Topics in Physics: Problem Set #8

Topics: thermodynamics, entropy

Half-length problem set

This problem set is designed to take about half of the afternoon session to complete. Plan to spend the remaining time in the session working on your final projects.

Challenge Problems (approx. 90 min)

You may work in small groups to solve these problems, but each student should submit and understand their own answer. These problems are challenging but not impossible to solve. If you get stuck, ask another student or a TA how to approach the problem, and if you are helping another student, try to explain so they understand how to solve the problem (don't just give them the answer). Show all your work and walk the reader through the solution; you may get feedback on both the approach and the clarity of your solutions.

1. Macrostate 1 could be any of Ω microstates. Macrostate 2 could be any of 2Ω microstates. Macrostate 3 could be any of Ω^2 microstates. Ω is a *very* large number. Compare the entropies of each macrostate to each other macrostate.

2. A pressure cooker slowly heats a constant volume of air. If the air pressure was 1 atmosphere when the pressure cooker was first turned on (at room temperature) and is now 1.5 atmospheres, how hot is the pressure cooker? (use the ideal gas law!)

3. Look up the performance of your computer's CPU online to get an estimate of the number of FLOPS (floating point operations per second) it can perform. If you can't find a direct statistic for FLOPS, you can estimate the number by [number of cores $\times$ clock speed of CPU (cycles / sec) $\times$ FLOPs / cycle]. (Typically this last value is either 8 or 16; you can probably find it on the Wikipedia page for FLOPS.) If your CPU uses double-precision (DP) FLOPS, there are 64 bits per floating point operation. Calculate the effective information processing speed of your CPU in bits/sec. If you assume that all information the CPU computes is quickly overwritten (this is a good assumption as most of it is stored in volatile L0-L3 cache memory), what is the theoretical minimum power cost to run your CPU at max capacity at room temperature? Look up the power consumption of your CPU. (This page may be helpful: `https://en.wikipedia.org/wiki/List_of_CPU_power_dissipation_figures`) How far from optimal efficiency is it? (Note: if you get stuck trying to find statistics for your CPU, don't worry too much about it. You can pick a common CPU like a core i7 and just use stats for that. This is an order of magnitude calculation, so specific numbers don't matter too much.)

4. On the wikipedia page for "Atmosphere of Jupiter", you'll find a plot which shows the pressure and temperature of Jupiter's atmosphere at various altitudes relative to the clouds. Use the ideal gas law to estimate the volume of 1 mole of gas at 100km, 320km, 50km, and -132km.

5. If the exhaust gas from a car engine has a temperature of 500 degrees Celsius and the temperature of the gas just after combustion is 1500 degrees Celsius, what is the maximum theoretical efficiency of the

engine? If the car gets 30 miles per gallon at this efficiency, how much money would you save each year if the combustion temperature were 1700 Celsius (you'll have to make some reasonable assumptions).

6. Advanced alien races may efficiently harness the energy of their home star by building a Dyson sphere - an enormous structure which completely encloses a star and absorbs its heat. If we built a Dyson sphere around the sun, what would its maximum efficiency be? (Hint: T_H would be the temperature of the sun, and T_C would be the temperature of space.) What would be its maximum possible power output?

7. Look at designs for perpetual motion machines. Choose one that looks particularly interesting to you and describe how it's supposed to work. Also describe why it doesn't actually work.