ENGR 352 – THERMODYNAMICS – FALL 2017 – TERM EXAM I

- You have **55 minutes** from the moment that the beginning of the exam is announced.
- Below you find three exam problems. Each carries the same weight, i.e., 7.5 credits (out of 100 credits for the course). At most 15 credits can be gained from the present term exam. If you **choose to work on two problems**, the outcome of these two problems will count. If you **choose to work on three problems**, the two best outcomes count, whereas the problem with the least amount of credits obtained is disregarded.
- Make sure that every sheet of paper you submit contains your **name** and **student ID**. Any access to means of communication, e.g., **cell phones**, constitutes a case of **cheating** irrespective of what is communicated.

[Problem I.1] A constant amount of molecular nitrogen N_2, with m = 0.05 kg, which is here to be regarded as an **ideal gas**, undergoes the following sequence of transitions:

- *State 1* to *state 2* (1 → 2), **isothermal** compression from p_1 = 60 kPa to p_2 = 100 kPa.
- *State 2* to *state 3* (2 → 3), **isobaric** expansion until a volume of V_3 = 75 l is reached.
- *State 3* to *state 1* (3 → 1), **isochoric** cooling until the pressure p_1 = 60 kPa is reached.

Show the states and the transitions between them in a **p-V diagram**.

Determine the total amount of **work done by the gas** (note: opposite sign as work *done to* the gas) and the total amount of **heat transferred to the gas** for the whole process 1 → 2 → 3 → 1.

The universal gas constant is R = 8.3145 J K^{-1} mol^{-1}. The molar mass of N_2 is M = 28.01 g mol^{-1}. Note that this series of transitions is a cycle, since the initial and final states are the same.

[Problem I.2] A piston-cylinder device, which maintains a constant pressure p = 80 kPa inside, contains n = 15 mol water, part of which are **steam** and part of which are **liquid water**. This system undergoes a transition during which part of the steam condenses, by which the volume decreases to 50% of the initial volume. In the final state, n^{l} = 14.4 mol of the water are liquid, while the remaining n^{ll} = 0.6 mol belong to the vapor phase.

How much heat is transferred from the water to the surroundings, and **how much work is done** to the water? Assume that the system is stationary and that no dissipation occurs.

For water at p = 80 kPa, the boiling temperature is T = 366.6 K, the saturated liquid density is ρ^{l} = 53.45 mol l^{-1}, the saturated vapor density is ρ^{ll} = 26.60 mol m^{-3}, and the molar enthalpy of vaporization is $\Delta h^{v} = h^{ll} - h^{l}$ = 40.95 kJ mol^{-1}. Water has a molar mass of M = 18.02 g mol^{-1}.

[Problem I.3] Heat transfer during isobaric processes is characterized by the specific isobaric heat capacity $c_p = (\partial h \,/\, \partial T)_p$. Thermodynamic data for **liquid butane** at p = 2500 kPa include:

p = 2500 kPa and T = 360.0 K:	v = 0.002 018 m^3 kg^{-1}	u = 418.2 kJ kg^{-1}	c_v = 1.964 kJ K^{-1} kg^{-1}
p = 2500 kPa and T = 370.0 K:	v = 0.002 089 m^3 kg^{-1}	u = 447.2 kJ kg^{-1}	c_v = 2.007 kJ K^{-1} kg^{-1}
p = 2500 kPa and T = 380.0 K:	v = 0.002 175 m^3 kg^{-1}	u = 477.6 kJ kg^{-1}	c_v = 2.054 kJ K^{-1} kg^{-1}
p = 2500 kPa and T = 390.0 K:	v = 0.002 286 m^3 kg^{-1}	u = 509.8 kJ kg^{-1}	c_v = 2.107 kJ K^{-1} kg^{-1}

Determine the **specific isobaric heat capacity of liquid butane** at p = 2500 kPa and T = 375 K.

You may interpolate between data points. Recall that the specific internal energy and the specific enthalpy are related by $h = u + pv$. The molar mass of butane is M = 58.12 g mol^{-1}.