

Write clearly and show all work leading to your results. Write on only one side of the page.

1. Use the number of microstates at fixed N, V, E to calculate the equation of state for a gas of hard spheres of radius ρ .
2. (a) If molecules of a given species are considered distinguishable, the entropy is $S(N, V, E) = Nk \ln \left[\frac{V}{h^3} \left(\frac{4\pi m E}{3N} \right)^{3/2} \right] + \frac{3}{2} Nk$. What is wrong with this formula?
 (b) How did Gibbs change the counting that led to (a)?
 (c) Use the correct Sakur-Tetrode entropy formula,

$$S(N, V, E) = Nk \left[\ln \frac{V}{N} + \frac{5}{2} + \frac{3}{2} \ln \frac{2\pi m k T}{h^2} \right],$$

to calculate the entropy of mixing for two different ideal gases of molecular masses m_1 and m_2 if the gases are initially in two chambers with volumes V_1 and V_2 at temperatures T_1 and T_2 and concentrations (i.e., number densities) n_1 and n_2 . You can also use the initial number of molecules of each gas in each chamber, $N_i = n_i V_i$.

- (d) Separate your result in (c) into terms connected with (i) the mixing of different species, (ii) the mixing of different concentrations, and (iii) the mixing of different temperatures.
3. A surface with N_0 adsorption centers has $N \leq N_0$ gas molecules adsorbed on it. Each adsorbed gas molecule has a quantum harmonic oscillator energy spectrum characterized by angular frequency ω . Use the grand canonical partition function to calculate an explicit formula for the chemical potential μ in terms of universal constants, N_0, N , and ω .
4. Find the relation between the fluctuation of the energy, $\langle (\Delta E)^2 \rangle = \langle (E - \langle E \rangle)^2 \rangle$, and the specific heat at constant volume, in the canonical ensemble.