General Physics II at EPFL -- Thermodynamics

Mock exam II

Schedule: work for 1h15min on the problems on your own, "pretending" it was an exam situation. In the last 60min, the exam problems will be solved together with the TA at the black board.

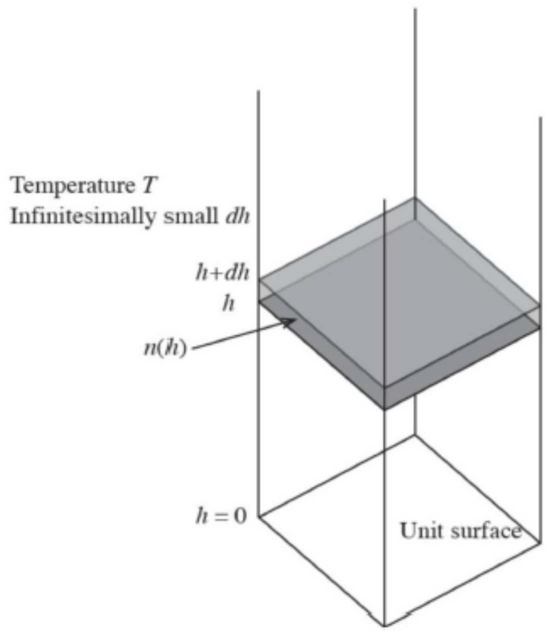
1. *Statistical physics & Boltzmann factor*

Boltzmann factor gives that the number of gas molecules with an energy E, for a gas at an absolute temperature T to be $\propto e^{-E/kT}$, where k is the Boltzmann constant. A gas molecule on the earth gains potential energy mgh, where h is the altitude of the molecule position measured from the sea level, m the mass of the gas molecule and g gravitational constant. By assuming that the energy of the gas molecule is totally given by the earth gravity (a reasonable assumption since the earth atmosphere does not escape to the outer space) and the temperature does not depend on the altitude:

1) Obtain the number of gas molecules for a unit surface with an infinitesimally small thickness at an altitude of $h, n(h)$, using n_0, which is the number of gas molecules per unit surface with an infinitesimally small thickness at $h = 0$.

2) Assuming that the gas is an ideal gas, obtain the pressure of the gas, $P(h)$, at an altitude h from $n(h)$.

3) Show that the gas pressure at the sea level is equal to the gravity force acting on the total mass of the gas molecules (altitudes from 0 to ∞) per unit surface.



2. Atkinson cycle

James Atkinson was a British engineer who designed several combustion engines. The Atkinson cycle is a modification of the Otto cycle intended to improve its efficiency. The trade-off in achieving higher efficiency is a decrease in the work performed per cycle. The idealised Atkinson cycle consists of the following reversible processes

- $1 \to 2$: adiabatic compression
- $2 \to 3$: isochoric heating
- $3 \to 4$: isobaric expansion
- $4 \to 5$: adiabatic expansion
- $5 \to 6$: isochoric cooling
- $6 \to 1$: isobaric cooling

Assume that the cycle is operated on an ideal gas. The following physical quantities that characterise the cycle are assumed to be known: volumes V_1, V_2, and V_6, pressure P_1 and P_3, temperature T_5 and the number of moles n of the gas. Analyse this cycle by answering the following questions:

a) Draw the PV diagram of the Atkinson cycle.

b) Determine the pressures P_2, P_4, P_5, P_6 and volumes V_3, V_4, V_5 and the temperatures T_1, T_2, T_3, T_4, T_6 in the terms of the known physical quantities (described above).

c) Calculate the works for each subprocess (W_{12}, W_{23}, W_{34}, W_{45} W_{56}, W_{61}) and the total work performed per cycle as a function of the temperatures.

d) Estimate the heat transfer for each subprocess (Q_{12}, Q_{23}, Q_{34}, Q_{45}, Q_{56}, Q_{61}) as a function of temperatures. Also estimate the change in internal energy during the isobaric processes as a function of temperatures.

e) Imagine the Atkinson cycle is used as a refrigerator. How does the cycle, work and heat exchange have to modified? What is the coefficient of performance (COOP) of such a refrigerator? How would the COP change, if it was used as a heat pump?