Name ________________
PID __________________

Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Chemical Engineering Thermodynamics Spring 2018

February 21, 2018, Ver. A. CLOSED NOTES, EQUATION SHEET PROVIDED
General Instructions

- Submit all problems in the order of the exam.
- Do all work on exam pages. Use back if necessary. Submit all exam pages and the PH chart.
- For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

$$\left(\frac{\partial F}{\partial w}\right)_z = \left(\frac{\partial F}{\partial x}\right)_y\left(\frac{\partial x}{\partial w}\right)_z + \left(\frac{\partial F}{\partial y}\right)_x\left(\frac{\partial y}{\partial w}\right)_z$$

$H = U + PV$, $A = U - TS$, $G = H - TS$

Differential Property		Corresponding Maxwell Relation
$dU = TdS - PdV$	$U(S, V)$	$-(\partial P/\partial S)_V = (\partial T/\partial V)_S$
$dH = TdS + VdP$	$H(S, P)$	$(\partial V/\partial S)_P = (\partial T/\partial P)_S$
$dA = -SdT - PdV$	$A(T, V)$	$(\partial P/\partial T)_V = (\partial S/\partial V)_T$
$dG = -SdT + VdP$	$G(T, P)$	$-(\partial V/\partial T)_P = (\partial S/\partial P)_T$

1. A real gas is expanded isothermally. The next three questions concern energy changes for this process.

(a) (5) How does the kinetic energy of the fluid atoms change?

__ increases ___ decreases ___ stays the same

Explain your answer using descriptions of molecular phenomena and without using equations.

(b) (5) How does the potential energy between molecules change for the system of molecules?

__ increases ___ decreases ___ stays the same

Explain your answer using descriptions of molecular phenomena and without using equations.

(c) (5) How does the internal energy change for the system of molecules?

__ increases ___ decreases ___ stays the same

Explain your answer using descriptions of molecular phenomena and without using equations.

2. (10) A tank holds 150 kg water/steam which exists as 0.15 m^3 liquid water at 130°C and the remainder is vapor. What is the quality?

3. Nitrogen (1.25 moles) is compressed isothermally in a piston/cylinder. The initial temperature and pressure are 25°C and 0.1 MPa. The final pressure is 0.3 MPa. Assume $C_P/R = 3.5$ is independent of temperature and model the fluid as an ideal gas.
   (a) (10) Determine ΔU (J/mol) and ΔS (J/mol-K).

   (b) (5) Taking the gas as the system, determine the total work interaction in (kJ).

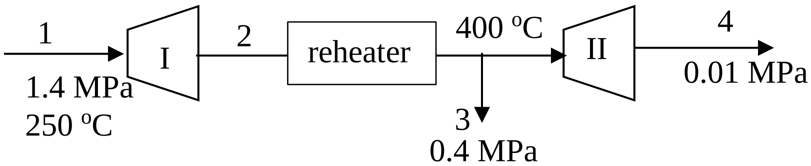
4. (10) A simple derivative manipulation is applied to each of the starting expressions in the left column below. Some of the manipulations may involve errors. Indicate whether the ending expression in each row is valid or invalid. Work that is shown in the scratch is necessary for partial credit.

Starting Expression	Ending Expression	Indicate valid or invalid
(a) $\left(\frac{\partial T}{\partial V}\right)_G$	$\left(\frac{\partial T}{\partial V}\right)_G = -\frac{\left(\frac{\partial T}{\partial G}\right)_V}{\left(\frac{\partial V}{\partial G}\right)_T}$	
(b) $dA = TdS - PdV$	$\left(\frac{\partial A}{\partial V}\right)_P = C_P\left(\frac{\partial V}{\partial T}\right)_P - P$	

Scratch work area:

This version has an error in the starting expression for (b)

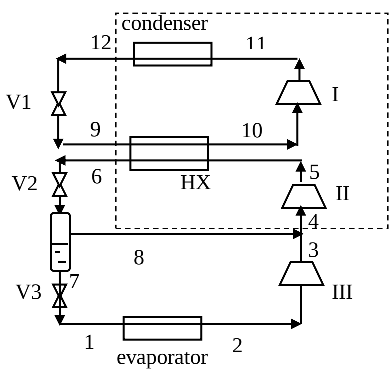
5. Adiabatic steam turbine I is 85% efficient.



(a) (10) Determine W_S for turbine I (kJ/kg). Provide the values used for any interpolation.

(b) (5) If $m_3/m_1 = 0.09$ and W_S for turbine II is -610 kJ/kg, find the work total produced by the turbine system per kg of flow of stream 1.

6. This problem considers the cascade refrigeration cycle shown below. The compressors are adiabatic and compressors I and II are 75% efficient. The operating fluid is ethylene (chart attached). HX is an evaporator for the upper cycle and a condenser for the lower cycle using standard assumptions for condensers and evaporators.
MARK YOU ANSWERS CLEARLY ON THE CHART AND SUBMIT THE CHART WITH YOUR WORK. The dotted line is a boundary used in part (d).



	P(MPa)	T(K)	H (kJ/kg)	S(kJ/kg-K)
1	0.1			
2	0.1		528	
3’				
3			640	
4				
5’				
5				
6	1.0			
7	0.45	200		
8	0.45	200		
9	0.8			
10				
11’				
11				
12		240		

(a) (10) Calculate H_{11} and label it on the chart with ‘11’, marking your method on the plot. Report here the values of H_{11} and T_{11}.

(b) (5) Locate state 6 on the graph and mark the point clearly with the label ‘6’. Find q out of valve V2, and determine the flowrate of m_8 and m_7 if m_6 = 40 kg/h. If you are unable to find q, use a value of 0.2 for any subsequent calculations that need q.

(c) (10) Find H_8 and H_4 if m_6 = 40 kg/h. Label any points used on the graph with stream numbers.

(d) (10) For the dotted boundary, write the simplified energy balance for ethylene. All compressors are adiabatic. Insert all relevant stream flow rates into the balance. If Q and W are relevant, indicate with subscripts the relevant equipment (e.g. I, II, III, evap, cond, HX, flash) using intensive terms (e.g. the heat transfer in the evaporator is written as m_1Q_{evap}). Do not rearrange the balance or combine with other balances.

Name ________________
PID __________________

Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Thermodynamics   Spring 2017

February 22, 2017, CLOSED NOTES Ver A.
General Instructions

- Submit all problems in the order of the exam.
- Do all work on exam pages. Use back if necessary. Submit all exam pages and the PH chart.
- For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

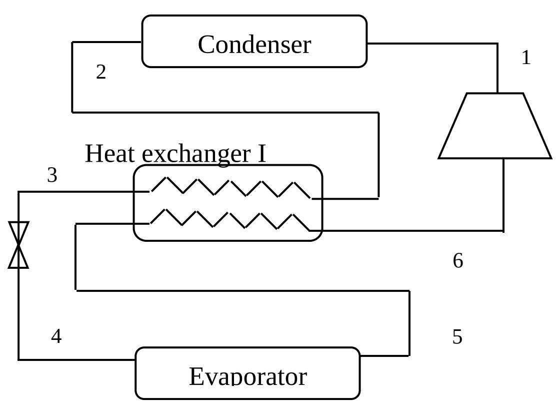
$H = U + PV, A = U - TS, G = H - TS$

$$\left(\frac{\partial F}{\partial w}\right)_z = \left(\frac{\partial F}{\partial x}\right)_y \left(\frac{\partial x}{\partial w}\right)_z + \left(\frac{\partial F}{\partial y}\right)_x \left(\frac{\partial y}{\partial w}\right)_z$$

Differential Property		Corresponding Maxwell Relation
$dU = TdS - PdV$	$U(S, V)$	$-(\partial P/\partial S)_V = (\partial T/\partial V)_S$
$dH = TdS + VdP$	$H(S, P)$	$(\partial V/\partial S)_P = (\partial T/\partial P)_S$
$dA = -SdT - PdV$	$A(T, V)$	$(\partial P/\partial T)_V = (\partial S/\partial V)_T$
$dG = -SdT + VdP$	$G(T, P)$	$-(\partial V/\partial T)_P = (\partial S/\partial P)_T$

1. (10) An ideal gas flows through a steady-state adiabatic expander (η_E = 0.85). The inlet is 580 K and 3 MPa. The outlet is 0.1 MPa. The temperature-independent heat capacity is C_P = 47.2 J/mol-K. Determine the reversible outlet temperature.

2. The refrigeration cycle below uses ethylene (PH diagram attached). Stream 5 is saturated vapor at 0.2 MPa and stream 2 is saturated liquid at 0.6 MPa. The compressor is adiabatic (η_C = 0.85). Heat exchanger I serves increase the temperature from 5 to 6 and decrease the temperature from 2 to 3. Stream 6 is at 220K and 0.2 MPa.



A table is provided for convenience. The problem may not require all values.
MARK YOUR POINTS CLEARLY ON THE ATTACHED CHART.

Stream	T(K)	P (MPa)	H(kJ/kg)	S(kJ/kg-K)
1				
2		0.6		
3’				
3				
4				
5		0.2		
6	220	0.2		

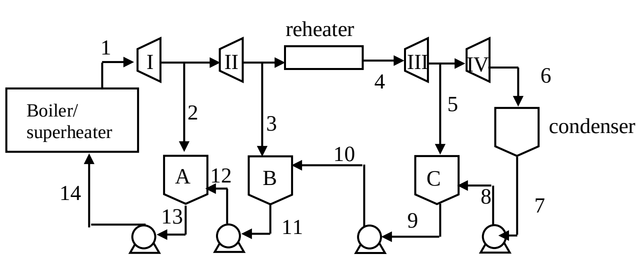
(a) (10) Determine the work done by the compressor (kJ/kg).

(b) (10) Determine the enthalpy of stream 3.

(c) (10) Determine the quality of stream 4 and the heat transfer in the evaporator (kJ/kg). (Note: if you are unable to locate H4, assume a value of H4 =100 kJ/kg for this calculation).

3. NOTE: ONLY SOME STREAMS ARE REQUIRED TO SOLVE THE PROBLEMS. DO NOT TAKE TIME TO FIND ALL STATES!

A steam power cycle is shown below.



	P(MPa)	T(C)	H (kJ/kg)	S(kJ/kg-K)
1	6	350	3043.9	6.3356
2	2	224	2833.7	6.4110
3	0.6			
4	0.6	450		
5	0.2			
6	0.05			
7	0.05			
8				
9	0.2			
10				
11	0.6			
12	2		678.4	
13	2		908.6	
14				

(a) (5) Determine P_8, P_{10}, P_{14} and enter the values in the table.

(b) (15) Determine the efficiency of Turbine I.

(c) (15) Turbine II is 85% efficient. Determine the work produced (kJ/kg).

(d) (5) Find the enthalpy of stream 9. Explain how you determine the value.

(e) (10) Perform a balance around preheater A to determine the mass flowrate ratio m_2/m_1.

4. (10) A simple derivative manipulation is applied in the left column below. The manipulation may involve errors. Indicate whether the ending expression is valid or invalid. Work shown in the scratch area is necessary for partial credit.

Starting Expression	Ending Expression	Indicate Valid or Invalid
$\left(\frac{\partial G}{\partial S}\right)_P$	$\frac{ST}{C_P}$	
$\left(\frac{\partial H}{\partial S}\right)_T$	$T - V\left(\frac{\partial T}{\partial V}\right)_P$	

Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Thermodynamics Spring 2016

February 24, 2016, CLOSED NOTES, Ver. A.
General Instructions

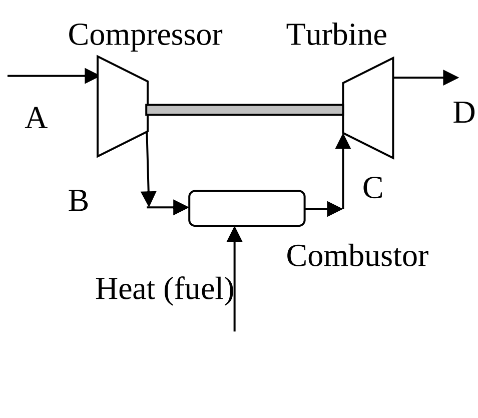
- Submit all problems in the order of the exam.
- Do all work on exam pages. Use back if necessary. Submit all exam pages and the PH chart.
- For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

1. Methane (1.6 moles) is compressed in a closed piston/cylinder isothermally. The initial temperature and pressure are 253K and 0.1 MPa. The final pressure is 0.5 MPa. Assume $C_P/R = 4.298$ is independent of temperature. Use the ideal gas model.
   (a) (5) Determine the work required (kJ).

   (b) (5) Determine $\Delta\underline{H}$ and $\underline{Q}$.

   (c) (5) Determine $\Delta\underline{S}$ (J/K).

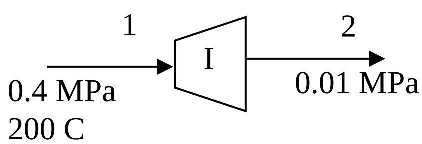
2. An ideal gas is used in a gas turbine as shown below. The compressor ($\eta = 0.8$) and the turbine ($\eta = 0.8$) are coupled through a shaft. The gas turbine is to be modeled as a Brayton cycle (ignoring moles of fuel and combustion products). $T_A = 25°C$, $P_A = P_D = 1$ bar. The pressure at B and C is 7 bar. The temperature at C is 845°C. For the ideal gas, use $C_P = 29.1$ J/mol-K, and assume C_P is independent of T.



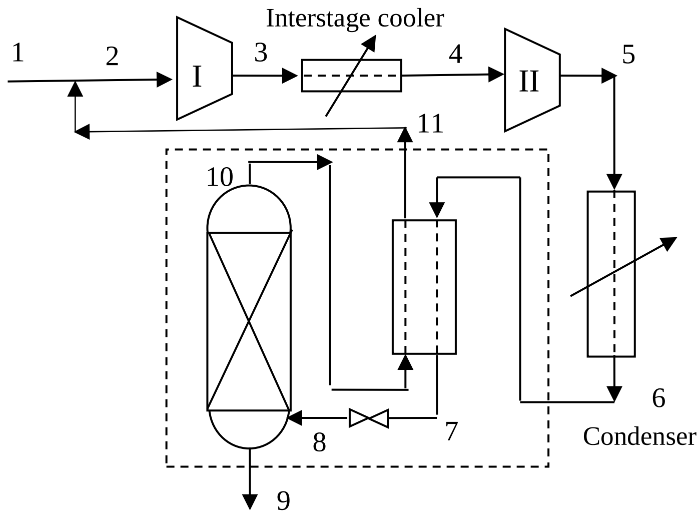
(a) (5) Determine the work required in the compressor (kJ/mol) and the outlet temperature B.

(b) (5) Determine the amount of heat that must be added to the combustor by burning fuel. (kJ/mol).

3. (15) The adiabatic steam turbine is 85% efficient. Determine the work produced (kJ/kg). Provide the numbers used for any interpolation.



The next few questions involve the liquefaction processing of methane using the following flowsheet. A partial set of conditions is provided in the table. Mark the attached chart as you use it and SUBMIT it with your exam.



	T(K)	P(MPa)	H(kJ/kg)
2		0.1	820
4		0.5	730
6		1.0	satL
7	140	1.0	
9		0.1	
10		0.1	

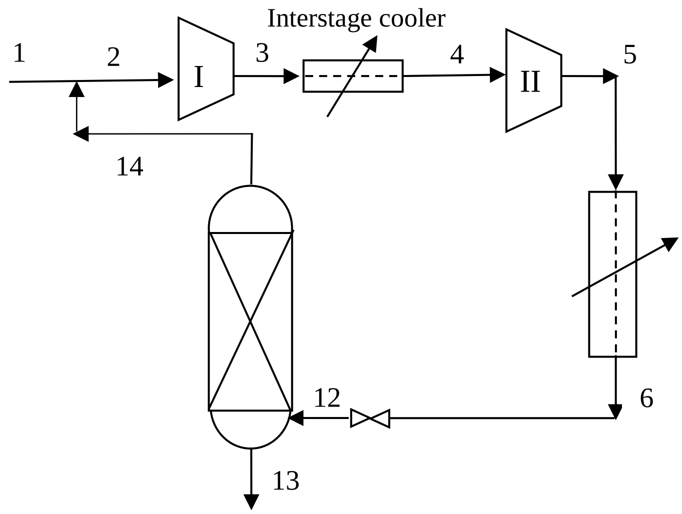
4. (10) H_9 is saturated liquid, H_{10} is saturated vapor, The flash drum is adiabatic. Find m_{10}/m_7 and m_9/m_7.

5. (10) Use the dotted boundary to find H_{11}. Note: if you were unable to find the answer for problem 4, and find it necessary, use $m_{10}/m_7 = 0.25$.

6. (10) Compressor II is 80% efficient. Find the work (kW) required to compress 120 kg/h.

7. (10) Find the heat transfer necessary (kJ/kg) in the condenser.

8. (10) Suppose that the heat exchanger is removed as shown below with all states 1-6 as given above. What fraction of stream 6 is liquefied with this modification? Different stream numbers are provided to avoid conflict with the previous part. Mark the chart with the stream values.



Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

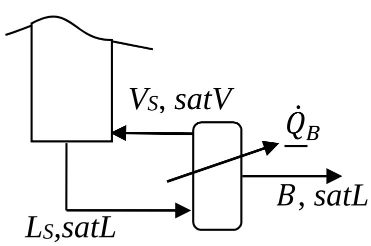
ChE 321: Thermodynamics Spring 2015

February 25, 2015, CLOSED BOOK, steam tables and one equation sheet provided, Ver. B.
General Instructions

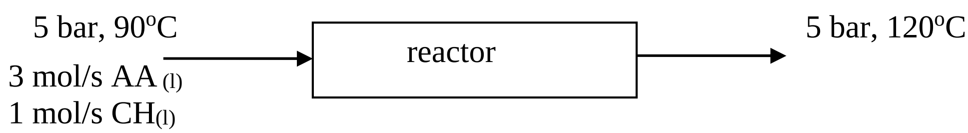
- Submit all problems in the order of the exam.
- Do all work on exam pages. Use back if necessary. Submit all exam pages.
- For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

1. (10) An ideal gas is expanded adiabatically and reversibly in a piston/cylinder from T_1 = 540K, P_1 = 0.8 MPa to P_2 = 0.1 MPa. C_P = 42 J/mol-K independent of T. Determine ΔH, Q, W_{EC}.

2. (10) Distillation column preliminary design often uses the assumption of constant molar overflow. For the case below, assume all H^{satL} are the same and all H^{satV} are the same, and ΔH^{vap} = 32 J/mol. Consider the partial reboiler below. Starting with an energy balance around the partial reboiler using all three streams, derive and calculate the amount of heat required when L_S = 53 mol/hr, V_S/B = 1.2.



3. Cyclohexyl acetate (CHA) (C8H14O2) can be formed by reacting cyclohexene (CH) (C6H10) and Acetic Acid (AA) (C2H4O2). Excess acetic acid is fed to the reactor as shown below. Conversion of CH is 85%. The reaction is run at high pressure to keep all reactants and products in the liquid phase. Ignore any pressure correction for liquids.



Thermodynamic Data:

	$\Delta H^o_{f,298.15(l)}$ (kJ/mol)	Cp(J/mol-K)
CH (l)	-37.8	165
AA (l)	-483.5	130
CHA (l)	-558.9	290

(a) (10) Balance the reaction and determine the outlet flow (mol/s) of each component for the basis in the figure.

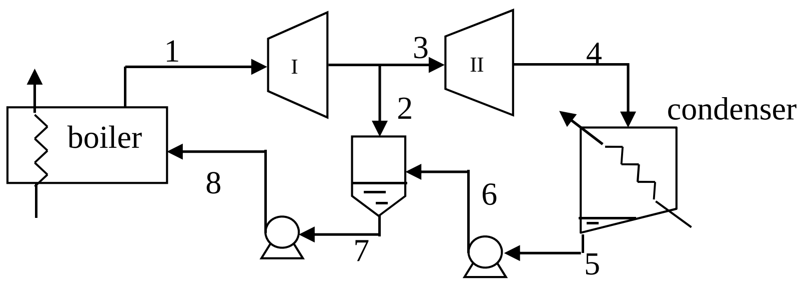
(b) (10) Determine the standard heat of reaction.

(c) (15) Complete the table of enthalpies at the inlet and outlet conditions from the figure. Use provided heat capacities and assume that they are *T*-independent. Calculate the enthalpy values in a manner that they can be properly used in the energy balance in part (d) below. Provide the formula and intermediate values for at least one species in each stream.

Specie	H^{in} (J/mol)	H^{out} (J/mol)
$CH_{(l)}$		
$AA_{(l)}$		
$CHA_{(l)}$		

4. (d) (10) Determine the required heat transfer (J/s) in the reactor to maintain the states given in the figure. Is heat added or removed?

5. A power plant uses a two-stage turbine with an open feedwater preheater as shown below. Steam exits the boiler/superheater at 550°C and 1.2 MPa. The outlet of the first adiabatic turbine is 400°C and 0.3 MPa. The outlet of the second adiabatic turbine (η_E = 0.8) is 0.01 MPa. For the pumps, (η_C = 0.75). Hint: you do not need to find states for all the streams. Solve for the streams as needed.



Stream	T(°C)	P(MPa)	H(kJ/kg)	S(kJ/kg-K)
1	550	1.2	3586.3	
2	400	0.3	3275.5	
3	400	0.3		
4		0.01		
5				
6			193.1	
7				
8				

(a) (10) Enter the missing pressures in the table above.

(b) (10) Determine the efficiency for turbine I. Note: if you interpolate using a calculator program, be sure to provide the values plugged in.

(b) (10) Determine the outlet enthalpy for turbine II and work (kJ/kg) produced.

(c) (10) Determine the ratio of flowrate ratio, m2/m1.

Name ___________________________

Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Thermodynamics Spring 2014

February 19, 2014, CLOSED BOOK, one 8.5x11 page of notes, both sides.
General Instructions

- Submit all problems in the order of the exam.
- Do all work on exam pages. Use back if necessary. Submit all exam pages.
- For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

1 kg = 2.2lb_m; 1m = 3.2808ft; 1m^3=35.315ft^3; 1ft^3=28.317L; 1N=.22411lb_f; 1atm=1.01325E5N/m^2(Pa)= 1.01325bar=760mmHg=14.696psia; 1J=1MPa-cm^3=0.23901cal; 1kJ=0.94781BTU; 1W=1J/s; 1hp=0.70726 BTU/s=0.74570kW; R=8.31447 J/mol-K=8.31447m^3-Pa/mol-K=82.057cm^3=atm/mol-K=1.987BTU/lbmol-R =1.9872cal/mol-K=10.731ft^3-psia/lbmol-R

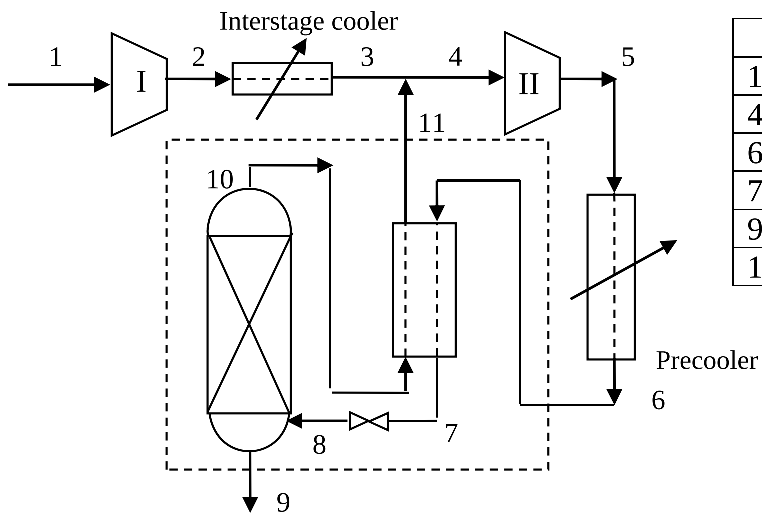
1. A 3m^3 tank holds pure water at 0.2 MPa. The tank has 1.7 m^3 of liquid and the remainder of the tank is vapor.
   a. (5) What mass (kg) is in the tank?

   b. (5) What is the quality?

2. (10) An adiabatic steam turbine has an inlet of 3 MPa and 600°C. The outlet pressure is 0.01 MPa. The turbine is 80% efficient. What is Ws (kJ/kg)?

Name ___________________________

The next few questions involve the liquefaction processing of ethylene using the following flowsheet. A partial set of conditions is provided in the table. Mark the attached chart as you use it and SUBMIT it with your exam.



	T(K)	P(MPa)	H(kJ/kg)
1	200	0.2	
4	240	0.5	
6		2.0	240
7	240	2.0	
9		0.5	
10		0.5	

3. (10) H_9 is saturated liquid, H_{10} is saturated vapor, Find m_{10}/m_7 and m_9/m_7.

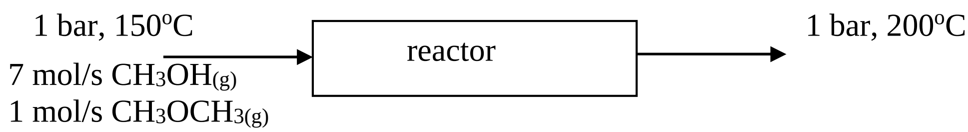
4. (10) Use the dotted boundary to find H_{11}. Note: if you were unable to find the answer for problem 3, and find it necessary, use $m_{10}/m_7 = 0.2$.

5. (10) Compressor II is 80% efficient. Find the work (kW) required to compress 120 kg/h.

6. (5) Find the heat transfer necessary (kJ/kg) in the precooler.

Name ___________________________

7. Methanol (MeOH) (CH_3OH) can be dehydrated over an acid catalyst to yield dimethyl ether (DME) (CH_3OCH_3) and water (H_2O). Due to reactor conditions, conversion is incomplete so a separation and recycle process is used (not shown) and the reactor feed has some DME content as shown below. Conversion of MeOH is 87%.



Thermodynamic Data:

	$\Delta H^o_{f,298.15}$ (kJ/mol)	$\Delta G^o_{f,298.15}$ (kJ/mol)	Cp/R
MeOH (g)	-200.94	-162.24	5.28
DME (g)	-184.1	-112.8	7.91
Water (g)	-241.84	-228.61	4.04

(a) (10) Balance the reaction and determine the outlet flow (mol/s) of each component for the basis in the figure.

(b) (10) Determine the standard heat of reaction.

(c) (15) Complete the table of enthalpies at the inlet and outlet conditions from the figure. Use provided heat capacities and assume that they are *T*-independent. Calculate the enthalpy values in a manner that they can be properly used in the energy balance in part (d) below. Provide the formula and intermediate values for at least one species in each stream.

Specie	C_P/R	Cp(J/mol-K)	H^{in} (J/mol)	H^{out} (J/mol)
$MeOH_{(g)}$				
$DME_{(g)}$				
$Water_{(g)}$				

Name ___________________________

(d) (10) Determine the required heat transfer (J/s) in the reactor to maintain the states given in the figure. Is heat added or removed?

Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Thermodynamics Spring 2013

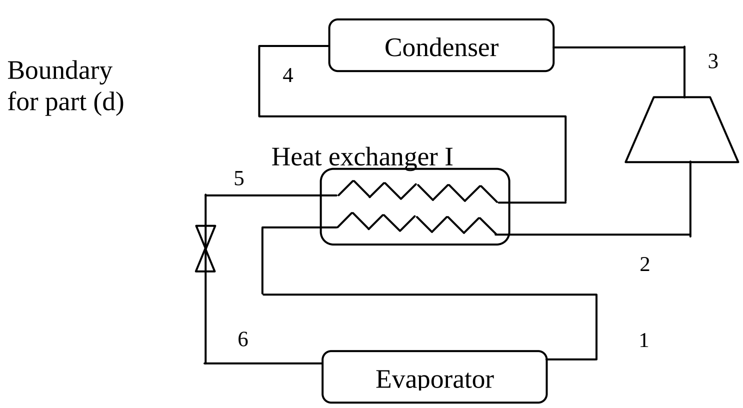
February 20, 2013, CLOSED BOOK, one 8.5x11 page of notes, both sides.
General Instructions

- Submit all problems in the order of the exam.
- Do all work on exam pages. Use back if necessary. Submit all exam pages.
- For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

1. An ideal gas flows through a steady-state adiabatic compressor (η_C = 0.8). The inlet is 295K and 0.1 MPa. The outlet is 0.3 MPa. The temperature-independent heat capacity is C_P = 44.2 J/mol-K.
   (a) (10) Determine the reversible outlet temperature.

   (b) (5) Determine the actual outlet temperature.

2. The refrigeration cycle below uses R-502 (PH diagram attached). Stream 1 is saturated vapor at 0.12 MPa and stream 4 is saturated liquid at 0.8 MPa. The compressor is adiabatic (η_C = 0.85). Heat exchanger I serves increase the temperature from 1 to 2 and decrease the temperature from 4 to 5. Stream 2 is at 260K and 0.12MPa.



A table is provided for convenience on pg 2. The problem may not require all values.

Stream	T(K)	P (MPa)	H(kJ/kg)	S(kJ/kg-K)
1		0.12		
2	260	0.12		
3’				
3				
4		0.8		
5				
6				

Mark your points clearly on the attached chart.

(a) (10) Determine the work done by the compressor (kJ/kg).

(b) (10) Determine the enthalpy of stream 5.

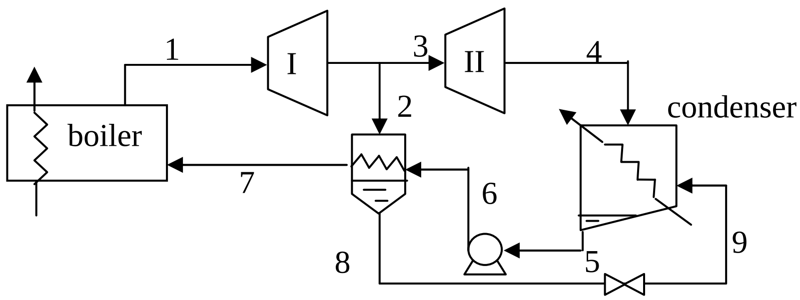
(c) (10) Determine the quality of stream 6 and the heat transfer in the evaporator (kJ/kg). (Note: if you were unable to locate H5 in part (b), assume a value of 70 kJ/kg for this calculation).

3. (10) A simple derivative manipulation is applied in the left column below. The manipulation may involve errors. Indicate whether the ending expression is valid or invalid. Work shown in the scratch area is necessary for partial credit.

Starting Expression	Ending Expression	Indicate Valid or Invalid
$\left(\frac{\partial A}{\partial S}\right)_P$	$\left(\frac{\partial A}{\partial S}\right)_P = -\frac{ST}{C_P} + \frac{PT}{C_P}\left(\frac{\partial V}{\partial T}\right)_P$	

R-502 chart

4. A power plant uses a two-stage turbine with a closed feedwater preheater as shown below. Steam exits the boiler/superheater at 500°C and 5 MPa. The outlet of the first adiabatic turbine is 300°C and 1 MPa. The outlet of the second adiabatic turbine ($\eta_E = 0.8$) is 0.1 MPa. For the pump, ($\eta_C = 0.75$). Hint: you do not need to find states for all the streams. Solve for the streams as needed.



Stream	T(°C)	P(MPa)	H(kJ/kg)	S(kJ/kg-K)
1	500	5	3434.7	
2	300	1	3051.6	
3	300	1		
4		0.1		
5				
6				
7	175	5		
8			762.5	
9				

(a) (10) Enter the missing pressures in the table above.

(b) (10) Determine the efficiency for turbine I. Note: if you interpolate using a calculator program, be sure to provide the values plugged in.

(c) (5) Determine the outlet enthalpy for turbine II and work (kJ/kg) produced.

(d) (10) Determine the enthalpies of streams 5, 6, 7.

(e) (10) Determine the ratio of flowrate ratio, m2/m1.

Name______________________________

Michigan State University

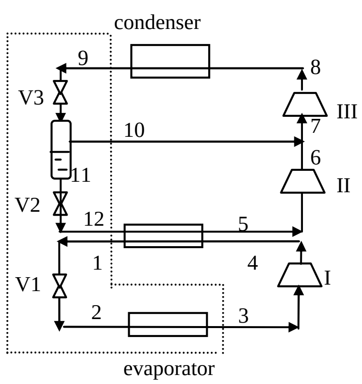
DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Chemical Engineering Thermodynamics Spring 2012

General Instructions

- Submit all problems in the order of the exam.
- Do all work on exam pages. Use back if necessary.
- For steam table interpolations, write down the values you use for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method. If you are stuck, make an assumption, *document the assumption*, and then proceed. Work all parts.

1. The following cascade cycle uses ethane. The compressors are adiabatic and 75% efficient. The operating fluid is ethane (chart attached). The dotted line is a boundary used in part (e).



	P(MPa)	T(K)	H (kJ/kg)	S(kJ/kg-K)
1				
2	0.1	230		
3	0.1			
4’	0.3			
4	0.3			
5	0.23	250		
6’				
6				
7				
8	1.5			
8’	1.5			
9				
10	0.6			
11	0.6			
12	0.23			

(a) (10) Determine the enthalpies for states 9, 11, 1. Record the values here. Label the states on the PH chart.

(b) (10) Determine the flowrate ratio m_{10}/m_9.

(c) (10) Mark states 2 and 3 on the chart. Determine the cooling provided by the evaporator, kJ/kg.

Name______________________________

(d) (10) Mark state 4' on the chart. Determine the work required in compressor I if has a mechanical efficiency of 85%.

(e) (10) For the dotted boundary, write the energy balance for ethane. Insert all relevant stream numbers into the balance. If heat and work are relevant for the boundary, use intensive Q's and W's with appropriate flowrate (e.g. m_1Q_{hx1}). Do not rearrange the balance or combine with other equations.

2. Acetone ($C_3H_6O_{(g)}$) is hydrogenated (reacting with $H_{2(g)}$) to form isopropanol ($C_3H_8O_{(g)}$) (also known as 2-propanol) in a catalytic reactor under conditions shown below. Conversion of $C_3H_6O_{(g)}$ is 79%.

(a) (10) Balance the reaction and determine the outlet flow (mol/s) of each component.

(b) (10) Determine the standard heat of reaction for vapor species at 298.15K.

Name______________________________

(c) (10) Complete the table of enthalpies at the inlet and outlet conditions from the figure. Use heat capacities from the back flap of the text for H_2 and isopropanol and assume that they are *T*-independent. Calculate the enthalpy values in a manner that they can be properly used in the energy balance in part (d) below. Provide the formula and intermediate values for at least one specie in each stream.

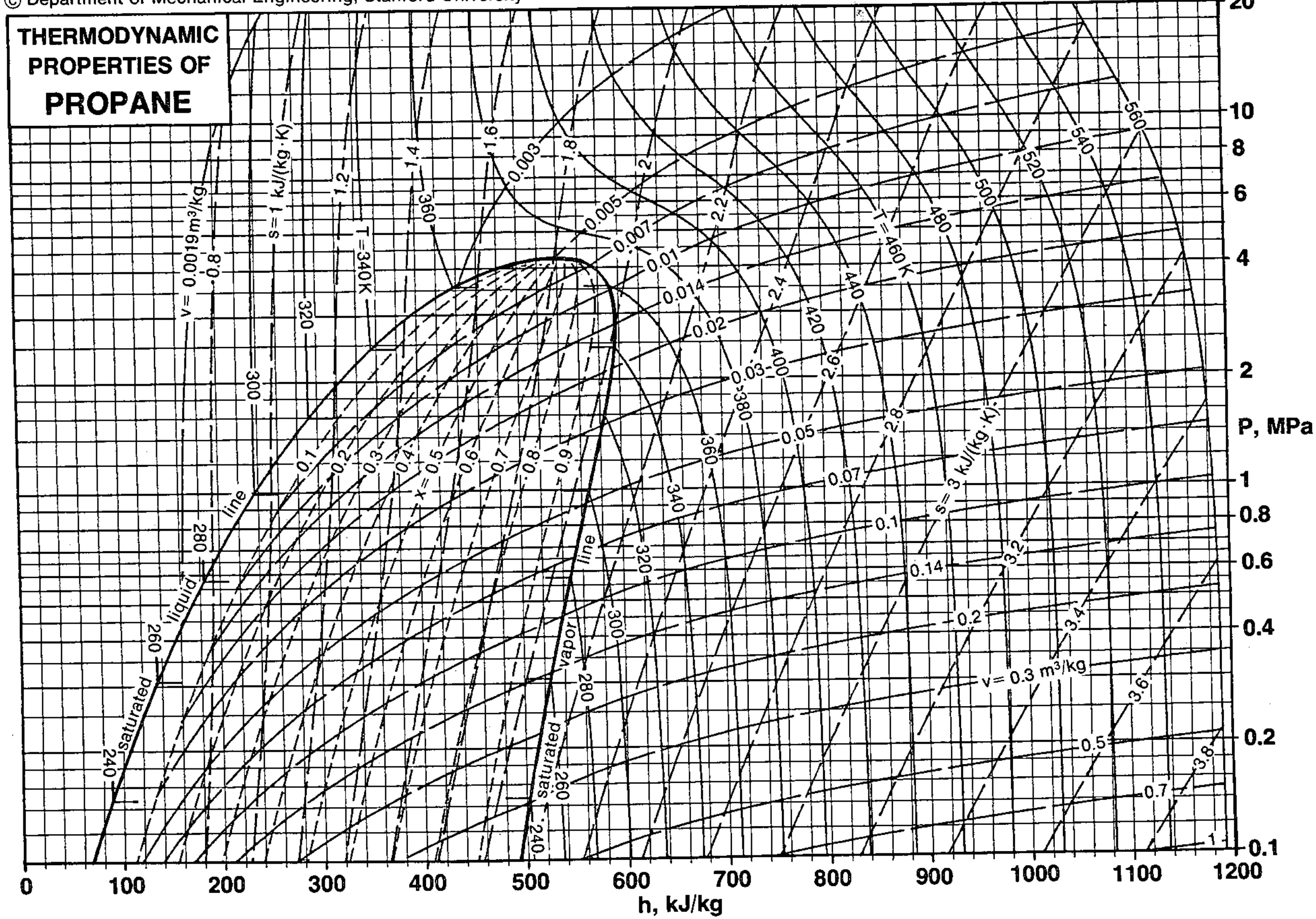
Specie	C_P/R	Cp(J/mol-K)	H^{in} (J/mol)	H^{out} (J/mol)
$H_{2(g)}$				
$C_3H_6O_{(g)}$	8.96			
$C_3H_8O_{(g)}$				

(d) (10) Determine the required heat transfer (J/s) in the reactor to maintain the states given in the figure. Is heat added or removed?

Name______________________________

3. (10) A simple derivative manipulation is applied to each of the starting expressions in the left column below. Some of the manipulations may involve errors. Indicate whether the ending expression in each row is valid or invalid. Valid work in the scratch area is necessary for full credit.

Starting Expression	Ending Expression	Indicate Valid or Invalid
$\left(\frac{\partial S}{\partial P}\right)_V$	$\left(\frac{\partial S}{\partial P}\right)_V = \frac{-C_V}{T}\left(\frac{\partial V}{\partial P}\right)_T$	
$\left(\frac{\partial U}{\partial V}\right)_P$	$\left(\frac{\partial U}{\partial V}\right)_P = C_P\left(\frac{\partial T}{\partial V}\right)_P$	
$\left(\frac{\partial A}{\partial T}\right)_P$	$\left(\frac{\partial A}{\partial T}\right)_P = C_P - P\left(\frac{\partial V}{\partial T}\right)_P$	


THERMODYNAMIC
PROPERTIES OF
PROPANE
P, MPa
h, kJ/kg
v = 0.0019 m³/kg
s = 1 kJ/(kg·K)
s = 3 kJ/(kg·K)
T = 340 K
T = 460 K
v = 0.3 m³/kg
x = 0.5
saturated liquid line
saturated vapor line

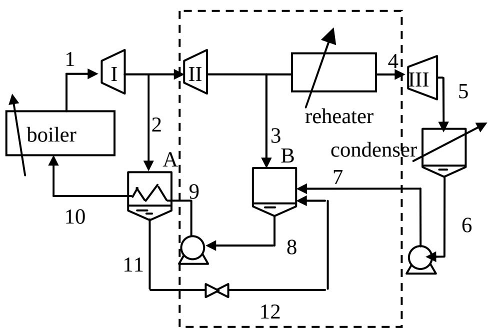
Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Chemical Engineering Thermodynamics Spring 2011
Part I, February 23, 2011, Open Book, Closed Notes
General Directions

- Submit all problems in the order of the exam
- Do all work on exam pages. Use the page back if necessary or request more paper.
- For steam table interpolations, write down all values used for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

1. Answer the following question using the schematic below using adiabatic turbines. The table is provided for your convenience. NOT ALL STATES ARE NEEDED.



	P(MPa)	T(C)	H(kJ/kg)	S(kJ/kgK)
1	8	600	3642.4	7.0221
2	1.2		3100.	
3	0.2	150		
4	0.2	300		
5	0.01			
6	0.01		191.8	
7	0.2		192.0	
8				
9			515	
10			763.8	
11			798.3	
12				

(a) (10) Determine the pressures for streams 8-12 and enter them in the table.

(b) (10) Find H3, H4, H12, H8, and $Q_{reheater}$(kJ/kg).

(c) (20) Find the work done by adiabatic turbine III and the quality of the outlet if the efficiency is 80%.

(d) (10) Write the energy balance around preheater B. Eliminate all mass flow rates except for m3/m1 and m2/m1. Rearrange to solve for m3/m1. Leave the enthalpies as variables; do not calculate the final number.

(e) (10) For the dotted boundary, write the simplified energy balance for the steam/water. Do not include Q or W for equipment where the values are zero for the designated boundary. If Q and W are relevant, indicate with subscripts the relevant equipment. Insert all relevant stream flow rates into the balance. Do not combine with other balances.

Michigan State University

DEPARTMENT OF CHEMICAL ENGINEERING AND MATERIALS SCIENCE

ChE 321: Chemical Engineering Thermodynamics Spring 2011
Part II, Open Book, Closed Notes
General Directions

- Submit all problems in the order of the exam
- Do all work on exam pages. Use the page back if necessary or request more paper.
- For steam table interpolations, write down all values used for interpolation even if you use a calculator.
- Avoid writing answers without showing the method. Partial credit cannot be given without documentation of the method.

2. Ethane is to be compressed from 0.1 MPa and 300K to 0.7 MPa in an adiabatic piston/cylinder. Assume ethane is an ideal gas with Cp = 6.3R.
(10) Determine the final T, W, ΔU, ΔH, if the compression is 80% efficient.

3. (15) A simple derivative manipulation is applied to each of the starting expressions in the left column below. Some of the manipulations may involve errors. Indicate whether the ending expression in each row is valid or invalid. Work that is shown in the scratch area is necessary for partial credit.

Starting Expression	Ending Expression	Indicate Valid or Invalid
$\left(\frac{\partial A}{\partial P}\right)_T$	$\left(\frac{\partial A}{\partial P}\right)_T = T\left(\frac{\partial V}{\partial T}\right)_P - P\left(\frac{\partial V}{\partial P}\right)_T$	
$\left(\frac{\partial S}{\partial G}\right)_T$	$\left(\frac{\partial S}{\partial G}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P\left(\frac{\partial P}{\partial G}\right)_T = -\frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$	
$\left(\frac{\partial A}{\partial P}\right)_T$	$\left(\frac{\partial A}{\partial P}\right)_T = -\left(\frac{\partial A}{\partial T}\right)_P \Big/ \left(\frac{\partial P}{\partial T}\right)_A$	

3. CO_2 sequestration is a topic of considerable debate due to the energy requirements. Suppose that CO_2 has been purified from a flue gas and is available at 300 K and 0.1 MPa.

(a) (5) One possibility for sequestration is to compress the CO_2 for storage. Using the attached chart, determine the work required to compress the CO_2 in a single stage if the reversible temperature rise is limited to 100K in a steady-state adiabatic compressor with an efficiency of 90%. Mark the chart clearly and submit it with your work.

(b) (10) Another proposal for sequestration is to liquefy CO_2 to a saturated liquid at 300K. From the initial condition of 300 K and 0.1 MPa, determine the minimum work and minimum heat transfer necessary (kJ/kg) for a steady-state flow process. Heat may be transferred to the surroundings at 295K. Though the outlet condition in part (a) is far from the target conditions of (b) compare the magnitude of the work.

Table of saturated CO_2 properties, and T-S diagram