Ge 212 Problem Set 3

Due Friday October 25, 2019

1. The meat thermometer: experience indicates that a piece of raw meat changes color in a predictable and monotonic way as heat flows into it during cooking. Perhaps we could imagine measuring relative temperatures of objects by letting them equilibrate with a standard piece of meat and quantifying its spectral properties. Does this meet our standards for a practical thermometer? (Compare to the conodont alteration index…)
2. Consider the following thought experiment. Take a one-component liquid at 1 atm pressure and cool it rapidly to 10 K below its freezing point.
   1. If we now hold it at constant *T* and *P*, what will happen?
   2. As the process you describe in (a) happens, what is the sign of the change in entropy of the system? (note *S*fus > 0 in all known one-component systems)
   3. While we’re at it, can you specify the signs of d*E*, D*q*, and D*w* during this process? (note *V*fus can be positive or negative; what parameters do you need to know to be sure of your answer about d*E*?) On Monday 10/21/19 we will define Gibbs free energy. What do you think is the sign of d*G* during this process?
   4. Now change the game: as soon as the sample reaches 10 K below the melting point, seal it in an isolated enclosure (constant *E*, constant *V*). Under these conditions, what is the constraint on the evolution of the entropy? And what will happen? In particular, will the system crystallize? Completely or partially (what parameters do you need to know to be sure of your answer)?
   5. Do your answers to the two questions in part (d) seem to be contradictory? That is, if *S*fus > 0 then crystallization seems to imply one sign of entropy change but perhaps you concluded that the sign would be the opposite. If so, how can that be?
3. The second law and air conditioning: An air conditioner can obey both the first and second laws of thermodynamics if it performs work in order to take in heat from a cold reservoir and exhaust it to a hot reservoir. Let *Q*C be the quantity of heat absorbed by the air conditioner (in one cycle) from the cold reservoir at *T*C, let *Q*H be the quantity of heat exhausted to the hot reservoir at *T*H. Let *W* be the work done **on** the air conditioner.
   1. Write the first law applied to one cycle of the air conditioner in terms of the above variables; the internal energy is the same at the beginning and end of a cycle (*E* = 0).
   2. Write the second law for one cycle (as an inequality, in terms of the variables given above).
   3. Combine the above two equations to get an inequality giving the minimum work that must be done on the system to drive this cycle.
   4. For *Q*C = 1000 J and *T*C = 293 K (a comfortable indoor temperature), calculate the minimum work required to drive the air conditioner for outdoor exhaust temperatures *T*H of 303 K and 313 K.
   5. Say instead that we wanted heat the interior, i.e. to dump 1000 J *into* a room at 303 K when the ambient temperature outside is 293 K. One option is to directly dissipate 1000 J of work in the room (say with a resistance heater). Another option is to build and operate a heat pump that runs the air conditioner cycle backwards. Calculate the *maximum* factor by which it would be more expensive (curiously enough, the electric company charges us to do work on the system or to make the system do work!) to dissipate the kJ directly vs. use the heat pump to transport 1 kJ into the cold reservoir.