Physics 306: Thermal Physics

First Midterm

Stony Brook University

Spring 2023

General Instructions:

You may use one page (front and back) of handwritten notes and a calculator. Graphing calculators are allowed. **No other materials may be used**.

Problem 1. Atoms 123

Twelve moles of atoms are placed in row. Each atom can be in one of three states: state 1, state 2, or state 3. Consider selecting two moles of atoms to be in state 1, four moles of atoms to be in 2, and, six moles of atoms to be in state 3.

(a) Explain why there are

$$W = \frac{N!}{N_1!N_2!N_3!}\,, \tag{1}$$

ways we can make this selection. Here $N = N_1+N_2+N_3$ is the total number atoms, and N_1, N_2 and N_3 are the number of atoms in each corresponding state, e.g. $N_1 = 2\,$moles.

(b) Evaluate W numerically.

Problem 2. Energy distribution of a 2d world

Consider a mono-atomic ideal gas of mass m in two spatial dimensions at temperature T. The number of atoms in the box is N and the box has area L^2.

(a) What is average energy and the rms velocity of the atoms in the gas?

(b) Find the normalized probability distribution for speeds between v and $v + \mathrm{d}v$

$$\mathrm{d}\mathscr{P} = P(v)\mathrm{d}v\,, \tag{2}$$

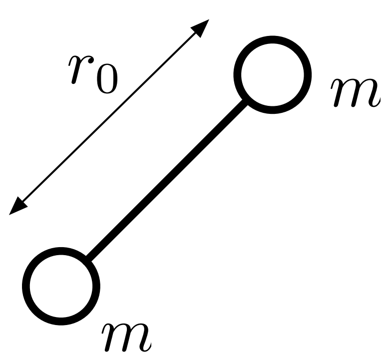
and determine the corresponding energy distribution

$$\mathrm{d}\mathscr{P} = P(\epsilon)\mathrm{d}\epsilon\,. \tag{3}$$

(c) What is the variance in the energy $\langle \delta\epsilon^2 \rangle$?

Problem 3. Angular velocity of oxygen in air

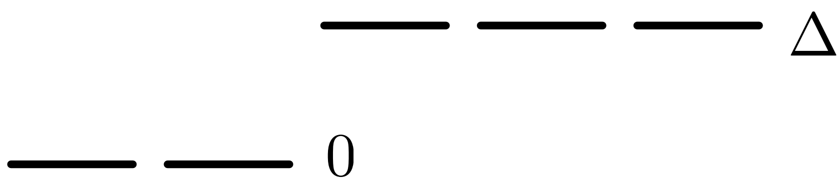
(a) Consider an ideal diatomic molecular gas at temperature T. The atoms have mass m and are separated by bond length of r_0. Determine the root-mean-square angular velocity, $\omega_{\mathrm{rms}} = \sqrt{\langle \omega^2 \rangle}$.



(b) Estimate ω_{rms} numerically in Hz for diatomic Oxygen O_2 in this room. An Oxygen atom consists of eight protons and eight neutrons.

Problem 4. High and Low

An Avogadro's number of atoms N_A are placed on a line at temperature T. The atoms are independent of each other and can be in one five states: the first two states have the same energy level, called 0, while the remaining three states have a higher energy level, Δ. The level scheme is shown below.



(a) Determine the mean energy of an atom.

(b) Determine the difference in the number of atoms with energy zero and energy Δ, i.e. $\delta N \equiv N_0 - N_\Delta$. Sketch the δN versus temperature, qualitatively explain the value of δN in the low and high temperature limits.

(c) Given an ensemble of atoms initially at temperature T, what is the energy required to put all of the atoms in the upper energy level.