

ENGR 352 – THERMODYNAMICS – SPRING 2018 – TERM EXAM I

At this exam, you have little time. Recommendation: Solve two out of the three given problems.

- You have **55 minutes** from the moment that the beginning of the exam is announced.
- This exam consists of three problems. Each is worth up to eight credits, out of 100 credits for the whole course. At most twelve credits can be gained from the present term exam.

You need to **work on two problems** to achieve an optimal outcome.

- If you **choose to work on two problems**, the problem with the best outcome will count normally (i.e., up to eight credits), and the other problem will count with a factor of 50% (i.e., up to four credits), yielding an **optimum total of 12 credits**.
- If you choose to work on all three problems, the outcomes will be ordered by the number of credits achieved. **The best problem counts with a factor of 100%**, and **the second best problem counts with a factor of 50%**, yielding up to 12 credits for the exam as a whole. The outcome of the remaining problem does not influence your grade.
- Any concerns on scheduling, grading, or any other matter should be addressed to the VHOD.

Make sure that **every paper** that you submit contains your **name** and **student ID**. Any access to means of communication is a case of cheating irrespective of what is communicated. It is enough to **turn off your cell phones**. *You absolutely do not need to place your cell phones on the front desk.*

Recall that it is sufficient to **solve two out of the three present exam problems**. Feel free to hand in your submission at any time and leave the room without disturbing the other participants.

AUIS student ID number: _____

Full name: _____

[Problem I.1] An amount $n = 6$ mol of ideal gas methane is compressed isothermally, at the temperature $T_1 = T_2 = 360$ K, from $p_1 = 300$ kPa to $p_2 = 600$ kPa.

Balancing the gas as a closed system, and assuming that the transition from state 1 to state 2 occurs reversibly and that no kinematic work is done (stationary system), determine the compression **work W** done to the gas, the amount of **heat $-Q$** transferred from the system to the surroundings, the **internal energy change $\Delta U = U_2 - U_1$** , and the **enthalpy change $\Delta H = H_2 - H_1$** .

Sketch the transition $1 \rightarrow 2$ in **p - v and T - s diagrams** (i.e., sketch both diagrams). *Here, a qualitative sketch is enough.*¹ The critical temperature of methane, $T_c = 190.6$ K, is much smaller than 360 K; accordingly, it is *not necessary to include the vapor-liquid coexistence curve* here.

The universal gas constant has the value $R = 8.3145$ J K⁻¹ mol⁻¹. For an ideal gas, changes in specific entropy can be obtained by integration of $ds = Rv^{-1} dv + c_v T^{-1} dT$, while $u(T)$ and $h(T)$ are functions of temperature only, with $c_v = du/dT$ and $c_p = dh/dT$. For methane at 360 K, the specific heat capacities are given by $c_v = 3.636 R$ and $c_p = 4.636 R$, and their ratio is $\kappa = c_p/c_v = 1.275$.

[Problem I.2] Refrigerant R41 (i.e., fluoromethane) undergoes an adiabatic throttling process. R41 enters the throttling valve, operating in a steady state, as a saturated liquid at $p_{in} = 4300$ kPa and $T_{in} = +30^\circ\text{C}$; it leaves in a vapor-liquid equilibrium state at $p_{out} = 200$ kPa and $T_{out} = -65^\circ\text{C}$.

Determine the **change of molar enthalpy $\Delta h = h_{out} - h_{in}$** , in units of kJ mol⁻¹, and the **change of molar entropy $\Delta s = s_{out} - s_{in}$** , in units of J K⁻¹ mol⁻¹, for the fluid as it goes through the throttling valve. By what amount Δs^{rev} would the entropy change if the process was reversible (but still adiabatic), and hence, **what percentage of the molar entropy change Δs is caused by dissipation?** What percentage of the molar entropy change Δs is **caused by heat transfer?**

Sketch the process in a **log p - h diagram** containing the vapor-liquid coexistence curve. *Here, a qualitative sketch is enough.*¹ The following data can be used:

The critical temperature of fluoromethane is $T_c = 44.1^\circ\text{C}$; the critical pressure is $p_c = 5900$ kPa.

At -65°C , the saturated vapor pressure is $p^{sat} = 200$ kPa, the saturated liquid has the molar enthalpy $h^l = 1.76$ kJ mol⁻¹ and the molar entropy $s^l = 13.37$ J K⁻¹ mol⁻¹, and the saturated vapor has the molar enthalpy $h^v = 17.71$ kJ mol⁻¹ and the molar entropy $s^v = 89.97$ J K⁻¹ mol⁻¹.

At $+30^\circ\text{C}$, the saturated vapor pressure is $p^{sat} = 4300$ kPa, the saturated liquid has the molar enthalpy $h^l = 9.84$ kJ mol⁻¹ and the molar entropy $s^l = 44.11$ J K⁻¹ mol⁻¹, and the saturated vapor has the molar enthalpy $h^v = 16.93$ kJ mol⁻¹ and the molar entropy $s^v = 67.48$ J K⁻¹ mol⁻¹.

[Problem I.3] A piston-cylinder device initially contains $n^l = 3$ mol liquid propylene and $n^v = 3$ mol propylene vapor. The propylene is compressed at constant pressure $p = 1400$ kPa. Assume the device to be stationary and the compression to occur reversibly without any dissipation. Accordingly, the only form of work done here is compression work, which amounts to $W = 4.45$ kJ.

Determine the change of entropy ΔS for the propylene inside the device, in units of J K⁻¹.

Vapor-liquid equilibrium data for propylene at a saturated vapor pressure of $p^{sat} = 1400$ kPa include the boiling temperature $T = 306.0$ K, the saturated liquid volume $v^l = 0.086$ l mol⁻¹, the saturated vapor volume $v^v = 1.411$ l mol, and the enthalpy of vaporization $\Delta h^v = 13.42$ kJ mol⁻¹. Recall the definition of entropy change as reversible heat transferred divided by temperature.

¹ **Intended interpretation:** *You have little time. Do not waste any time drawing overly beautiful or accurate diagrams.*

ENGR 352 - THERMODYNAMICS - SPRING 2018 - TERM EXAM I

AUIS student ID number: _____

Full name: _____