APPROVED SOLUTION

CADET ____________________ SECTION ______TIME OF DEPARTURE ________

DEPARTMENT OF CHEMISTRY & LIFE SCIENCE

CH365 2024-2025
WRITTEN PARTIAL REVIEW I
11 September 2024, 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 5 pages (not including the cover page). Print 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	60	
B	70	
C	70	
TOTAL CUT		
TOTAL GRADE	200	

Cadet: **APPROVED SOLUTION**

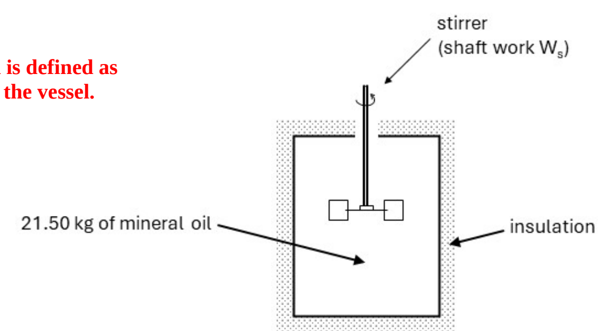
Problem:	Weight:
A	60

Joule Experiment: An unsealed but well-insulated container filled with 21.50 kg of mineral oil at 17.910 °C is fitted with a stirrer made to turn by gravity acting on a weight of mass 150.00 kg connected to the stirrer by a cable and a system of pulleys. Initially, the weight and the fluid are completely at rest. 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 is allowed to come to rest so that any swirling motion ceases and the bulk velocity of the fluid is zero. At this point, the weight and the fluid are again completely at rest, but the temperature is observed to have increased, leading to the hypothesis that the potential energy change of the weight is transferred to the mineral oil.

The first law for a steady-state, steady flow process is given by equation 2.31 in the textbook. Note carefully that this equation also applies to non-flowing systems because the flow rate was subsumed into the different terms. The local acceleration of gravity is 9.807 (m)(s^{-2}), and the specific heat of mineral oil is 1.67 (kJ)(kg^{-1})(°C^{-1}).

(a) Define the thermodynamic system in a way that allows direct application of equation 2.31. Provide a sketch of the system.

The system is defined as the fluid in the vessel.



(b) Write and simplify equation 2.31 for the Joule experiment as described above, in a manner consistent with your answer to part (a). Explain any simplifying assumptions.

Solution:

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

The system (fluid) is at rest before and after the weight drop.

The fluid does not change elevation.

There is no heat transfer to or from the surroundings.

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

ANS

(c) Use the definition of enthalpy to explain how ΔH in equation 2.31 leads to ΔU and explain any additional simplifying assumptions needed.

Solution:

- Since the experiment is open to the atmosphere, pressure is assumed constant.
- Molar volume of the oil is assumed constant for small temperature changes.

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

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

(d) Determine the internal energy change of the oil if the weight drops a total of 30.0$\underline{0}$ m. Report your answer in kJ.

Solution:

- Assume all potential energy of the falling weight is transmitted into the fluid through the stirring mechanism.
- The change in potential energy of the weight is equal but opposite in sign to the change in internal energy of the fluid.

$$\Delta U = W_{shaft} = -mg\Delta z = -150.0\underline{0}\ \text{kg}\cdot 9.80\underline{7}\,\frac{\text{m}}{\text{s}^2}\cdot\left(0\,\text{m} - 30.00\,\text{m}\right)\cdot\frac{1\ \text{J}}{\frac{1\,\text{kg}\cdot\text{m}^2}{\text{s}^2}}\cdot\frac{1000\,\text{J}}{1\,\text{kJ}} = \underline{\underline{44.1\underline{3}\,\text{kJ}}}_{\text{ANS}}$$

(e) What is the final temperature of the oil in °C?

Solution:

- ΔH is given by eq. 2.21 with constant C_p, which leads to $\Delta H = mC_P\Delta T$ (= ΔU):

$$\Delta H = m\cdot C_P\cdot\Delta T = \Delta U$$

$$44.13\,\text{kJ} = 21.5\underline{0}\,\text{kg}\cdot\frac{1.6\underline{7}\,\text{kJ}}{\text{kg}\ {}^{\circ}\text{C}}\cdot\left(T\ {}^{\circ}\text{C} - 17.91\underline{0}\ {}^{\circ}\text{C}\right)$$

$$\underline{\underline{T = 19.\underline{1}39\ {}^{\circ}\text{C}}}_{\text{ANS}}$$

Problem: Weight:
B 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 32.23 inches of mercury (in Hg) and the absolute pressure in the vessel is 63.09 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. Additional conversion factors can be found in Appendix A.

Solution:

$$P_{absolute} = P_{gauge} + P_{atm},\ \therefore\ P_{atm} = P_{absolute} - P_{gauge} = 63.0\underline{9} - 32.2\underline{3} = 30.8\underline{6}\ \text{in Hg}$$

$$\frac{13.54\underline{3}\,\text{g}}{\text{cm}^3}\cdot\frac{2.20462\,\text{lb}_m}{1000\,\text{g}}\cdot\frac{10^6\,\text{cm}^3}{35.3147\,\text{ft}^3} = 845.4\underline{6}01\frac{\text{lb}_m}{\text{ft}^3}$$

$$\frac{\left(\frac{845.4\underline{6}01\,\text{lb}_m}{\text{ft}^3}\right)\cdot\left(\frac{32.24\underline{3}\,\text{ft}}{\text{s}^2}\right)\cdot(30.8\underline{6}\,\text{in})\cdot\left(\frac{1\text{ft}}{12\,\text{in}}\right)}{\frac{\frac{32.1740\,\text{ft}\cdot\text{lb}_m}{\text{s}^2}}{1\,\text{lb}_f}}\cdot\left(\frac{1\,\text{ft}}{12\,\text{in}}\right)^2 = \frac{15.1\underline{3}\,\text{lb}_f}{\text{in}^2} = 15.1\underline{3}\,\text{psi}$$

ANS

2. A mass of 75.0 kg is placed on a dead-weight gauge produces a pressure of 260.13 bar. What is the diameter of the piston in millimeters? The local acceleration of gravity is 9.828 m/s^2.

Solution:

Pressures is force per area, so calculate the force, calculate the area in terms of unknown r, then divide, set equal to pressure with appropriate conversion factor, and solve for r:

$$\frac{75.\underline{0}\,\text{kg}\cdot\frac{9.82\underline{8}\,\text{m}}{\text{s}^2}\cdot\frac{1\,\text{N}}{\frac{1\,\text{kg}\cdot\text{m}}{\text{s}^2}}}{\frac{\pi}{4}\left(r\,\frac{1\,\text{m}}{1000\,\text{mm}}\right)^2} = 260.1\underline{3}\,\text{bar}\cdot\frac{\frac{10^5\,\text{N}}{\text{m}^2}}{1\,\text{bar}}$$

$$r = 6.0\underline{1}\ \text{mm}$$

ANS

Problem:	Weight:
C	70

One kilogram of hydrogen is compressed reversibly and isothermally from an initial state of 20.0 L/mol and 2.500 bar (State 1) until its molar volume is reduced to 5.00 L/mol (State 2).

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 C_p = 30.74 J mol^{-1} K^{-1} for hydrogen.

	State 1	State 2
P, bar	2.500	**10.0** ??
T, K	**601.4** ??	**601.4** ??
V, L/mol	20.0	5.00

Solution:

Solve for T_1:

$$\frac{P_1 V_1}{T_1} = 0.08314 \Rightarrow T_1 = \frac{P_1\,V_1}{0.08134} = \frac{2.500\,\text{bar}\cdot 20.0\,\frac{\text{L}}{\text{mol}}}{0.08314\,\frac{\text{bar}\cdot\text{L}}{\text{mol}\cdot\text{K}}} = 601.4\ \text{K}$$

The system is at constant temperature, so T_2 = $\underline{\underline{T_1 = 601.4}}$ K.
ANS

Now solve for P_2:

$$\frac{P_2 V_2}{T_2} = 0.08314 \Rightarrow P_2 = \frac{T_2\cdot 0.08314}{V_2} = \frac{601.40\,\text{K}\cdot 0.08314\,\frac{\text{bar}\cdot\text{L}}{\text{mol}\cdot\text{K}}}{5.00\,\frac{\text{L}}{\text{mol}}} = \underline{\underline{10.0}}\ \text{bar}$$
ANS

Enthalpy change: $\underline{\underline{\Delta H = 0\ \frac{\text{kJ}}{\text{mol}}}}$ (isothermal)
ANS

Internal energy change: $\underline{\underline{\Delta U = 0\ \frac{\text{kJ}}{\text{mol}}}}$ (isothermal)
ANS

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Reversible work done on the system:

$$W = -\int_{V_1}^{V_2} PdV = -\int_{V_1}^{V_2} \frac{RT}{V} dV = -\int_{20.0}^{5.00} \frac{0.08314 \cdot 601.4}{V} dV = 69.\underline{3}2 \cdot \frac{\text{bar} \cdot \text{L}}{\text{mol}}$$

Note: work done on the system is positive for a compression.

Convert this to kJ/mol:

$$\frac{69.\underline{3}2\,\text{bar}\cdot\text{L}}{\text{mol}} \cdot \frac{10^5\ \text{Pa}}{\text{bar}} \cdot \frac{\frac{1\text{N}}{\text{m}^2}}{\text{Pa}} \cdot \frac{1\ \text{m}^3}{1000\ \text{L}} \cdot \frac{1\text{J}}{1\,\text{Nm}} \cdot \frac{1\ \text{kJ}}{1000\ \text{J}} = \underline{\underline{6.9\underline{3}2 \frac{\text{kJ}}{\text{mol}}}}_{\text{ANS}}$$

Heat removed from system:

$$\Delta U = Q + W \quad \Rightarrow \quad Q = \Delta U - W = 0\frac{\text{kJ}}{\text{mol}} - 6.9\underline{3}2\frac{\text{kJ}}{\text{mol}} = \underline{\underline{-6.9\underline{3}2\frac{\text{kJ}}{\text{mol}}}}_{\text{ANS}}$$

Note: heat is negative.

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A	60	
B	70	
C	70	
TOTAL CUT		
TOTAL GRADE	200	

Cadet: **APPROVED SOLUTION**

Problem: A Weight: 60

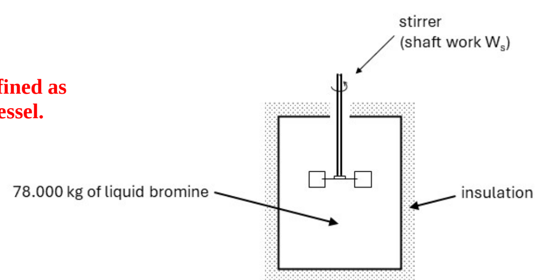
Joule Experiment: An unsealed but well-insulated container filled with 78.0$\underline{0}$ kg of liquid bromine at 19.00$\underline{0}$ °C is fitted with a stirrer made to turn by gravity acting on a weight of mass 100.0$\underline{0}$ kg connected to the stirrer by a cable and a system of pulleys. Initially, the weight and the fluid are completely at rest. When the weight drops, energy is transferred through the pulley system into the bromine through the stirrer. After the weight stops falling, the bromine is allowed to come to rest so that any swirling motion ceases and the bulk velocity of the fluid is zero. At this point, the weight and the fluid are again completely at rest, but the temperature is observed to have increased, leading to the hypothesis that the potential energy change of the weight is transferred to the bromine.

The first law for a steady-state, steady flow process is given by equation 2.31 in the textbook. Note carefully that this equation also applies to non-flowing systems because the flow rate was subsumed into the different terms. The local acceleration of gravity is 9.80$\underline{7}$ (m)(s^{-2}), and the specific heat of bromine is 0.473$\underline{6}$ (kJ)(kg^{-1})(°C^{-1}).

(a) Define the thermodynamic system in a way that allows direct application of equation 2.31. Provide a sketch of the system.

Solution:

The system is defined as the fluid in the vessel.



(b) Write and simplify equation 2.31 for the Joule experiment as described above, in a manner consistent with your answer to part (a). Explain any simplifying assumptions.

Solution:

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

The system (fluid) is at rest before and after the weight drop.

The fluid does not change elevation.

There is no heat transfer to or from the surroundings.

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

ANS

(c) Use the definition of enthalpy to explain how ΔH in equation 2.31 leads to ΔU and explain any additional simplifying assumptions needed.

Solution:

- Since the experiment is open to the atmosphere, pressure is assumed constant.
- Molar volume of the oil is also essentially constant for small temperature changes.

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

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

(d) Determine the internal energy change of the liquid bromine if the weight drops a total of 60.00 m. Report your answer in kJ.

Solution:

- Assume all potential energy of the falling weight is transmitted into the fluid through the stirring mechanism.
- The change in potential energy of the weight is equal but opposite in sign to the change in internal energy of the fluid.

$$\Delta U = W_{shaft} = -mg\Delta z = -100.0\underline{0}\ \text{kg} \cdot 9.80\underline{7}\frac{\text{m}}{\text{s}^2} \cdot (0\,\text{m} - 60.00\,\text{m}) \cdot \frac{1\ \text{J}}{\frac{1\,\text{kg} \cdot \text{m}^2}{\text{s}^2}} \cdot \frac{1000\,\text{J}}{1\,\text{kJ}} = \underline{\underline{58.8\underline{4}2\,\text{kJ}}}_{\text{ANS}}$$

(e) What is the final temperature of the bromine in °C?

Solution:

- ΔH is given by eq. 2.21 with constant C_P, which leads to $\Delta H = mC_P\Delta T$ (= ΔU):

$$\Delta H = m \cdot C_P \cdot \Delta T = \Delta U$$

$$58.84\,\text{kJ} = 78.0\underline{0}\,\text{kg} \cdot \frac{0.473\underline{6}\,\text{kJ}}{\text{kg}\ {}^{o}\text{C}} \cdot (T\ {}^{o}\text{C} - 19.00\underline{0}\ {}^{o}\text{C})$$

$$\underline{\underline{T = 20.5\underline{9}\ {}^{o}\text{C}}}_{\text{ANS}}$$

Cadet: **APPROVED SOLUTION**

Problem:	Weight:
B	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 $42.2\underline{3}$ inches of mercury (in Hg) and the absolute pressure in the vessel is $72.1\underline{6}$ 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 $13.54\underline{3}$ g/cm^3, the local acceleration of gravity is $32.24\underline{3}$ ft/s^2, and 1 torr = 1 mm Hg. Additional conversion factors can be found in Appendix A.

Solution:

$$P_{absolute} = P_{gauge} + P_{atm},\ \therefore\ P_{atm} = P_{absolute} - P_{gauge} = 72.1\underline{6} - 42.2\underline{3} = 29.9\underline{3}\ \text{in Hg}$$

$$\frac{13.54\underline{3}\,\text{g}}{\text{cm}^3}\cdot\frac{2.20462\,\text{lb}_m}{1000\,\text{g}}\cdot\frac{10^6\,\text{cm}^3}{35.3147\,\text{ft}^3} = 845.4\underline{6}01\frac{\text{lb}_m}{\text{ft}^3}$$

$$\frac{\left(\frac{845.4\underline{6}01\,\text{lb}_m}{\text{ft}^3}\right)\cdot\left(\frac{32.24\underline{3}\,\text{ft}}{\text{s}^2}\right)\cdot\left(29.9\underline{3}\,\text{in}\right)\cdot\left(\frac{1\,\text{ft}}{12\,\text{in}}\right)}{\frac{\frac{32.1740\,\text{ft}\cdot\text{lb}_m}{\text{s}^2}}{1\,\text{lb}_f}}\cdot\left(\frac{1\,\text{ft}}{12\,\text{in}}\right)^2 = \frac{14.6\underline{7}\,\text{lb}_f}{\text{in}^2} = \underline{\underline{14.6\underline{7}\,\text{psi}}}$$

ANS

2. A mass of $15\underline{0}$ kg is placed on a dead-weight gauge produces a pressure of 292.65 bar. What is the diameter of the piston in millimeters? The local acceleration of gravity is $9.82\underline{8}$ m/s^2.

Solution:

Pressures is force per area, so calculate the force, calculate the area in terms of unknown r, then divide, set equal to pressure with appropriate conversion factor, and solve for r:

$$\frac{15\underline{0}\,\text{kg}\cdot\frac{9.82\underline{8}\,\text{m}}{\text{s}^2}\cdot\frac{1\,\text{N}}{\frac{1\,\text{kg}\cdot\text{m}}{\text{s}^2}}}{\frac{\pi}{4}\left(r\,\frac{1\,\text{m}}{1000\,\text{mm}}\right)^2} = 292.6\underline{5}\,\text{bar}\cdot\frac{\frac{10^5\,\text{N}}{\text{m}^2}}{1\,\text{bar}}$$

$$\underline{\underline{r = 8.0\underline{1}\ \text{mm}}}$$

ANS

Cadet: APPROVED SOLUTION

Problem: C   Weight: 70

One kilogram of oxygen is expanded reversibly and isothermally from an initial state of 5.00 L/mol ~~and 200 K bar~~ (State 1) until its molar volume increases to 30.0 L/mol and its pressure decreases to 2.5 bar (State 2).

The table summarizes the conditions at states 1 and 2, where the question marks (??) designate unknowns. Complete the table below 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 C_p = 32.41 J mol^{-1} K^{-1} for oxygen.

	State 1	State 2
P, bar	15.0 ??	2.500
T, K	902.1 ??	902.1 ??
V, L/mol	5.00	30.0

Solution:

Solve for T_2:

$$\frac{P_2V_2}{T_2} = 0.08314 \Rightarrow T_2 = \frac{P_2V_2}{0.08314} = \frac{2.500\ \text{bar} \cdot 30.0 \frac{\text{L}}{\text{mol}}}{0.08314 \frac{\text{bar} \cdot \text{L}}{\text{mol} \cdot \text{K}}} = 902.1\ \text{K}$$

The system is at constant temperature, so $T_1 = T_2 = 902.1$ K.

ANS

Now solve for P_1:

$$\frac{P_1V_1}{T_1} = 0.08314 \Rightarrow P_1 = \frac{T_1 \cdot 0.08314}{V_1} = \frac{902.1\text{K} \cdot 0.08314 \frac{\text{bar} \cdot \text{L}}{\text{mol} \cdot \text{K}}}{5.00 \frac{\text{L}}{\text{mol}}} = 15.0\ \text{bar}$$

ANS

Enthalpy change: $\Delta H = 0 \frac{\text{kJ}}{\text{mol}}$ (isothermal)

ANS

Internal energy change: $\Delta U = 0 \frac{\text{kJ}}{\text{mol}}$ (isothermal)

ANS

Cadet: **APPROVED SOLUTION**

This page intentionally left blank for cadet calculations.

Reversible work done by the system:

$$W = -\int_{V_1}^{V_2} PdV = -\int_{V_1}^{V_2} \frac{RT}{V} dV = -\int_{5.0\underline{0}}^{30.\underline{0}} \frac{0.08314 \cdot 90\underline{2}.1}{V} dV = -13\underline{4}.383 \cdot \frac{\text{bar} \cdot \text{L}}{\text{mol}}$$

Convert this to kJ/mol:

Note: work done on the system is negative for an expansion.

$$\frac{-13\underline{4}.383\,\text{bar} \cdot \text{L}}{\text{mol}} \cdot \frac{10^5\ \text{Pa}}{\text{bar}} \cdot \frac{\frac{1\text{N}}{\text{m}^2}}{\text{Pa}} \cdot \frac{1\ \text{m}^3}{1000\ \text{L}} \cdot \frac{1\text{J}}{1\,\text{Nm}} \cdot \frac{1\ \text{kJ}}{1000\ \text{J}} = \underbrace{-13.\underline{4}383 \frac{\text{kJ}}{\text{mol}}}_{\text{ANS}}$$

Heat added to system:

$$\Delta U = Q + W \quad \Rightarrow \quad Q = \Delta U - W = 0 \frac{\text{kJ}}{\text{mol}} - \left(-13.\underline{4}383\right) \frac{\text{kJ}}{\text{mol}} = \underbrace{13.\underline{4}383 \frac{\text{kJ}}{\text{mol}}}_{\text{ANS}}$$

Note: heat is positive.