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Problem Set #9

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Problems 1-3 refer to: N identical, noninteracting, and *distinguishable* quantum harmonic oscillators (i.e., their separation is much greater than their de Broglie wavelength) are in thermal equilibrium at temperature T . The energy of each oscillator can be expressed as $\varepsilon_n = n\varepsilon$, where ε is the level spacing and $n = 0, 1, 2, \dots$. Note: For distinguishable particles, the chemical potential cancels out of calculation of probabilities, so $P_\sigma = \exp(-\varepsilon_\sigma/k_B T) / \sum_{\sigma'} \exp(-\varepsilon_{\sigma'}/k_B T)$. Here each quantum state σ corresponds to the integer n only.

1. Show that the probability of finding an oscillator in state n is

$P_n = [1 - \exp(-\varepsilon/k_B T)] \exp(-n\varepsilon/k_B T)$. (Hint: To do this, you have to evaluate the denominator in the probability expression above. You will also need to recall that the sum of a geometric series is $\sum_{n=0}^{\infty} x^n = \frac{1}{1-x}$, provided $x < 1$.)

2. Using the result in problem 1 above, show that the probability an oscillator is in an excited state goes to zero as $T \rightarrow 0$.

3. Suppose $\varepsilon/k_B = 100$ K. What is the probability of finding an oscillator in the ground state at room temperature ($T = 300$ K)?