APPROVED SOLUTION

CADET ____________________ SECTION ______TIME OF DEPARTURE ________

DEPARTMENT OF CHEMISTRY & LIFE SCIENCE

CH365 2020-2021
WRITTEN PARTIAL REVIEW I
7 September 2022, A-Hour

TEXT: Smith, Van Ness, & Abbott
SCOPE: Lessons 1-8

References Permitted: Open note, book, and computer. You may not share files or communicate with other cadets in any way during the exam.

INSTRUCTIONS

1. You will have 55 minutes to complete the exam.
2. Do not mark the exam or open it until "begin work" is given.
3. There are 3 problems on 4 pages (not including the cover page). Write your name on the top of each sheet. Answer all questions.
4. Solve the problems in Mathematica or in the space provided. Show work to receive for partial credit.

(TOTAL WEIGHT: 200 POINTS)

DO NOT WRITE IN THIS SPACE

PROBLEM	VALUE	CUT
A	50	
B	70	
C	80	
TOTAL CUT		
TOTAL GRADE	200	

Problem:	Weight:
A	50

A well-insulated container filled with 19.75 kg of mineral oil at 18.000 °C is fitted with a stirrer made to turn by gravity acting on a weight of mass 125.00 kg connected to the stirrer by a string and a system of pulleys. When the weight drops, energy is transferred through the pulley system into the mineral oil through the stirrer. After the weight stops falling, the mineral oil comes to rest so that any swirling motion ceases, and the bulk velocity is zero. At this point, the temperature is observed to have increased.

Assume that the fluid and mass are completely at rest before and after the mass drops and that the potential energy change of the weight is completely transferred to the mineral oil. The local acceleration of gravity is 9.807 (m)(s^{-2}), and that the specific heat of mineral oil is 1.67 (kJ)(kg^{-1})(°C^{-1}).

The first law for a steady-state, steady flow process is given by equation 2.31. Note carefully that this equation also applies to non-flow systems because the flow rate was subsumed into the different terms. (a) Write this equation in this exam and simplify it for the Joule experiment as described above. (b) Use the definition of enthalpy to explain how ΔH in equation 2.31 leads to ΔU. (c) Determine the internal energy change of the mineral oil if the final temperature is 18.402 °C.

Solution:

(a) Equation 2.31 is written and simplified below:

Define the system: Fluid in the vessel.

$$\Delta H + \cancelto{0}{\frac{\Delta(u^2)}{2}} + \cancelto{0}{g\Delta z} = \cancelto{0}{Q} + W_{shaft} \qquad \text{(Equation 2.31)}$$

The fluid system is at rest before and after the weight

The fluid does not change elevation. The weight does, but it is not part of the system.

There is no heat transfer to the surroundings because the vessel is well-insulated.

$$\underline{\underline{\Delta H = W_{shaft}}}$$

ANS

(b) ΔH is defined as ΔU+Δ(PV). The experiment is open to the atmosphere, so pressure is constant. Assume that the molar volume (and therefore density) is constant. Under these conditions, Δ(PV)=0, and ΔH=ΔU:

$$\Delta H = \Delta U + \cancelto{0}{\Delta(PV)} = \Delta U$$

$$\therefore \underline{\underline{\Delta H = \Delta U}}$$

ANS

(c) ΔH is given by equation 2.21 with constant C_p, $\Delta H = C_P\Delta T$, or $\Delta H^t = mC_P\Delta T$:

$$\therefore \Delta H^t = m \cdot C_P \cdot \Delta T = 19.7\underline{5}\,\text{kg} \cdot \frac{1.6\underline{7}\,\text{kJ}}{\text{kg deg C}} \cdot (18.402\,\text{deg C} - 18.000\,\text{deg C}) = \underline{\underline{13.\underline{2}59\ \text{kJ} = \Delta U^t}}$$

ANS

Cadet: APPROVED SOLUTION

Problem: B

Weight: 70

1. A mercury manometer is attached at one end to a pressure vessel containing a gas and is open to the atmosphere at the other end. The reading on the manometer is 23.32 inches of mercury (in Hg) and the absolute pressure in the vessel is 52.45 in Hg. What is the atmospheric pressure in psia?

Additional information: The temperature of the vessel and the surroundings are both 70 °F, the density of mercury at 70 °F is 13.543 g/cm^3, the local acceleration of gravity is 32.243 ft/s^2, and 1 torr = 1 mm Hg.

Solution:

The absolute pressure in the vessel is the sum of the manometer pressure and the atmospheric pressure, so the atmospheric pressure is obtained by subtracting the manometer (gauge) pressure from the total:

$$P_{total} = P_{gauge} + P_{atm},\ \therefore\ P_{atm} = P_{total} - P_{gauge} = 52.45 - 23.32 = 29.13 \text{ in Hg}$$

$$29.1\underline{3} \text{ inches Hg} \cdot \frac{1000 \text{ mm Hg}}{39.3701 \text{ inches Hg}} \cdot \frac{14.5038 \text{ psi}}{750.063 \text{ torr}} \cdot \frac{1 \text{ torr}}{1 \text{ mm Hg}} = \underline{\underline{14.3\underline{0}7 \text{ psi}}}_{\text{ANS}}$$

2. A mass of 14$\underline{4}$ kg is placed on a dead-weight gauge with a piston diameter of 3.0$\underline{0}$ mm. What is the pressure produced by the gauge in bar?

Additional information: The local acceleration of gravity is 9.80665 m/s^2.

Solution:

Pressures is force per area, so calculate the force, calculate the area, then divide and apply the appropriate conversion factor:

$$\text{force} = 14\underline{4} \text{ kg} \cdot \frac{9.80665 \text{ m}}{\text{s}^2} \cdot \frac{1 \text{ N}}{1 \text{ kg} \cdot \text{m/s}^2} = 14\underline{1}2.16 \text{ N}$$

$$\text{area} = \frac{\pi}{4}\left(3.0\underline{0} \text{ mm} \cdot \frac{1 \text{ m}}{1000 \text{ mm}}\right)^2 = 7.0\underline{6}86 \times 10^{-6} \text{ m}^2$$

$$\text{pressure} = \frac{\text{force}}{\text{area}} = \frac{1412.16 \text{ N}}{7.0686 \times 10^{-6} \text{ m}^2} \cdot \frac{1 \text{ bar}}{10^5 \text{ N/m}^2} = 19\underline{9}7.8 \text{ bar} = \underline{\underline{20\underline{0}0 \text{ bar}}}_{\text{ANS}}$$

Problem: C   Weight: 80

The space launch system (SLS) rocket on the Artemis 1 system uses four RS-25 engines originally developed for the space shuttle. Typical feed flow rates to the RS-25 are 907 lb/sec of oxygen and 149 lb/sec of hydrogen (in a stoichiometric ratio), from which the engine produces 1056 lb/sec of exhaust gases (clean water vapor). The pressure and temperature in the combustion chamber are 206.4 bar and 3573 K (State 1). The exhaust gases then travel out of the combustion chamber, through the nozzle, and out to the surrounding atmosphere.

The nozzle itself is actually a countercurrent heat exchanger consisting of 1,080 stainless steel tubes brazed to themselves and to a surrounding structural jacket. Hydrogen fuel gas is pre-heated by entering the tubes near the bottom of the nozzle, travelling in a circular pattern around the nozzle back to the combustion chamber, cooling the exhaust gas to about 1060 K and about 1.0 bar (State 2) at the exit of the nozzle.

The table below summarizes the conditions at States 1 and 2, where the question marks (??) designate unknowns. Complete the table and then calculate W, Q, ΔH, and ΔU for the process, in units of kJ mol^{-1}.

Assume that PV/T = 0.0831$\underline{4}$ bar L mol^{-1} K^{-1} and that the average C_P = 49.5$\underline{2}$ J mol^{-1} K^{-1} and C_V = 40.8$\underline{4}$ J mol^{-1} K^{-1} for gas-phase water.

	State 1	State 2
P, bar	206.$\underline{4}$	1.$\underline{0}$
T, K	357$\underline{3}$	106$\underline{0}$
V, L/mol	____ ??	____ ??

Solution:

Solve for V_1 and V_2:

$$\frac{P_1V_1}{T_1} = 0.08314 \Rightarrow V_1 = \frac{0.08314T_1}{P_1} = \frac{0.08314\ \frac{\text{bar}\cdot\text{L}}{\text{mol}\cdot\text{K}}\cdot 357\underline{3}\,\text{K}}{206.\underline{4}\ \text{bar}} = \underline{\underline{1.43\underline{9}2\ \frac{\text{L}}{\text{mol}}}}_{\text{ANS}}$$

$$\frac{P_2V_2}{T_2} = 0.08314 \Rightarrow V_2 = \frac{0.08314T_2}{P_2} = \frac{0.08314\ \frac{\text{bar}\cdot\text{L}}{\text{mol}\cdot\text{K}}\cdot 106\underline{0}\,\text{K}}{1.\underline{0}\ \text{bar}} = \underline{\underline{8\underline{8}.1284\ \frac{\text{L}}{\text{mol}}}}_{\text{ANS}}$$

Cadet: **APPROVED SOLUTION**

Solve for work done by the system:

Note: work done by the system is negative for an expansion where the system is the gas in the nozzle.

$$W = -P_{external}\Delta V = 1.\underline{0}\ \mathrm{bar}\cdot\left(\frac{8\underline{8}.1284\ \mathrm{L}}{\mathrm{mol}} - \frac{1.43\underline{9}2\,\mathrm{L}}{\mathrm{mol}}\right) = -8\underline{6}.6892\ \frac{\mathrm{bar}\cdot\mathrm{L}}{\mathrm{mol}}$$

Convert this to kJ/mol:

$$-\frac{8\underline{6}.6892\,\mathrm{bar}\cdot\mathrm{L}}{\mathrm{mol}}\cdot\frac{10^5\ \mathrm{Pa}}{\mathrm{bar}}\cdot\frac{\frac{1\mathrm{N}}{\mathrm{m}^2}}{\mathrm{Pa}}\cdot\frac{1\ \mathrm{m}^3}{1000\ \mathrm{L}}\cdot\frac{1\mathrm{J}}{1\,\mathrm{Nm}}\cdot\frac{1\ \mathrm{kJ}}{1000\ \mathrm{J}} = \underline{\underline{-8.\underline{6}6892\ \frac{\mathrm{kJ}}{\mathrm{mol}}}}_{\mathrm{ANS}}$$

Enthalpy change:

$$\Delta H = C_p\cdot\Delta T = \frac{49.5\underline{2}\,\mathrm{J}}{\mathrm{mol}\cdot\mathrm{K}}\cdot(106\underline{0}\,\mathrm{K} - 357\underline{3}\,\mathrm{K})\cdot\frac{1\mathrm{kJ}}{1000\,\mathrm{J}} = \underline{\underline{-124.\underline{4}438\ \frac{\mathrm{kJ}}{\mathrm{mol}}}}_{\mathrm{ANS}}$$

Internal energy change:

$$\Delta U = C_V\cdot\Delta T = \frac{40.8\underline{4}\,\mathrm{J}}{\mathrm{mol}\cdot\mathrm{K}}\cdot(106\underline{0}\,\mathrm{K} - 357\underline{3}\,\mathrm{K})\cdot\frac{1\mathrm{kJ}}{1000\,\mathrm{J}} = \underline{\underline{-102.\underline{6}309\ \frac{\mathrm{kJ}}{\mathrm{mol}}}}_{\mathrm{ANS}}$$

Heat:

$$\Delta U = Q + W \Rightarrow Q = \Delta U - W = -102.\underline{6}309\frac{\mathrm{kJ}}{\mathrm{mol}} - \left(-8.\underline{6}6892\frac{\mathrm{kJ}}{\mathrm{mol}}\right) = \underline{\underline{-93.\underline{9}62\frac{\mathrm{kJ}}{\mathrm{mol}}}}_{\mathrm{ANS}}$$

Note: heat is negative.

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PROBLEM	VALUE	CUT
A	50	
B	70	
C	80	
TOTAL CUT		
TOTAL GRADE	200	

Cadet: **APPROVED SOLUTION**

Problem: A

Weight: 50

A well-insulated container filled with 37.50 kg of liquid bromine at 18.000 °C is fitted with a stirrer made to turn by gravity acting on a weight of mass 50.00 kg connected to the stirrer by a string and a system of pulleys. When the weight drops, energy is transferred through the pulley system into the bromine through the stirrer. After the weight stops falling, the bromine comes to rest so that any swirling motion ceases, and the bulk velocity is zero. At this point, the temperature is observed to have increased.

Assume that the fluid and mass are completely at rest before and after the mass drops and that the potential energy change of the weight is completely transferred to the bromine. The local acceleration of gravity is 9.807 (m)(s^{-2}), and that the specific heat of bromine is 5.928 (kJ)(kg^{-1})($°C^{-1}$).

The first law for a steady-state, steady flow process is given by equation 2.31. Note carefully that this equation also applies to non-flow systems because the flow rate was subsumed into the different terms. (a) Write this equation in this exam and simplify it for the Joule experiment as described above. (b) Use the definition of enthalpy to explain how ΔH in equation 2.31 leads to ΔU. (c) Determine the internal energy change of the bromine if the final temperature of the bromine is 18.262 °C.

Solution:

(a) Equation 2.31 is written and simplified below:

Define the system: Fluid in the vessel.

$$\Delta H + \cancelto{0}{\frac{\Delta(u^2)}{2}} + \cancelto{0}{g\Delta z} = \cancelto{0}{Q} + W_{shaft} \qquad \text{(Equation 2.31)}$$

The fluid system is at rest before and after the weight drops.

The fluid does not change elevation. The weight does, but it is not part of the system.

There is no heat transfer to the surroundings because the vessel is well-insulated.

$$\underline{\underline{\Delta H = W_{shaft}}}_{\text{ANS}}$$

(b) ΔH is defined as ΔU+Δ(PV). The experiment is open to the atmosphere, so pressure is constant. Assume that the molar volume (and therefore density) is constant. Under these conditions, Δ(PV)=0, and ΔH=ΔU:

$$\Delta H = \Delta U + \cancelto{0}{\Delta(PV)} = \Delta U$$

$$\therefore \underline{\underline{\Delta H = \Delta U}}_{\text{ANS}}$$

(c) ΔH is given by equation 2.21 with constant C_p, $\Delta H = C_P\Delta T$, or $\Delta H^t = mC_P\Delta T$:

$$\Delta H^t = m \cdot C_p \cdot \Delta T = 37.50\,kg \cdot \frac{5.928\,kJ}{kg\ deg\,C} \cdot (18.262\,deg\,C - 18.000\,deg\,C) = \underline{\underline{58.2426\ kJ = \Delta U^t}}_{\text{ANS}}$$

Cadet: **APPROVED SOLUTION**

Problem: B

Weight: 70

1. A mercury manometer is attached at one end to a pressure vessel containing a gas and is open to the atmosphere at the other end. The reading on the manometer is 23.99 inches of mercury (in Hg) and the absolute pressure in the vessel is 53.87 in Hg. What is the atmospheric pressure in psia?

Additional information: The temperature of the vessel and the surroundings are both 70 °F, the density of mercury at 70 °F is 13.543 g/cm^3, the local acceleration of gravity is 32.243 ft/s^2, and 1 torr = 1 mm Hg.

Solution:

The absolute pressure in the vessel is the sum of the manometer pressure and the atmospheric pressure, so the atmospheric pressure is obtained by subtracting the manometer (gauge) pressure from the total:

$$P_{total} = P_{gauge} + P_{atm},\ \therefore\ P_{atm} = P_{total} - P_{gauge} = 53.87 - 23.99 = 29.88\ \text{in Hg}$$

$$29.8\underline{8}\ \text{inches Hg} \cdot \frac{1000\ \text{mm Hg}}{39.3701\ \text{inches Hg}} \cdot \frac{14.5038\ \text{psi}}{750.063\ \text{torr}} \cdot \frac{1\ \text{torr}}{1\ \text{mm Hg}} = \underset{\text{ANS}}{\underline{\underline{14.6\underline{7}6\ \text{psi}}}}$$

2. A mass of 288 kg is placed on a dead-weight gauge with a piston diameter of 5.00 mm. What is the pressure produced by the gauge in bar?

Additional information: The local acceleration of gravity is 9.80665 m/s^2.

Solution:

Pressures is force per area, so calculate the force, calculate the area, then divide and apply the appropriate conversion factor:

$$\text{force} = 28\underline{8}\ \text{kg} \cdot \frac{9.80665\ \text{m}}{\text{s}^2} \cdot \frac{1\ \text{N}}{1\ \text{kg} \cdot \text{m}/\text{s}^2} = 28\underline{2}4.3152\ \text{N}$$

$$\text{area} = \frac{\pi}{4}\left(5.0\underline{0}\ \text{mm} \cdot \frac{1\ \text{m}}{1000\ \text{mm}}\right)^2 = 1.9\underline{6}350 \times 10^{-5}\ \text{m}^2$$

$$\text{pressure} = \frac{\text{force}}{\text{area}} = \frac{28\underline{2}4.3152\ \text{N}}{1.96350 \times 10^{-5}\ \text{m}^2} \cdot \frac{1\ \text{bar}}{10^5\ \text{N}/\text{m}^2} = 14\underline{3}8.409\ \text{bar} = \underset{\text{ANS}}{\underline{\underline{14\underline{4}0\ \text{bar}}}}$$

Cadet: **APPROVED SOLUTION**

Problem: C   Weight: 80

The space launch system (SLS) rocket on the Artemis 1 system uses four RS-25 engines originally developed for the space shuttle. Typical feed flow rates to the RS-25 are 907 lb/sec of oxygen and 149 lb/sec of hydrogen (in a stoichiometric ratio), from which the engine produces 1056 lb/sec of exhaust gases (clean water vapor). The pressure and temperature in the combustion chamber are 206.4 bar and 3573 K (State 1). The exhaust gases then travel out of the combustion chamber, through the nozzle, and out to the surrounding atmosphere.

The nozzle itself is actually a countercurrent heat exchanger consisting of 1,080 stainless steel tubes brazed to themselves and to a surrounding structural jacket. Hydrogen fuel gas is pre-heated by entering the tubes near the bottom of the nozzle, travelling in a circular pattern around the nozzle back to the combustion chamber, cooling the exhaust gas to about 1060 K and about 1.0 bar (State 2) at the exit of the nozzle.

The table below summarizes the conditions at States 1 and 2, where the question marks (??) designate unknowns. Complete the table and then calculate W, Q, ΔH, and ΔU for the process, in units of kJ mol^{-1}.

Assume that PV/T = 0.08314 bar L mol^{-1} K^{-1} and that the average C_P = 49.52 J mol^{-1} K^{-1} and C_V = 40.84 J mol^{-1} K^{-1} for gas-phase water.

	State 1	State 2
P, bar	206.4	1.0
T, K	3573	1060
V, L/mol	____ ??	____ ??

Solution:

Solve for V_1 and V_2:

$$\frac{P_1V_1}{T_1} = 0.08314 \Rightarrow V_1 = \frac{0.08314T_1}{P_1} = \frac{0.08314\ \frac{\text{bar}\cdot\text{L}}{\text{mol}\cdot\text{K}}\cdot 3573\ \text{K}}{206.4\ \text{bar}} = \underline{\underline{1.4392\ \frac{\text{L}}{\text{mol}}}}_{\text{ANS}}$$

$$\frac{P_2V_2}{T_2} = 0.08314 \Rightarrow V_2 = \frac{0.08314T_2}{P_2} = \frac{0.08314\ \frac{\text{bar}\cdot\text{L}}{\text{mol}\cdot\text{K}}\cdot 1060\ \text{K}}{1.0\ \text{bar}} = \underline{\underline{88.1284\ \frac{\text{L}}{\text{mol}}}}_{\text{ANS}}$$

Cadet: **APPROVED SOLUTION**

Solve for work done by the system:

Note: work done by the system is negative for an expansion where the system is the gas in the nozzle.

$$W = -P_{external}\Delta V = 1.\underline{0}\,\text{bar}\cdot\left(\frac{8\underline{8}.1284\ \text{L}}{\text{mol}} - \frac{1.43\underline{9}2\,\text{L}}{\text{mol}}\right) = -8\underline{6}.6892\ \frac{\text{bar}\cdot\text{L}}{\text{mol}}$$

Convert this to kJ/mol:

$$-\frac{8\underline{6}.6892\,\text{bar}\cdot\text{L}}{\text{mol}}\cdot\frac{10^5\ \text{Pa}}{\text{bar}}\cdot\frac{\frac{1\text{N}}{\text{m}^2}}{\text{Pa}}\cdot\frac{1\ \text{m}^3}{1000\ \text{L}}\cdot\frac{1\text{J}}{1\,\text{Nm}}\cdot\frac{1\ \text{kJ}}{1000\ \text{J}} = \underline{\underline{-8.\underline{6}6892}}\ \frac{\text{kJ}}{\text{mol}}$$

ANS

Enthalpy change:

$$\Delta H = C_p\cdot\Delta T = \frac{49.5\underline{2}\,\text{J}}{\text{mol}\cdot\text{K}}\cdot(106\underline{0}\,\text{K} - 357\underline{3}\,\text{K})\cdot\frac{1\text{kJ}}{1000\,\text{J}} = \underline{\underline{-124.\underline{4}438}}\ \frac{\text{kJ}}{\text{mol}}$$

ANS

Internal energy change:

$$\Delta U = C_V\cdot\Delta T = \frac{40.8\underline{4}\,\text{J}}{\text{mol}\cdot\text{K}}\cdot(106\underline{0}\,\text{K} - 357\underline{3}\,\text{K})\cdot\frac{1\text{kJ}}{1000\,\text{J}} = \underline{\underline{-102.\underline{6}309}}\ \frac{\text{kJ}}{\text{mol}}$$

ANS

Heat:

$$\Delta U = Q + W \Rightarrow Q = \Delta U - W = -102.\underline{6}309\frac{\text{kJ}}{\text{mol}} - \left(-8.\underline{6}6892\frac{\text{kJ}}{\text{mol}}\right) = \underline{\underline{-93.\underline{9}62}}\frac{\text{kJ}}{\text{mol}}$$

ANS

Note: heat is negative.