Thermodynamics and Statistical Physics

## Part I – Thermodynamics

## Intermediate Exam 2

Thursday, October 11 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 pressure in in the thermosphere outside the international space station (about 340 km above sea level) is about $10^{-5}$ Pa and the temperature is about 1100 $^{o}$C. Estimate the mean free path of an $N_2$ molecule ($M_{N2}$=28 g/mol, d=0.37 nm) under these conditions **(7 pt).** At which pressure would the mean free path be as long as the ISS orbit (the radius of the earth is 6371 km) **(3 pt)**?
2) Express the first law of thermodynamics as an equation and with words. **(5 pt)**
3) Explain the concept of thermodynamic "reversibility" for the case of an expanding ideal gas. **(10 pt)**
4) a) The number of ideal gas particles hitting a unit area in unit time, having speeds between $v$ and $dv$ and traveling at angles between $\theta$ and $d\theta$ with respect to the normal of the hit area is given by:

$$v\,cos\,\theta\,n\,f(v)\,dv\,\frac{1}{2}\sin\theta\,d\theta$$

Use this information together with the definition of the heat flux in *z*-direction

$$J_z = -\kappa\left(\frac{\partial T}{\partial z}\right)$$

to show that

$$\kappa = \tfrac{1}{3}C_V\lambda\langle v\rangle$$ **(6 pt).**

b) In a 1.3 $m^2$ double glazed window, the panes of glass are separated by 1 cm and the volume in between is filled with Ar ( $M_{Ar}$=40 g/mol, $\kappa = 0.016$ $JK^{-1}m^{-1}s^{-1}$). How much energy is lost per second through the glass when the temperature inside is 23 $^{o}$C whereas outside it is -5 $^{o}$C? Is Ar a better heat conductor than $N_2$? **(9 pt)**

5) The thermal diffusion equation for a sphere can be written as

$$\frac{\partial T}{\partial t} = D\,\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T}{\partial r}\right)$$

if there is no dependence on the angular coordinates and r is the radial coordinate. Give a general solution for the steady state case **(5 pt)**. Give the solution for the boundary condition of a spherical animal of radius $r_0$, with body temperature $T_{body}$ for $r = r_0$ and a temperature of the outside medium $T_{outside}$ for $r \to \infty$. The thermal conductivity of the medium is $\kappa$ **(5 pt)**. How much heat does the animal loose to the medium per second **(5 pt)**?

6) What is the heat capacity at constant volume $C_V$(per particle) of a (monoatomic) ideal gas such as H? Why can $C_V$ be different for an ideal gas of diatomic molecules such as $H_2$? Why is $C_V < C_p$ for an ideal gas? **(15 pt)**
7) The internal energy of a system is
   a) the sum of the translational kinetic energy of all particles in the system.
   b) the sum of the energy of all the internal degrees of freedom that the system possesses.
   c) a quantity that can only be changed by heat flow into the system of out of the system **(10 pt)**.
8) Which one of the following quantities is NOT a state function?
   a) pressure
   b) expansion work
   c) temperature
   d) volume **(10 pt).**

**Physical constants**:

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|---|---|
| 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 |