f}{2} NkT\right)}{3Nh^2}\right)^{3/2} \right] + {}^{5}/_{2} \right]$$

$$S \approx Nk \left[\ln \left[\frac{V}{N} \left(\frac{2\pi m f kT}{3h^2} \right)^{3/2} \right] + 5/2 \right]$$

Use the ideal gas law to replace the volume divided by the number of molecules.

$$S \approx Nk \left[\ln \left[\frac{kT}{P} \left(\frac{2\pi m f kT}{3h^2} \right)^{3/2} \right] + 5/2 \right]$$

$$S \approx Nk \left[\ln \left[\frac{(kT)^{5/2}}{P} \left(\frac{2\pi m f}{3h^2} \right)^{3/2} \right] + 5/2 \right]$$

The number of moles is known, so rewrite the term out front.

$$S \approx nR \left[\ln \left[\frac{(kT)^{5/2}}{P} \left(\frac{2\pi m f}{3h^2} \right)^{3/2} \right] + 5/2 \right]$$

For argon, $f = 3$ and $m = 40\ amu = 40 \times 1.67 \times 10^{-27}\ kg$. Plug in these and the known values. Note that atmospheric pressure is $1.01 \times 10^5\ Pa = 1.01 \times 10^5\ N/m^2$.

$$S \approx (1\ mol) \left(8.314\ J/mol\ K \right) \left[\ln \left[\frac{\left[\left(1.38 \times 10^{-23} J/K \right) (300\ K) \right]^{5/2}}{1.01 \times 10^5\ N/m^2} \left(\frac{2\pi (40 \times 1.67 \times 10^{-27}\ kg)(3)}{3(6.63 \times 10^{-34}\ J\ s)^2} \right)^{3/2} \right] + 5/2 \right]$$

$$S \approx 155\ J/K$$

c) enthalpy,

Start with the definition of enthalpy.

$$H = U + PV$$

Rewrite the second term using the ideal gas law.

$$H = U + nRT$$

Rewrite the first term using the equipartition theorem.

$$H = \frac{f}{2} nRT + nRT$$

$$H = \left(\frac{f}{2} + 1\right) nRT$$

Plug in values.

$$H \approx \left(\frac{3}{2} + 1\right) (1 \; mol) \left(8.314 \; {}^J\!/_{mol \; K}\right) 300 \; K$$

$$H \approx 6235.5 \; J$$

$$H \approx 6230 \; J$$

d) Helmholtz free energy, and

Start with the definition of the Helmholtz free energy.

$$F = U - TS$$

Plug in the temperature and the results for energy and entropy from parts a) and b).

$$F = 3741.3 \; J - (300 \; K) \left(155 \; {}^J\!/_K\right)$$

$$F \approx -42758.7 \; J$$

$$F \approx -42800 \; J$$

e) Gibbs free energy.

Write the Gibbs free energy in terms of the Helmholtz free energy.

$$G = F + PV$$

Rewrite the second term using the ideal gas law.

$$G = F + nRT$$

Plug in values, using the answer from part d).

$$G \approx -42758.7 \; J + (1 \; mol) \left(8.314 \; {}^J\!/_{mol \; K}\right) 300 \; K$$

$$G \approx -40264.5 \; J$$

$$G \approx -40300 \; J$$

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.

$$N_2 + 3H_2 \rightarrow 2NH_3$$
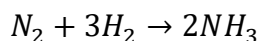
Suppose this reaction occurs at 298 K and 1 bar. Calculate the change in Gibbs free energy of this reaction in two different ways.

a) Use the values of ΔH and S in the table on page 405 of Schroeder.

Start with the Gibbs free energy in terms of enthalpy and entropy. (See the chart in Figure 5.2.)

$$G = H - TS$$

Look at the change of this quantity at constant temperature.

$$\Delta G = \Delta H - \Delta TS - T\Delta S$$

$$\Delta G = \Delta H - T\Delta S$$

The reactants (on the left side above) are in their most stable states. Therefore the enthalpy of the reactants is zero. Thus, the change in enthalpy is just the enthalpy of formation of the product (the right side). Look up the enthalpy for ammonia and multiply it by two because there are two moles.

$$2\Delta_f H = 2 \times -46.11 \ kJ = -92.22 \ kJ$$

Look up the entropies for product and reactants.

$$S_{N_2} = 191.61 \ {}^J\!/_K$$

$$S_{H_2} = 130.68 \ {}^J\!/_K$$

$$S_{NH_3} = 192.45 \ {}^J\!/_K$$

Calculate the change in entropy. Be sure to consider the number of moles of each.

$$\Delta S = S_{product} - S_{reactants}$$

$$\Delta S = \left(2 \times 192.45 \ {}^J\!/_K\right) - 191.61 \ {}^J\!/_K - \left(3 \times 130.68 \ {}^J\!/_K\right)$$

$$\Delta S = -198.75 \ {}^J\!/_K$$

Substitute in the values for change in enthalpy and entropy to find the change in the Gibbs free energy at the given constant temperature.

$$\Delta G = -92.22 \ kJ - (298 \ K)\left(-198.75 \ {}^J\!/_K\right)$$

$$\Delta G = -92200 \ J + (298 \ K)\left(198.75 \ {}^J\!/_K\right)$$

$$\Delta G \approx -32992.5 \ J$$

$$\Delta G \approx -33000 \, J$$

b) Find the value directly in the table on page 405 of Schroeder.

Find the value of the Gibbs free energy from page 405 and multiply by two because there are two moles.

$$\Delta G \approx 2 \times -16.45 \, kJ$$

$$\Delta G \approx -32900 \, J$$

The values are very close. The difference primarily comes from rounding and uncertainty in tabulated values.

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.