Final Exam — New Materials

- Boltzmann Statistics
  - What is the Boltzmann factor of a microstate?
  - What is the partition function?
  - Under what condition are Boltzmann factors useful? (Call said condition "Boltzmann statistics")
  - What is the probability that a system is in a particular microstate, under Boltzmann statistics?
  - Which is the most likely microstate under said conditions?
  - Why are lower energy levels more likely than higher energy levels?
- Average Energy
  - How do you calculate the average of any quantity X, using Boltzmann statistics?
  - How do you calculate the average energy of a system, using its partition function? (There are two equations.)
- Paramagnet Example
  - What is the probability that a single dipole in equilibrium with a thermal reservoir will point in the direction of the magnetic field if the temperature of the reservoir is
    - high?
    - low?
    - negative and large in magnitude?
    - negative and small in magnitude?
- Equipartition Theorem
  - How can you derive the equipartition theorem using Boltzmann statistics?
  - When is this derivation not valid?
- Partition Function and Free Energy
  - What are the natural variables of the partition function Z?
  - How is the partition function related to the Helmholtz free energy?
  - How can I calculate the entropy, pressure, and chemical potential of a system, given its partition function?
- Composite Systems
  - If the partition function of a particle is Z1, what is the partition function of N such particles if they are distinguishable? How about if they are indistinguishable?
  - What is the quantum volume of an ideal gas?
  - What is the partition function of an ideal gas of N particles, in the high-temperature limit?
  - What determines whether an ideal gas is in the "high-temperature limit", so that this partition function is valid?
- Gibbs Statistics

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- In Chapter 7 we discuss "Gibbs statistics", when a system is in what kind of equilibrium with its environment? (That is, what can the system exchange with its environment?) Note: this is not related to the Gibbs free energy (in any direct way at least)
- What is the Gibbs factor for a microstate?
- What is the grand partition function?
- What is the probability that a particular microstate is occupied, under Gibbs statistics?
- Understand the carbon monoxide poisoning example (you may see something like it on the exam)
- How is the chemical potential of an ideal gas related to the number density of molecules in that gas?

Gibbs Statistics Applied to N Particles

- In the rest of this chapter we will consider a set of N identical particles, each with a set of energy microstates. We will apply Gibbs statistics by defining our "system" to be all particles in a given microstate, and the "reservoir" as all the other particles. Be sure you're comfortable with this concept
- Define the occupancy of a microstate.
- We considered a high-energy and a low-energy regime. In which regime might the particles be considered to be non-interacting? Why?
- What is the baseline energy that we will consider when determining whether a given microstate is high– or low–energy?

Non-Interacting Particles

- Why can we use Boltzmann statistics in this case?
- What is the partition function of N non-interacting particles, in terms of the chemical potential μ?
- What is the average occupancy of an energy level E in this case?
- What is the Maxwell-Boltzmann distribution?

Bosons and Fermions

- What is the chief difference between bosons and fermions, in the context of this chapter?
- If you have N identical particles, in which energy microstates (high or low) does the boson/fermion distinction become important?
- What is the grand partition function for bosons? for fermions?
- What is the average occupancy for an energy microstate E of a boson?
- What is the average occupancy for an energy microstate E of a fermion?
- What is the Fermi-Dirac distribution?
  - How are the energy microstates of fermions occupied at low temperature? high temperature?
  - What is the significance of an energy microstate with energy $E=\mu$?

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- What is the Bose-Einstein distribution?
    - What is the relationship between the chemical potential μ and the possible energy values of a boson's microstates?
- For high-energy microstates, both Fermi-Dirac and Bose-Einstein approach the same distribution. What is it?

- Fermi Gas at Low Temperature
    - What is the Fermi energy EF of a Fermi gas?
    - How do the fermions fill up the available energy microstates?
    - How do we calculate the Fermi energy of a gas in 3D?
    - What is the degeneracy pressure of a fermion gas? Name a circumstance where it is important.
    - What is the density of states g(E)?
    - What is the difference between n(E), g(E), and n(E)g(E)?
- Photons
    - Why do we consider photons to be bosons?
    - What is the ultraviolet catastrophe, and how did Planck solve it?
    - What is the chemical potential of photons, and what does it mean?
    - What are the possible energy states of photons in a 3D box of side L, how are they numbered, and what are their energies?
    - What is the blackbody spectrum u(E), and how is it's derived?
    - How does the total energy density U/V of a photon gas depend on temperature?
    - How does the peak in the spectrum depend on temperature?
- Phonons
    - What are phonons?
    - What are the three ways phonons are different from photons?
    - How do we calculate the total energy of a phonon gas?
    - How does the heat capacity of a solid depend on temperatures, at low T? What if the solid is a metal?
- Ising Model
    - What is the difference between a paramagnet and a ferromagnet?
    - What is the Ising model?
    - How does the mean field approximation work?
    - What happens in the mean field approximation of the Ising model at the critical temperature?