Thermodynamics and Statistical Physics

Part I – Thermodynamics

Intermediate Exam 1

Thursday, September 20 2018, 15:00-17:00, Aletta Jacobshal 01

The total number of points that can be reached in this exam is 90.

Final grade = (points/10) + 1.

This exam has **TWO** pages, please also look at the other side!

1) The molecular weight of a hemoglobin protein is about 64458 u. Calculate the number of moles in a mg of hemoglobin. **(10 pt)**
2) Write down the ideal gas law. **(5 pt)**
3) A freshly cast iron object (m=0.4 kg, T=900 ^oC) is thrown into a bucket containing 1l of water at room temperature for cooling. There is no heat flow to the surroundings. The heat capacity of iron is $C_{p,m} = 25.09$ $JK^{-1}mol^{-1}$ and the heat capacity of water is $C_{p,m} = 75.3$ $JK^{-1}mol^{-1}$. The molar mass of iron is 55.85 g/mol and for water it is 18 g/mol. Heat capacities can be assumed as constant for the temperature range under study. Volume effects can be neglected and the pressure is constant. Calculate the heat capacity of the given amounts of the iron and of the water. Determine the final temperature of the combined system. Discuss the result. **(25 pt)**
4) Assume a quantum system with two energy levels that are separated by E_1-E_0= 1.66 x 10^{-19} J. Assuming a canonical ensemble, what is the probability of finding the system in the lower state when the temperature is 10^6 K? **(10 pt)**
5) Give the thermodynamic definition of the temperature in terms of the number of microstates and the energy of the system. **(10 pt)**
6) You throw two dice and get a 2 and a 4. Use this to explain the concept of microstates and macrostates. What is the probability of the macrostate and the microstate for this outcome? **(10 pt)**
7) The distribution of molecular speeds (Maxwell-Boltzmann distribution) has the form $f(v) \propto v^2 e^{-mv^2/2kT}$. The factor v^2 before the exponential comes from …
   a) the quadratic dependency of the particle kinetic energy on v.
   b) the integration of a spherical shell volume in velocity space.
   c) averaging the Boltzmann distribution.

   Tick the correct answer. **(10 pt)**

8) Assume a bottle filled with (ideal) gas at temperature T_{bottle}. The particles have a mean free path λ and an average speed $\langle v_{bottle} \rangle$. When particles effuse out of the bottle through a small hole, their average speed $\langle v_{effused} \rangle$ is

a. larger than $\langle v_{bottle} \rangle$, if the hole diameter is larger than λ
b. larger than $\langle v_{bottle} \rangle$, if the hole diameter is smaller than λ
c. smaller than $\langle v_{bottle} \rangle$, if the hole diameter is larger than λ

Tick the correct answer. **(10 pt)**

Physical constants:

Avogadro's number:	$N_0 = 6.02 \times 10^{23}$ mol^{-1}
Planck's constant:	$h = 6.626 \times 10^{-34}$ Js
	$\hbar = \frac{h}{2\pi} = 1.055 \times 10^{-34}$ Js
Boltzmann's constant:	$k = 1.381 \times 10^{-23}$ J K^{-1}
Gas constant:	$R = 8.31$ J mol^{-1} K^{-1}
Speed of light:	$c = 3 \times 10^{8}$ m s^{-1}
Electron rest mass:	$m_e = 9.11 \times 10^{-31}$ kg
Proton rest mass:	$m_p = 1.67 \times 10^{-27}$ kg
Charge of the electron:	$e = 1.60 \times 10^{-19}$ C
Bohr magneton:	$\mu_B = \frac{e\hbar}{2m_e} = 9.27 \times 10^{-24}$ A m^2
Permeability of vacuum:	$\mu_0 = 4\pi \times 10^{-7}$ N A^{-2}
Molar volume at STP:	22.4 litre