Tutorial 3: First Law of Thermodynamics (closed & open system) including specific heats

Note: numerical solution are based on one approach to solving the tutorial questions. Other approaches can also be correct and could lead to slightly different numerical answers.

Conceptual Questions:

1. For the classical sign convention of the first law (i.e. $\Delta E_{sys} = Q_{net} - W_{net}$), what is regarded as positive work and positive heat?

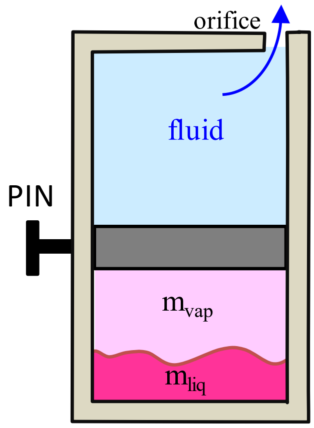
2. Briefly explain the three modes of heat transfer.

3. Using the definition of enthalpy (h = u + Pv) and the definitions du = Cv*dT and dh = Cp*dT, show that $C_P = C_V + R$ for an ideal gas.

4. What is the definition of the specific heat ratio (k)?

Problem Solving Questions:

5. A piston cylinder device is comprised of two compartments. The bottom compartment is closed and contains refrigerant R-134a. The top compartment is open with a small orifice and contains an unknown fluid. The closed compartment contains 2.5 kg of refrigerant R134a at -20°C. Initially 25% of the refrigerant exists as a vapor, while the remaining exists as a liquid. A pin is used to secure the piston in place.



(a) Heat is transferred to the cylinder via an electric heater, while the pin is still locked. The refrigerant temperature rises to 30°C. Determine the heat transferred (in kJ).

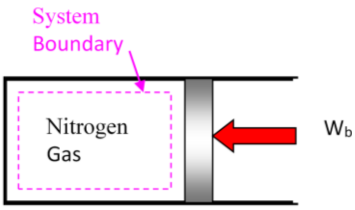
(b) The electric heater is turned off and the pin is removed. The piston moves upward and fluid exits the top compartment such that the pressure in the closed compartment decreases linearly with increasing volume. The cylinder expands until the refrigerant is a saturated vapor at 400 kPa. Determine the final temperature, boundary work, and any heat transfer to the surroundings.

[(a) Q = 439.25 kJ, (b) 8.84°C, W_b = 17.5 kJ, Q = -18.95kJ]

6. Complete the table below (for substances that can be assumed to be ideal gases, where these are properties at 300K, R_u = 8.314 kJ/(kmolK)).

Substance	**Molar mass kg/kmol**	**R kJ/(kgK)**	**C_p kJ/(kgK)**	**C_v kJ/(kgK)**	**k**
Air		0.287			1.400
Carbon Dioxide			0.846	0.657	
Hydrogen	2.016			10.18	
Nitrogen	28.01		1.039		
Oxygen			0.918		1.395

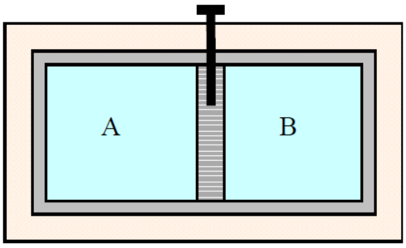
7. Three kilograms of nitrogen gas at 27°C, 0.15 MPa are compressed isothermally to 0.3 MPa in a piston-cylinder device. For nitrogen: R = 0.2968 kJ/(kgK) and the critical temperatures and pressures are T_{cr} = 126.2K, P_{cr} = 3.39MPa.



a. Show that nitrogen can be expected to behave as an ideal gas during this process.
b. Determine the minimum work of compression, in kJ.
c. Determine the heat transfer involved in this process?

[ans: (b) W_b = -184.5 kJ , (c) Q_{21} = -184.5 kJ]

8. An insulated cylinder is divided into two sections of 0.5 m^3 each by a piston which is locked by a pin. Side A has air at 300 kPa, 360 K, while side B has air at 1.2 MPa, 1000K. The piston is now unlocked so that it is free to move and it conducts heat so that the air comes to a uniform temperature $T_A = T_B$. The piston reaches an equilibrium position. Assume ideal gas with variable specific heats (i.e. use ideal gas AIR TABLES in the BACK of the BOOK (A.7 Borgnakke/Sonntag, or Table A-17 Cengel & Boles) and R = 0.287 kJ/kgK.



(a) Find the mass in section A and B.

(b) Determine the work done of the entire system.

(c) Find the final temperature and pressure

(d) Determine the piston movement in meters if the cross sectional area of the piston is A = 0.25m^2.

[ans: (a)m_A = 1.45 kg, m_B = 2.09kg, (b) 0 kJ, (c) T_2 = 751.6K, P_2 = 764.1 kPa, (d) d = 0.36 m]