

CADET _____ SECTION _____ TIME OF DEPARTURE _____

DEPARTMENT OF CHEMICAL & BIOLOGICAL SCIENCE & ENGINEERING

CH365 2025-2026

WRITTEN PARTIAL REVIEW II

16 October 2025, A-Hour

TEXT: Smith, Van Ness, Abbott & Swihart

SCOPE: Lessons 10-20

TIME: 55 Minutes

References Permitted: Open notes, book, internet, Mathematica, and Excel.

INSTRUCTIONS

1. Do not mark this exam or open it until “begin work” is given.
2. You have 55 minutes to complete the exam.
3. Solve the problems in the space provided. Show all work to receive full credit.
4. There are 3 problems on 3 pages in this exam (not including the cover page). Write your name on the top of each sheet. Use the back of the pages for extra workspace as needed.
5. Save Mathematica files on your desktop and re-save frequently.
6. When finished, upload your Mathematica work to CANVAS.

(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

Cyclohexane ($\text{C}_6\text{H}_{12}(\text{g})$) is fed to a combustion reactor with 100% excess air.

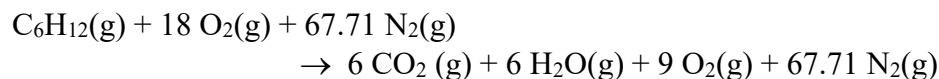
- (a) Balance the reaction on a basis of one mole of cyclohexane in the feed.
- (b) Calculate the heat of reaction at 25 °C and 1.0 bar in J/mol on a basis of one mole of cyclohexane in the feed.
- (c) Calculate the standard gas-phase isothermal heat of reaction at 400 °C and 1.0 bar for one mole of cyclohexane in 100% excess air.

The following table contains ideal gas heat capacity polynomial coefficients and standard heats of formation at 298 K from Appendix C:

species	a	$b \times 10^3$	$c \times 10^6$	$d \times 10^{-5}$	$\Delta H_{f,298}^0$, J/mol
$\text{C}_6\text{H}_{12}(\text{g})$	-3.876	63.249	-20.928	0.000	-123,140
$\text{O}_2(\text{g})$	3.639	0.506	0.000	-0.227	0
$\text{N}_2(\text{g})$	3.280	0.593	0.000	0.040	0
$\text{CO}_2(\text{g})$	5.457	1.045	0.000	-1.157	-393,509
$\text{H}_2\text{O}(\text{g})$	3.470	1.450	0.000	0.121	-241,818

Solution, part (a):

Balanced reaction in 100% excess air:



Solution of parts (b) and (c) in Mathematica are shown on the following page.

Solution, part (b):

```
(*List of stoichiometric coefficients*)
(*cyclohexane, oxygen, nitrogen, carbon dioxide, water, oxygen, nitrogen*)
v = {-1, -18, -67.71, 6, 6, 9, 67.71};

(*List of standard Heats of Formation*)
ΔHf298 = {-123140, 0, 0, -393509, -241818, 0, 0};

(*Standard Heat of Reaction at 298 K*)
ΔH298 = Plus @@ (v * ΔHf298) (*J/mol*)
-3.688822 × 106
_____
ANS, J per mole of cyclohexane
```

Solution, part (c):

```
(*Heat Capacity polynomial coefficients, Given, from Table C.1:*)
a = { -3.876, 3.639, 3.280, 5.457, 3.470, 3.639, 3.280};
b = { 63.249, 0.506, 0.593, 1.045, 1.450, 0.506, 0.593} * 10-3;
c = {-20.928, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000} * 10-6;
d = { 0.000, -0.227, 0.040, -1.157, 0.121, -0.227, 0.040} * 105;

Δa = Plus @@ (v * a);
Δb = Plus @@ (v * b);
Δc = Plus @@ (v * c);
Δd = Plus @@ (v * d);

(*Temperatures, K*)
T = 400 + 273.15;
T0 = 25 + 273.15;

(*Gas constant*)
R = 8.314; (*  $\frac{J}{mol \cdot K}$  *)

(*Equation 4.21 for MDCPH*)
MDCPH = Δa +  $\frac{\Delta b}{2} * (T + T0) + \frac{\Delta c}{3} * (T^2 + T0^2 + T * T0) + \frac{\Delta d}{T * T0}$ 
2.13067

(*Equation 4.22 for corrected heat of reaction*)
(*Gives molar heat of reaction in J/mol*)
ΔH673 = ΔH298 + MDCPH * R * (T - T0)
-3.682179 × 106
_____
ANS, J per mole of cyclohexane
```

Problem: Weight:
B 70

An engineering plan for a vinyl chloride plant includes a pipeline carrying ethylene (C_2H_4) at a volumetric flow rate of 47.105 MMSCFD (million standard cubic feet per day). Standard conditions are 519.67°R and 14.696 psia. At these conditions, the molar volume of C_2H_4 is 376.98 ft³/lbmol.

(a) Calculate the molar flow rate of C_2H_4 in lbmol/sec.

(b) Use the Redlich-Kong (RK) equation of state (equations 3.41, 3.44, and 3.45), constants in Table 3.1, and gas constant $R = 10.73 \text{ ft}^3 \cdot \text{psia}/(\text{lbmol} \cdot \text{R})$ to determine the isothermal reversible compression work required to reduce the molar volume of C_2H_4 by 5%. Report the work in hp.

From Appendix B, the critical temperature, pressure, and acentric factor for ethylene are $T_C = 508.14$ Rankine, and $P_C = 730.99$ psia, and $\omega = 0.087$.

Solution, part (a):

$$\frac{47,105,000 \text{ ft}^3}{\text{day}} \cdot \frac{1 \text{ day}}{24 \text{ h}} \cdot \frac{1 \text{ h}}{3600 \text{ s}} \cdot \frac{1 \text{ lbmol}}{376.98 \text{ ft}^3} = \underline{\underline{1.44622 \frac{\text{lbmol}}{\text{s}}}}_{\text{ANS}}$$

Solution, part (b):

```

T = 519.67; (*Rankine, given*)
R = 10.73; (* $\frac{\text{ft}^3 \cdot \text{psia}}{\text{lbmol} \cdot \text{R}}$ , given*)
ω = 0.087; (*App. B, p.665*)
Tc = 508.14; (*Rankine, given*)
Pc = 730.99; (*psia, given*)
Tr1 = T / Tc; (*reduced temperature*)
(*Table 3.1, p.100*)
σ = 1;
ε = 0;
Ω = 0.08664;
Φ = 0.42748;
α = 1 / √Tr1;
(*Equations 3.41, 3.44, and 3.45*)
b = Ω *  $\frac{R * Tc}{Pc}$ ;
a = Φ *  $\frac{\alpha * R^2 * Tc^2}{Pc}$ ;
P[V_] =  $\frac{R * T}{V - b} - \frac{a}{(V + \epsilon * b) * (V + \sigma * b)}$ ;

```

Cadet: _____

$$W = - \int_{376.98}^{0.95 \times 376.98} P[V] dV \left(\text{*eq 1.4, units } \frac{\text{psia} \cdot \text{ft}^3}{\text{lbmol}} \right)$$

284.1225

$$\frac{284.1225 \text{ psia} \cdot \text{ft}^3}{\text{lbmol}} \cdot \frac{\frac{\text{lbf}}{\text{in}^2}}{\text{psia}} \cdot \left(\frac{12 \text{ in}}{\text{ft}} \right)^2 \cdot \frac{1.446222 \text{ lbmol}}{\text{s}} \cdot \frac{1.34102 \text{ hp}}{737.562 \frac{\text{ft} \cdot \text{lbf}}{\text{s}}}$$

107.582 hp
ANS

Problem: Weight:
C 80

0.100 kmol of an ideal gas in a closed system initially at 6.0 m³, 1.5 bar and 1082.5 K undergoes a two-step process consisting of an adiabatic compression followed by cooling at constant volume to a final state of 1.5 m³, 6.0 bar, and 1082.5 K.

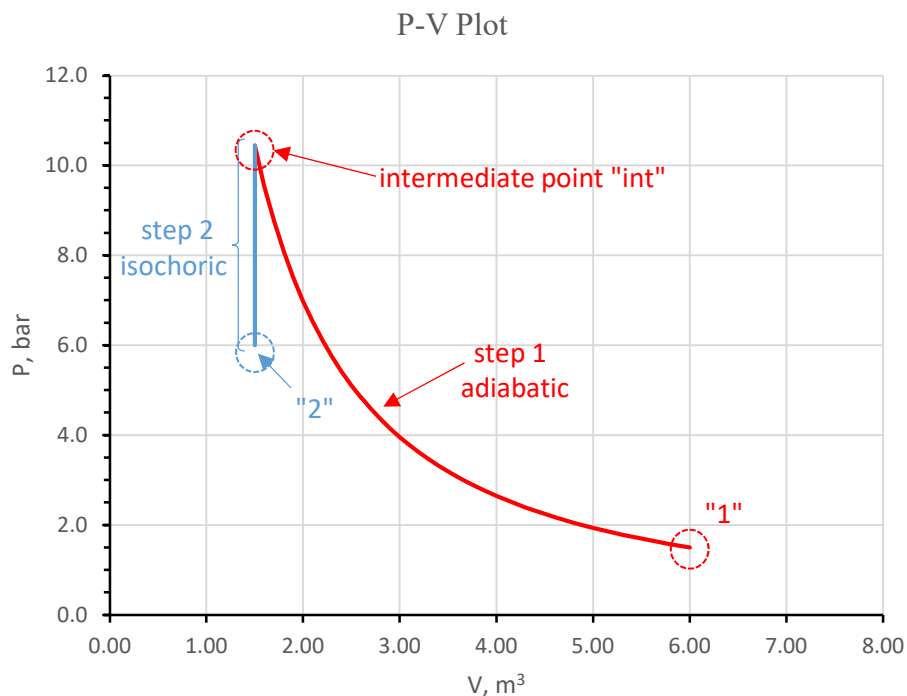
- (a) Sketch the process path on the PV axes below.
- (b) Calculate Q, W, ΔU and ΔH for the overall process in units of kJ.
- (c) Calculate the intermediate temperature after step 1.

$$R = 8.314 \text{ J/(mol} \cdot \text{K)} = 0.08314 \text{ (bar} \cdot \text{m}^3\text{)/(kmol} \cdot \text{K)}$$

$$C_P = (7/2) \cdot R, \text{ and}$$

$$C_V = (5/2) \cdot R$$

Solution, part (a):



Solution, part (b):

The overall process is isothermal ($T_2 = T_1$), so $\Delta H_{\text{Overall}} = \Delta U_{\text{Overall}} = 0 \text{ kJ}$
ANS

Equation 3.23c gives the P-V relation for an adiabatic process. Let the intermediate state be denoted with subscript “int” with $V_{\text{int}} = V_2$ since the second step is at constant volume.

Also $\gamma = C_P/C_V = (7R/2)/(5R/2) = (7/5) = 1.4$ from equation 3.24.

Solve for intermediate pressure, P_{int} , using equation 3.23c from lesson 11:

$$P_{\text{int}} V_{\text{int}}^{\gamma} = P_1 V_1^{\gamma} \Rightarrow P_{\text{int}} = P_1 \cdot \left(\frac{V_1}{V_{\text{int}}} \right)^{\gamma} = 1.5 \text{ bar} \cdot \left(\frac{6.0 \text{ m}^3}{1.5 \text{ m}^3} \right)^{1.4} = 10.447 \text{ bar}$$

Once P_{int} is known, the adiabatic work for step 1 is given by equation 3.26:

$$W_{\text{Step1}} = \frac{P_{\text{int}} \cdot V_{\text{int}} - P_1 \cdot V_1}{\gamma - 1} = \frac{10.447 \text{ bar} \cdot 1.5 \text{ m}^3 - 1.5 \text{ bar} \cdot 6.0 \text{ m}^3}{1.4 - 1} = +16.676 \text{ bar} \cdot \text{m}^3$$

Step 2 is at constant volume, so work $-P\Delta V=0$.

The total overall work is the sum of the work of each step:

$$W_{\text{Overall}} = W_{\text{Step1}} + W_{\text{Step2}} = 16.676 \text{ bar} \cdot \text{m}^3 + 0 \text{ bar} \cdot \text{m}^3 = 16.676 \text{ bar} \cdot \text{m}^3$$

Now convert the units to kJ:

$$W_{\text{Overall}} = 16.67625 \text{ bar} \cdot \text{m}^3 \left(\frac{1 \text{ J}}{10^{-5} \text{ bar} \cdot \text{m}^3} \right) \cdot \left(\frac{1 \text{ kJ}}{1000 \text{ J}} \right) = \underline{\underline{1667.67 \text{ kJ}}}_{\text{ANS}}$$

Finally, for Q:

$$\Delta U_{\text{Overall}} = Q_{\text{Overall}} + W_{\text{Overall}} = 0 \Rightarrow Q_{\text{Overall}} = -W_{\text{Overall}} = \underline{\underline{-1667.67 \text{ kJ}}}_{\text{ANS}}$$

Solution, part (c):

$$PV = nRT \Rightarrow T_{\text{int}} = \frac{P_{\text{int}} \cdot V_{\text{int}}}{n \cdot R} = \frac{10.447 \text{ bar} \cdot 1.5 \text{ m}^3}{0.100 \text{ kmol} \cdot \left(0.08314 \frac{\text{bar} \cdot \text{m}^3}{\text{kmol} \cdot \text{K}} \right)} = \underline{\underline{1884.76 \text{ K}}}_{\text{ANS}}$$

CADET _____ SECTION _____ TIME OF DEPARTURE _____

DEPARTMENT OF CHEMICAL & BIOLOGICAL SCIENCE & ENGINEERING

CH365 2025-2026

WRITTEN PARTIAL REVIEW II

16 October 2025, C-Hour

TEXT: Smith, Van Ness, Abbott & Swihart

SCOPE: Lessons 10-20

TIME: 55 Minutes

References Permitted: Open notes, book, internet, Mathematica, and Excel.

INSTRUCTIONS

1. Do not mark this exam or open it until “begin work” is given.
2. You have 55 minutes to complete the exam.
3. Solve the problems in the space provided. Show all work to receive full credit.
4. There are 3 problems on 3 pages in this exam (not including the cover page). Write your name on the top of each sheet. Use the back of the pages for extra workspace as needed.
5. Save Mathematica files on your desktop and re-save frequently.
6. When finished, upload your Mathematica work to CANVAS.

(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

Acetic acid ($\text{C}_2\text{H}_4\text{O}_2(\text{g})$) is fed to a combustion reactor with 100% excess air.

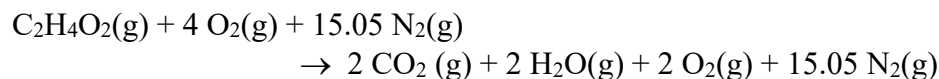
- (a) Balance the reaction on a basis of one mole of acetic acid in the feed.
- (b) Calculate the heat of reaction at 25 °C and 1.0 bar in J/mol on a basis of one mole of acetic acid in the feed.
- (c) Calculate the standard gas-phase isothermal heat of reaction at 400 °C and 1.0 bar for one mole of acetic acid in 100% excess air.

The following table contains ideal gas heat capacity polynomial coefficients and standard heats of formation at 298 K from Appendix C:

species	a	$b \times 10^3$	$c \times 10^6$	$d \times 10^{-5}$	$\Delta H_{f,298}^0$, J/mol
$\text{C}_2\text{H}_4\text{O}_2(\text{g})$	-0.319	28.883	-4.052	0.000	-432,800
$\text{O}_2(\text{g})$	3.639	0.506	0.000	-0.227	0
$\text{N}_2(\text{g})$	3.280	0.593	0.000	0.040	0
$\text{CO}_2(\text{g})$	5.457	1.045	0.000	-1.157	-393,509
$\text{H}_2\text{O}(\text{g})$	3.470	1.450	0.000	0.121	-241,818

Solution, part (a):

Balanced reaction in 100% excess air:



Solution of parts (b) and (c) in Mathematica are shown on the following page.

Solution, part (b):

```
(*List of stoichiometric coefficients*)
(*acetic acid, oxygen, nitrogen, carbon dioxide, water, oxygen, nitrogen*)
v = {-1, -4, -15.05, 2, 2, 2, 15.05};

(*List of standard Heats of Formation*)
ΔHf298 = {-432 800, 0, 0, -393 509, -241 818, 0, 0};

(*Standard Heat of Reaction at 298 K*)
ΔH298 = Plus @@ (v * ΔHf298) (*J/mol*)
-837 854.
```

ANS, J per mole of acetic acid

Solution, part (c):

```
(*Heat Capacity polynomial coefficients, Given, from Table C.1:*)
a = { -0.319, 3.639, 3.280, 5.457, 3.470, 3.639, 3.280};
b = { 28.883, 0.506, 0.593, 1.045, 1.450, 0.506, 0.593} * 10-3;
c = { -4.052, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000} * 10-6;
d = { 0.000, -0.227, 0.040, -1.157, 0.121, -0.227, 0.040} * 105;

Δa = Plus @@ (v * a);
Δb = Plus @@ (v * b);
Δc = Plus @@ (v * c);
Δd = Plus @@ (v * d);

(*Temperatures, K*)
T = 400 + 273.15;
T0 = 25 + 273.15;

(*Gas constant*)
R = 8.314; (*  $\frac{\text{J}}{\text{mol} \cdot \text{K}}$  *)

(*Equation 4.21 for MDCPH*)
MDCPH = Δa +  $\frac{\Delta b}{2} * (T + T0) + \frac{\Delta c}{3} * (T^2 + T0^2 + T * T0) + \frac{\Delta d}{T * T0}$ 
-1.00312

(*Equation 4.22 for corrected heat of reaction*)
(*Gives molar heat of reaction in J/mol*)
ΔH673 = ΔH298 + MDCPH * R * (T - T0)
-840 981.5
```

ANS, J per mole of acetic acid

Problem: Weight:
B 70

An engineering plan for a methylene chloride plant includes a pipeline carrying methane (CH₄) at a volumetric flow rate of 23.553 MMSCFD (million standard cubic feet per day). Standard conditions are 519.67°R and 14.696 psia. At these conditions, the molar volume of CH₄ is 378.34 ft³/lbmol.

(a) Calculate the molar flow rate of CH₄ in lbmol/sec.

(b) Use the Peng-Robinson (PR) equation of state (equations 3.41, 3.44, and 3.45), constants in Table 3.1, and gas constant R = 10.73 ft³·psia/(lbmol·R) to determine the isothermal reversible work produced by expanding the molar volume of CH₄ by 5%. Report the work in units of hp.

From Appendix B, the critical temperature, pressure, and acentric factor for CH₄ are T_C = 343.08 Rankine, and P_C = 667.03 psia, and ω = 0.012.

Solution, part (a):

$$\frac{23,553,000 \text{ ft}^3}{\text{day}} \cdot \frac{1 \text{ day}}{24 \text{ h}} \cdot \frac{1 \text{ h}}{3600 \text{ s}} \cdot \frac{1 \text{ lbmol}}{378.34 \text{ ft}^3} = \underline{\underline{0.720527 \frac{\text{lbmol}}{\text{s}}}}_{\text{ANS}}$$

Solution, part (b):

```

T = 519.67; (*Rankine, given*)
R = 10.73; (*  $\frac{\text{ft}^3 \cdot \text{psia}}{\text{lbmol} \cdot \text{R}}$ , given*)
ω = 0.012; (*App. B, p.665*)
Tc = 343.08; (*Rankine, given*)
Pc = 667.03; (*psia, given*)
Tr1 = T / Tc; (*reduced temperature*)
(*Table 3.1, p.100*)
σ = 1 + √2;
ε = 1 - √2;
Ω = 0.07780;
Φ = 0.45724;
α = (1 + (0.37464 + 1.54226 * ω - 0.26992 * ω²) * (1 - √Tr1))²;
(*Equations 3.41, 3.44, and 3.45*)
b = Ω *  $\frac{R * Tc}{Pc}$ ;
a = Φ *  $\frac{\alpha * R² * Tc²}{Pc}$ ;
P[V_] =  $\frac{R * T}{V - b} - \frac{a}{(V + \epsilon * b) * (V + \sigma * b)}$ ;

```

Cadet: _____

$$W = - \int_{378.34}^{1.05 \times 378.34} P[V] dV \left(\text{*eq 1.4, units } \frac{\text{psia} \cdot \text{ft}^3}{\text{lbmol}} \right)$$

$$-271.3939$$

$$\frac{-271.3939 \text{ psia} \cdot \text{ft}^3}{\text{lbmol}} \cdot \frac{\frac{\text{lb}_f}{\text{in}^2}}{\text{psia}} \cdot \left(\frac{12 \text{ in}}{\text{ft}} \right)^2 \cdot \frac{0.720527 \text{ lbmol}}{\text{s}} \cdot \frac{1.34102 \text{ hp}}{737.562 \frac{\text{ft} \cdot \text{lb}_f}{\text{s}}}$$

$$-51.19759 \text{ hp}$$

_____ANS

Problem: Weight:
C 80

0.200 kmol of an ideal gas in a closed system initially at 1.5 m³, 6.0 bar and 541.3 K undergoes a two-step process consisting of an adiabatic expansion followed by heating at constant volume to a final state of 6.0 m³, 1.5 bar, and 541.3 K. Additionally,

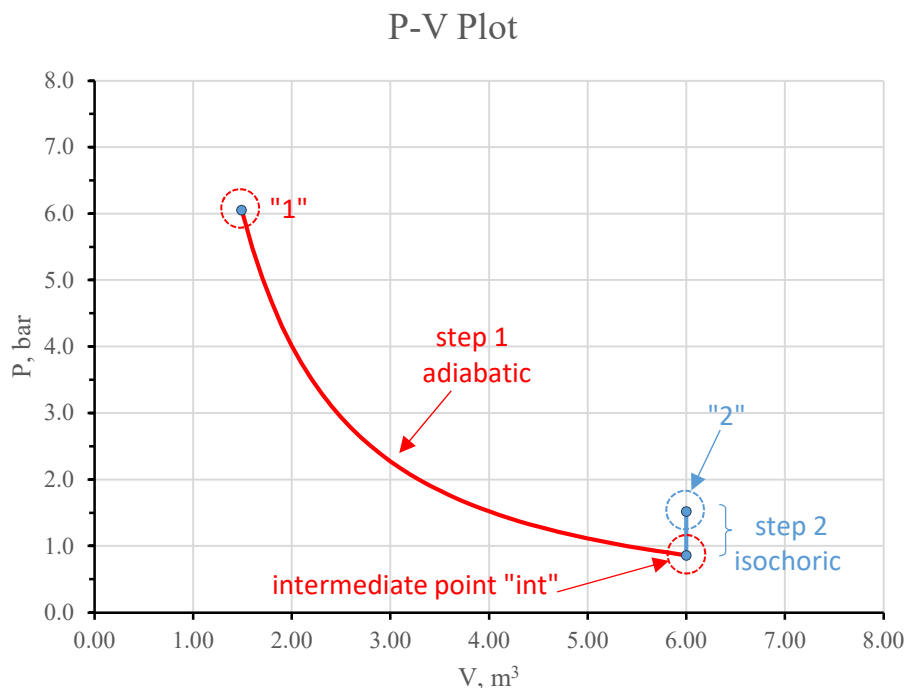
$$R = 8.314 \text{ J/(mol} \cdot \text{K)} = 0.08314 \text{ (bar} \cdot \text{m}^3\text{)/(kmol} \cdot \text{K)}$$

$$C_P = (7/2) \cdot R, \text{ and}$$

$$C_V = (5/2) \cdot R$$

- (a) Sketch the process path on the PV axes below, and label the initial, intermediate and final process points on your sketch.
- (b) Calculate Q, W, ΔU and ΔH for the overall process in units of kJ.
- (c) Calculate the intermediate temperature after step one in the two-step process.

Solution, part (a):



Solution, part (b):

Since $T_1 = T_2$ ($T_{\text{Initial}} = T_{\text{Final}}$), the overall process is isothermal, so $\Delta H_{\text{Overall}} = \Delta U_{\text{Overall}} = 0 \text{ kJ}$ ANS

Equation 3.23c gives the P-V relation for an adiabatic process. Let the intermediate state be denoted with subscript “int” with $V_{\text{int}} = V_2$ since the second step is at constant volume.

Also $\gamma = C_P/C_V = (7R/2)/(5R/2) = (7/5) = 1.4$ from equation 3.24.

Solve for intermediate pressure, P_{int} , using equation 3.23c from lesson 11:

$$P_{\text{int}} V_{\text{int}}^{\gamma} = P_1 V_1^{\gamma} \Rightarrow P_{\text{int}} = P_1 \cdot \left(\frac{V_1}{V_{\text{int}}} \right)^{\gamma} = 6.0 \text{ bar} \cdot \left(\frac{1.5 \text{ m}^3}{6.0 \text{ m}^3} \right)^{1.4} = 0.861 \text{ bar}$$

Once P_{int} is known, the adiabatic work for step 1 is given by equation 3.26:

$$W_{\text{Step1}} = \frac{P_{\text{int}} \cdot V_{\text{int}} - P_1 \cdot V_1}{\gamma - 1} = \frac{0.861 \text{ bar} \cdot 6.0 \text{ m}^3 - 6.0 \text{ bar} \cdot 1.5 \text{ m}^3}{1.4 - 1} = -9.577 \text{ bar} \cdot \text{m}^3$$

Step 2 is at constant volume, so $W_{\text{Step2}}=0$.

The total overall work is the sum of the work of each step:

$$W_{\text{Overall}} = W_{\text{Step1}} + W_{\text{Step2}} = -9.577 \text{ bar} \cdot \text{m}^3 + 0 \text{ bar} \cdot \text{m}^3 = -9.577 \text{ bar} \cdot \text{m}^3$$

Now convert the units to kJ:

$$W_{\text{Overall}} = -9.577 \text{ bar} \cdot \text{m}^3 \left(\frac{1 \text{ J}}{10^{-5} \text{ bar} \cdot \text{m}^3} \right) \cdot \left(\frac{1 \text{ kJ}}{1000 \text{ J}} \right) = \underline{\underline{-957 \text{ kJ}}}_{\text{ANS}}$$

Finally, to get Q_{Overall} , note that for an isothermal process, $\Delta U_{\text{Overall}}=0$, so $Q_{\text{Overall}}=-W_{\text{Overall}}$:

$$\Delta U_{\text{Overall}} = Q_{\text{Overall}} + W_{\text{Overall}} = 0 \Rightarrow Q_{\text{Overall}} = -W_{\text{Overall}} = \underline{\underline{+957 \text{ kJ}}}_{\text{ANS}}$$

Solution, part (c):

$$PV = nRT \Rightarrow T_{\text{int}} = \frac{P_{\text{int}} \cdot V_{\text{int}}}{n \cdot R} = \frac{0.861 \text{ bar} \cdot 6.0 \text{ m}^3}{0.200 \text{ kmol} \cdot \left(0.08314 \frac{\text{bar} \cdot \text{m}^3}{\text{kmol} \cdot \text{K}} \right)} = \underline{\underline{310.87 \text{ K}}}_{\text{ANS}}$$

CADET _____ SECTION _____ TIME OF DEPARTURE _____

DEPARTMENT OF CHEMICAL & BIOLOGICAL SCIENCE & ENGINEERING

CH365 2025-2026

TEXT: Smith, Van Ness, Abbott & Swihart

WRITTEN PARTIAL REVIEW II

SCOPE: Lessons 10-20

14 October 2025, **Make-ahead**

TIME: 55 Minutes

References Permitted: Open notes, book, internet, Mathematica, and Excel.

INSTRUCTIONS

1. Do not mark this exam or open it until “begin work” is given.
2. You have 55 minutes to complete the exam.
3. Solve the problems in the space provided. Show all work to receive full credit.
4. There are 3 problems on 3 pages in this exam (not including the cover page). Write your name on the top of each sheet. Use the back of the pages for extra workspace as needed.
5. Save Mathematica files on your desktop and re-save frequently.
6. When finished, upload your Mathematica work to CANVAS.

(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

Methanol ($\text{CH}_4\text{O}(\text{g})$) is fed to a combustion reactor with 100% excess air.

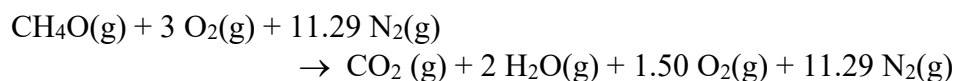
- (a) Balance the reaction on a basis of one mole of methanol in the feed.
- (b) Calculate the heat of reaction at 25 °C and 1.0 bar in J/mol on a basis of one mole of methanol in the feed.
- (c) Calculate the standard gas-phase isothermal heat of reaction at 300 °C and 1.0 bar for one mole of methanol in 100% excess air.

The following table contains ideal gas heat capacity polynomial coefficients and standard heats of formation at 298 K from Appendix C:

species	a	$b \times 10^3$	$c \times 10^6$	$d \times 10^{-5}$	$\Delta H_{f,298}^0$, J/mol
$\text{CH}_4\text{O}(\text{g})$	2.211	12.216	-3.450	0.000	-200,660
$\text{O}_2(\text{g})$	3.639	0.506	0.000	-0.227	0
$\text{N}_2(\text{g})$	3.280	0.593	0.000	0.040	0
$\text{CO}_2(\text{g})$	5.457	1.045	0.000	-1.157	-393,509
$\text{H}_2\text{O}(\text{g})$	3.470	1.450	0.000	0.121	-241,818

Solution, part (a):

Balanced reaction in 100% excess air:



Solution of parts (b) and (c) in Mathematica are shown on the following page.

Solution, part (b):

```
(*List of stoichiometric coefficients*)
(*methanol, oxygen, nitrogen, carbon dioxide, water, oxygen, nitrogen*)
v = {-1, -3, -11.29, 1, 2, 1.5, 11.29};

(*List of standard Heats of Formation*)
ΔHf298 = {-200 660, 0, 0, -393 509, -241 818, 0, 0};

(*Standard Heat of Reaction at 298 K*)
ΔH298 = Plus @@ (v * ΔHf298) (*J/mol*)
-676 485.
```

ANS, J per mole of methanol

Solution, part (c):

```
(*Heat Capacity polynomial coefficients, Given, from Table C.1:*)
a = { 2.211, 3.639, 3.280, 5.457, 3.470, 3.639, 3.280};
b = {12.216, 0.506, 0.593, 1.045, 1.450, 0.506, 0.593} * 10-3;
c = {-3.450, 0.000, 0.000, 0.000, 0.000, 0.000, 0.000} * 10-6;
d = { 0.000, -0.227, 0.040, -1.157, 0.121, -0.227, 0.040} * 105;

Δa = Plus @@ (v * a);
Δb = Plus @@ (v * b);
Δc = Plus @@ (v * c);
Δd = Plus @@ (v * d);

(*Temperatures, K*)
T = 300 + 273.15;
T0 = 25 + 273.15;

(*Gas constant*)
R = 8.314; (*  $\frac{\text{J}}{\text{mol}\cdot\text{K}}$  *)

(*Equation 4.21 for MDCPH*)
MDCPH = Δa +  $\frac{\Delta b}{2} * (T + T0) + \frac{\Delta c}{3} * (T^2 + T0^2 + T * T0) + \frac{\Delta d}{T * T0}$ 
```

1.13391

```
(*Equation 4.22 for corrected heat of reaction*)
(*Gives molar heat of reaction in J/mol*)
ΔH573 = ΔH298 + MDCPH * R * (T - T0)
```

-673 892.5

ANS, J per mole of methanol

Problem: Weight:
B 70

An engineering plan for a vinyl chloride plant includes a pipeline carrying ethylene (C₂H₄) at a volumetric flow rate of 25.750 MMSCFD (million standard cubic feet per day). Standard conditions are 519.67°R and 14.696 psia. At these conditions, the molar volume of C₂H₄ is 377.27 ft³/lbmol.

(a) Calculate the molar flow rate of C₂H₄ in lbmol/sec.

(b) Use the van der Waals (vdW) equation of state (equations 3.41, 3.44, and 3.45), constants in Table 3.1, and gas constant R = 10.73 ft³·psia/(lbmol·R) to determine the isothermal reversible work produced by increasing the molar volume of C₂H₄ by 5%. Report the work in hp.

From Appendix B, the critical temperature, pressure, and acentric factor for ethylene are T_C = 508.14 Rankine, and P_C = 730.99 psia, and ω = 0.087.

Solution, part (a):

$$\frac{25,750,000 \text{ ft}^3}{\text{day}} \cdot \frac{1 \text{ day}}{24 \text{ h}} \cdot \frac{1 \text{ h}}{3600 \text{ s}} \cdot \frac{1 \text{ lbmol}}{377.27 \text{ ft}^3} = \underline{\underline{0.78997 \frac{\text{lbmol}}{\text{s}}}}_{\text{ANS}}$$

Solution, part (b):

```

T = 519.67; (*Rankine, given*)
R = 10.73; (* ft³·psia / (lbmol·R), given*)
ω = 0.087; (*App. B, p.665*)
Tc = 508.14; (*Rankine, given*)
Pc = 730.99; (*psia, given*)
Tr1 = T / Tc; (*reduced temperature*)
(*Table 3.1, p.100*)
σ = 0;
ε = 0;
Ω = 1 / 8;
Φ = 27 / 64;
α = 1;
(*Equations 3.41, 3.44, and 3.45*)
b = Ω * (R * Tc) / Pc;
a = Φ * (α * R² * Tc²) / Pc;
P[V_] = (R * T) / (V - b) - (a / ((V + ε * b) * (V + σ * b)));

```

Cadet: _____

$$W = - \int_{377.27}^{1.05 \times 377.27} P[V] dV \left(\text{*eq 1.4, units } \frac{\text{psia} \cdot \text{ft}^3}{\text{lbmol}} \text{*} \right)$$

$$-270.5491$$

$$\frac{-270.5491 \text{ psia} \cdot \text{ft}^3}{\text{lbmol}} \cdot \frac{\frac{\text{lb}_f}{\text{in}^2}}{\text{psia}} \cdot \left(\frac{12 \text{ in}}{\text{ft}} \right)^2 \cdot \frac{0.78997 \text{ lbmol}}{\text{s}} \cdot \frac{1.34102 \text{ hp}}{737.562 \frac{\text{ft} \cdot \text{lb}_f}{\text{s}}}$$

$$-55.95719 \text{ hp}$$

_____ ANS

Problem: Weight:
C 80

0.200 kmol of an ideal gas in a closed system is changed from an initial state of 1.5 m³, 5.0 bar and 451.0 K to a final state of 5.0 m³, 1.5 bar, and 451.0 K by a two-step process consisting of an adiabatic expansion followed by heating at constant pressure.

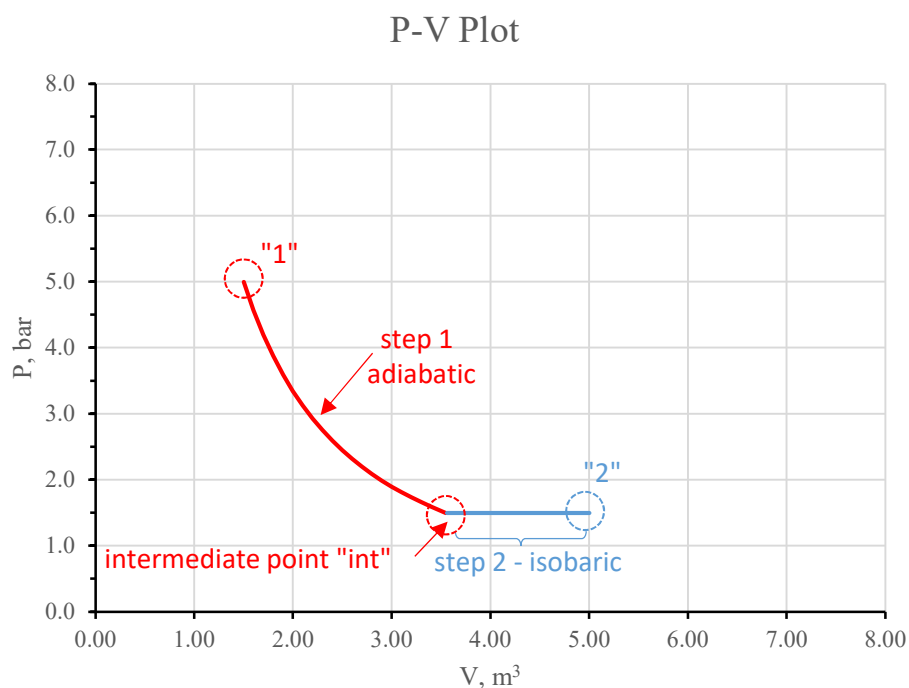
- (a) Sketch the process path on the PV axes below.
- (b) Calculate Q, W, ΔU and ΔH for the overall process in units of kJ.
- (c) Calculate the intermediate temperature after step 1.

$$R = 8.314 \text{ J/(mol} \cdot \text{K)} = 0.08314 \text{ (bar} \cdot \text{m}^3\text{)/(kmol} \cdot \text{K)}$$

$$C_P = (7/2) \cdot R, \text{ and}$$

$$C_V = (5/2) \cdot R$$

Solution, part (a):



Solution, part (b):

The overall process is isothermal ($T_2 = T_1$), so $\Delta H_{\text{Overall}} = \Delta U_{\text{Overall}} = 0 \text{ kJ}$
ANS

Equation 3.23c gives the P-V relation for an adiabatic process. Let the intermediate state be denoted with subscript “int” with $P_{\text{int}} = P_2$ since the second step is at constant pressure.

Also $\gamma = C_P/C_V = (7R/2)/(5R/2) = (7/5) = 1.4$ from equation 3.24.

Solve for intermediate volume, V_{int} , using equation 3.23c from lesson 11:

$$P_{\text{int}} V_{\text{int}}^{\gamma} = P_1 V_1^{\gamma} \Rightarrow V_{\text{int}} = \sqrt[\gamma]{\frac{P_1}{P_{\text{int}}}} V_1^{\gamma} = \sqrt[1.4]{\frac{5.0 \text{ bar}}{1.5 \text{ bar}}} (1.5 \text{ m}^3)^{1.4} = 3.544672 \text{ m}^3$$

Once V_{int} is known, the adiabatic work for step 1 is given by equation 3.26:

$$W_{\text{Step1}} = \frac{P_{\text{int}} \cdot V_{\text{int}} - P_1 \cdot V_1}{\gamma - 1} = \frac{1.5 \text{ bar} \cdot 3.544672 \text{ m}^3 - 5.0 \text{ bar} \cdot 1.5 \text{ m}^3}{1.4 - 1} = -5.457479 \text{ bar} \cdot \text{m}^3$$

Step 2 is at constant pressure, so work $-P\Delta V$:

$$W_{\text{Step2}} = -P \cdot \Delta V = -P \cdot (V_2 - V_{\text{int}}) = -1.5 \cdot (5.0 \text{ m}^3 - 3.544672 \text{ m}^3) = -2.18299 \text{ bar} \cdot \text{m}^3.$$

The total overall work is the sum of the work of each step:

$$W_{\text{Overall}} = W_{\text{Step1}} + W_{\text{Step2}} = -5.45748 \text{ bar} \cdot \text{m}^3 + (-2.18299) \text{ bar} \cdot \text{m}^3 = -7.64047 \text{ bar} \cdot \text{m}^3$$

Now convert the units to kJ:

$$W_{\text{Overall}} = -7.640471 \text{ bar} \cdot \text{m}^3 \left(\frac{1 \text{ J}}{10^{-5} \text{ bar} \cdot \text{m}^3} \right) \cdot \left(\frac{1 \text{ kJ}}{1000 \text{ J}} \right) = \underline{\underline{-764.047 \text{ kJ}}}_{\text{ANS}}$$

Finally, for Q:

$$\Delta U_{\text{Overall}} = Q_{\text{Overall}} + W_{\text{Overall}} = 0 \Rightarrow Q_{\text{Overall}} = -W_{\text{Overall}} = \underline{\underline{764.047 \text{ kJ}}}_{\text{ANS}}$$

Solution, part (c):

$$PV = nRT \Rightarrow T_{\text{int}} = \frac{P_{\text{int}} \cdot V_{\text{int}}}{n \cdot R} = \frac{1.5 \text{ bar} \cdot 3.544672 \text{ m}^3}{0.200 \text{ kmol} \cdot \left(0.08314 \frac{\text{bar} \cdot \text{m}^3}{\text{kmol} \cdot \text{K}} \right)} = \underline{\underline{319.8 \text{ K}}}_{\text{ANS}}$$