Ge 212 Problem Set 3

Due Friday October 23, 2015

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 (this is identical in principle to the conodont alteration index, something geologists actually use). Does this meet our standards for a practical thermometer?
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) We may not have defined Gibbs free energy yet at this point, but perhaps you’ve heard of it. If so, what do you think is the sign of dG during this process?
   4. Now change the game: as soon as the sample reaches 10 K below the melting point, enclose 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?
   5. Do your answers to the two questions in part (c) seem to be contradictory? That is, how do you deal with the fact that the solid crystal has lower entropy per unit mass than the liquid, at equal temperature?
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 QC be the quantity of heat absorbed by the air conditioner (in one cycle) from the cold reservoir at TC, let QH be the quantity of heat exhausted to the hot reservoir at TH. 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).
   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 QC = 1000 J and TC = 293 K (a comfortable indoor temperature), calculate the minimum work required to drive the air conditioner for outdoor exhaust temperatures TH 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. What is 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 directly dissipate 1000 J of work in the room (say with a resistance heater) rather than to build a heat pump that runs this air conditioner cycle backwards?