Thermodynamics: Summary and Reflections

Spring 2021

1. **Conservation of Energy**
   (a) Ideal gas law: $PV = NkT = nRT$.
   (b) Equipartition theorem: At temperature T the average energy of any quadratic degree of freedom is $(1/2)kT$.
   (c) Heat and Work.
   (d) First law of thermodynamics $\Delta U = Q + W$.
   (e) Compression work. PV diagrams.
   (f) Adiabatic and isothermal expansion/compression.
   (g) Heat capacities and latent heat.
   (h) Enthalpy.
2. **Entropy and the Second Law**
   (a) Probability and counting. Binomial distribution.
   (b) Multiplicity. Micro- and macro-states.
   (c) Einstein model of solid.
   (d) Normal vs. large vs. very large numbers. Stirling approximation.
   (e) Sharpness of the multiplicity function.
   (f) The second law: any large system in equilibrium will be found in the macrostate with the greatest multiplicity, aside from fluctuations that are normally too small to measure.
   (g) Multiplicity function for the ideal gas.
   (h) Entropy $S = k \ln \Omega$.
   (i) The second law: any large system in equilibrium will be found in the macrostate with the greatest entropy, aside from fluctuations that are normally too small to measure. Or, entropy tends to increase.
   (j) Entropy of the ideal gas (Sakur-Tetrode equation).
   (k) Entropy of mixing.
   (l) Temperature: $T = (\frac{\partial S}{\partial U})^{-1}$.
   (m) When two objects are in thermal equilibrium, their temperatures are equal.
   (n) Pressure: $P = T(\frac{\partial S}{\partial V})$.

(o) When two objects are in mechanical equilibrium, their pressures are equal.

(p) Chemical potential: $\mu = -T(\frac{\partial S}{\partial N})$.

(q) When two objects are in diffusive equilibrium, their chemical potentials are equal.

(r) Thermodynamic identity: $dU = TdS - PdV$. True for any infinitesimal change in any system.

(s) Using $Q = TdS$ (quasi-static) to calculate entropies.

(t) Macroscopic views of entropy.

3. **Applications: Heat Engines**

   (a) Upper bound on efficiency: $e \leq 1 - \frac{T_c}{T_h}$.

   (b) Carnot cycle.

   (c) Refrigerators and heat pumps.

   (d) Otto cycles and diesel engines.

   (e) Steam engines and steam tables.

4. **Applications: Chemistry**

   (a) Helmhotz free energy: $F = U - TS$.

   (b) Gibbs free energy: $G = U - TS + PV$.

   (c) Free energies as available work.

   (d) Free energies for "energy and entropy accounting".

   (e) Thermodynamic identity: $dG = -SdT + VdP + \mu dN$.

   (f) System in contact with thermal reservoir at constant P will, at equilibrium, minimize G.

   (g) Phase transitions and phase diagrams.

   (h) Clausius-Clapeyron relationship.

   (i) Vapor pressure equation.

   (j) Chemical potential is Gibbs free energy per particle: $G = \mu N$.

   (k) Relative humidity, partial pressure, and dew point.

Some math topics:

1. Combinatorics and probability.
2. Taylor expansions.
3. Normal vs. large vs. very large numbers.
4. Lots of Calc I, II and III material.

Some themes and ideas:

1. Structure and style of physics
2. Physics vs. chemistry
3. Physics vs. math
4. Thermodynamics is a broadly applicable theory built from a small number of general principles: the first law (conservation of energy); the second law (entropy increases, which is really a mathematical result concerning very large systems); and a number of useful definitions and constructions (temperature, Gibbs free energy, etc.).
5. Some features of large systems are independent of the system's constituents.

Thoughts on the course:

1. This is the third time I've taught this course at COA. I think I'm happy with how it went, but it's hard to know how to think about things given we're 15 months into a global pandemic.
2. I think this is a good course for COA because it is a broadly applicable area of physics, touching on physics, chemistry, geology, and some aspects of biology.
3. I find myself lecturing in this course more than I have in almost any other class. I think that's ok, even though I think there are limits to the effectiveness of lecturing.

Goals for the course:

1. Stay physically and mentally healthy and maintain intellectual and personal connection in a time of dispersal and isolation.
2. Experience the challenge, joy, and beauty of physics. I want you to gain an understanding and appreciation of the structure and style of physics as an intellectual approach and discipline.
3. I want to learn the basic principles and techniques of thermodynamics, and be able to apply thermodynamics to problems across the sciences.
4. Improve your problem solving skills and mathematical confidence. Leave this course with an increased ability to do mathematics and physics.
5. Have fun while learning a lot.