Solution Key

First Name ___________________ **Last Name** ___________________

CIRCLE YOUR LECTURE BELOW:

Div. 1 – 08:30 am
Prof. Chen

Div. 2 – 11:30 am
Prof. Braun

EXAM # 3

INSTRUCTIONS

1. This is a closed book examination. You are allowed to have two single sheets of 8.5 in. x 11 in. paper with notes on both sides for the examination. All needed property tables are provided.
2. Do not hesitate to ask the instructor if you do not understand a problem statement.
3. Start each problem on the same page as the problem statement. Write on only one side of the page. Materials on the back side of the page **will not** be graded.
4. Put only one problem on a page. A second problem on the same page **will not** be graded.
5. If you give multiple solutions, you will receive only a partial credit although one of the solutions is correct. Delete the solutions you do not want.
6. For your own benefit, please write clearly and legibly. Maximum credit for each problem is indicated below.
7. After you have completed the exam, **at your seat**, put your papers in order. This may mean that you have to remove the staple and re-staple. **Do not turn in loose pages**.
8. Once time is called you will have three minutes to turn in your exam. Points will be subtracted for exams turned in after these three minutes.

Problem	Possible	Score
1	20	
2	30	
3	20	
4	30	
Total	**100**	

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Problem 1. (20 points) This problem consists of 10 parts. Each part is 2 points. Place your brief answers in the boxes.

a) Which contains more chemical energy, 1 kmol of H_2 or 1 kmol of H_2O?

$\boxed{H_2}$

b) Consider a fuel that is burned with (a) 130% theoretical air and (b) 70% excess air. In which case is the fuel burned with more air?

70% excess air

c) Complete combustion is achieved with (a) 100% theoretical air and (b) 200% theoretical air. If both the reactants and the product are maintained with the same temperature and pressure, is there any difference in the heat produced between the two cases?

No

d) Does the area enclosed by the ideal vapor-compression refrigeration cycle represent the net work input for the cycle?

No

e) Does the ideal vapor-compression refrigeration cycle involve any internal irreversibilities? throttling valve

Yes

f) With given pressure and temperature of refrigerant R-134a, can you determine its quality?

No

g) When a system and its surroundings are at equilibrium, does the Gibbs free energy reach its maximum value or minimum value?

Minimium

h) For a chemical reaction process, does the entropy of an isolated system increase, decrease, or remain the same?

Increase

i) Which case means more complete reaction, (a) K = 1000 or (b) K = 0.001?

(a)

j) At which case is dissolution more likely to occur for N_2, (a) temperature = 10,000 K or (b) temperature = 1,000 K?

(a)

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Problem 2. (30 points) Methane gas (CH_4) at 25°C, 1 atm enters a steam generator operating at steady state. The methane burns completely with 50% excess air entering at 25°C, 1 atm. Product of combustion exit at 177°C, 1 atm. The heat needed for generating steam is 2,000 kW. Neglect kinetic and potential energy effects.

a) Determine the moles of each product per mole of fuel added for complete combustion
b) Determine the required molar flow rate of the methane, in kmol/s
c) Determine the required volumetric flow rate of the methane, in m^3/s

Please circle your answers!

Solution: Stoichiometric reaction:

$$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$$

actual reaction:

$$CH_4 + 3(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + O_2 + 11.28N_2$$

(a) $\boxed{CO_2: 1\text{ mole},\ H_2O: 2\text{ moles},\ O_2: 1\text{ mole},\ N_2: 11.28\text{ moles}}$

(b) $$\cancel{\frac{dE_{cv}}{dt}}^{0} = \dot{Q} - \cancel{\dot{W}}^{0} + \sum_{in} \dot{m}_{in}\left(h + \cancel{\frac{V^2}{2}} + \cancel{gz}\right)_{in} - \sum_{out} \dot{m}_{out}\left(h + \cancel{\frac{V^2}{2}} + \cancel{gz}\right)_{out}$$

$$0 = \frac{\dot{Q}}{\dot{n}_{fuel}} + \sum_{react} n_i\left[\bar{h}^o_{f,i} + \cancel{(\bar{h}_T - \bar{h}_{298})_i}^{0}\right] - \sum_{prod} n_i\left[\bar{h}^o_{f,i} + (\bar{h}_T - \bar{h}_{298})_i\right]$$

$$0 = \frac{-2000\text{ KW}}{\dot{n}_{fuel}} + \underbrace{\left(-74{,}850\frac{KJ}{Kmol}\right)}_{CH_4} + \underbrace{0}_{O_2} + \underbrace{0}_{N_2} - \underbrace{[-393{,}520 + 15{,}483 - 9{,}364]}_{CO_2}\frac{KJ}{Kmol}$$

$$-2\underbrace{[-241{,}820 + 15{,}080 - 9{,}904]}_{H_2O}\frac{KJ}{Kmol} - \underbrace{[0 + 13{,}228 - 8{,}682]}_{O_2}\frac{KJ}{Kmol}$$

$$-11.28\underbrace{[0 + 13{,}105 - 8{,}669]}_{N_2}\frac{KJ}{Kmol}$$

$$\boxed{\dot{n}_{fuel} = 0.002735\text{ Kmol/s}}$$

(c) $\dot{m} = \dot{n}\,\bar{v} = \dot{n}\,\frac{\bar{R}T}{p}$

$= 0.002735\ \frac{\text{Kmol}}{\text{s}}\ \frac{8314\ \frac{\text{N}\cdot\text{m}}{\text{Kmol}\cdot\text{K}} \times 298\ \text{K}}{101{,}325\ \text{N}/\text{m}^2}$

$$\boxed{\dot{m} = 0.0669\ \text{m}^3/\text{s}}$$

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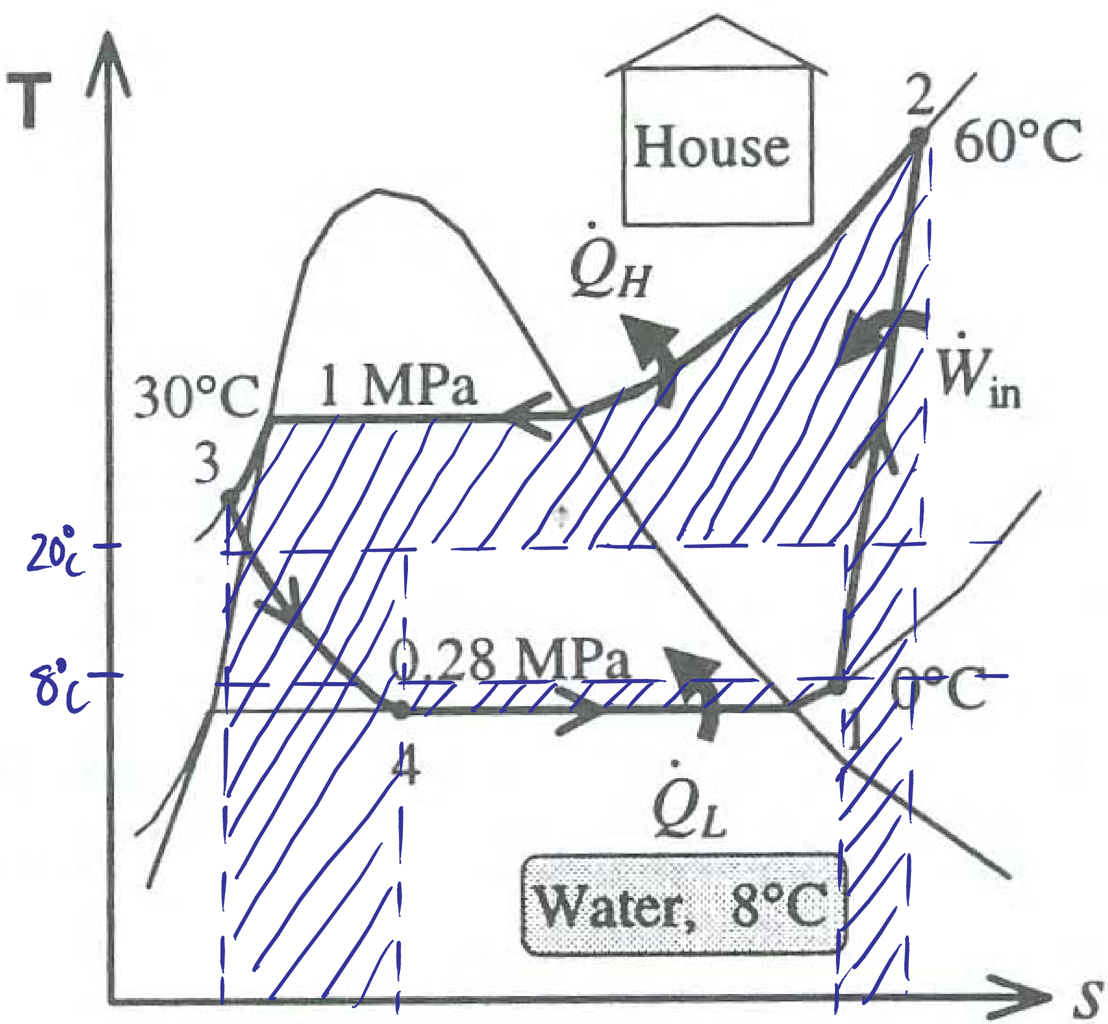
Problem 3. (20 points) A heat pump using refrigerant R-134a heats a house by using underground water at 8°C as the heat source. The house is losing heat at a rate of 15 kW. The following table shows the properties of the refrigeration cycle

State	P [MPa]	T [°C]	h [kJ/kg]	Region
1	0.28	0	247.64	Superheated
2	1	60	291.36	Superheated
3	1	30	91.49	Subcooled
4	0.28	-1.23	91.49	2 phase mixture

a) The increase in electric power input if an electric resistance heater is used instead of the heat pump, in kW

b) If the room air temperature is 20°C, draw the irreversibilities of the cycle as shaded areas on the T-s chart



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Solution: Let $|\dot{Q}_{ele,res}|$ be the increased power input.

(a) $|\dot{Q}_{ele,res}| = |\dot{Q}_H| - |\dot{W}_{in}| = |\dot{Q}_L|$

$$\dot{m} = \frac{|\dot{Q}_H|}{h_2 - h_3} = \frac{15\ \text{KW}}{(291.36 - 91.49)\ \text{KJ/Kg}} = 0.075\ \text{Kg/s}$$

$$|\dot{Q}_{ele,res}| = |\dot{Q}_L| = \dot{m}(h_1 - h_4)$$

$$= 0.075\ \text{Kg/s}\,(247.64 - 91.49)\ \text{KJ/Kg}$$

$$\boxed{|\dot{Q}_{ele,res}| = 11.71\ \text{KW}}$$

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Problem 4. (30 points) A mixture of 3 mol of N_2, 1 mol of O_2, and 0.1 mol of Ar (an inert gas) is heated to 2400 K at a pressure of 10 atm. Assuming the equilibrium mixture consists of N_2, O_2, Ar, and NO,

a) Which of the following molar values for NO in the equilibrium mixture is correct? (Circle one answer. You must show your work supporting that choice.)

0.0835 mol   0.0435 mol

c) Determine the a, b, c, and d in the following actual reaction equation (Please note the a equals to either 0.0835 or 0.0435)

$3\,N_2 + O_2 + 0.1\,Ar \longrightarrow a\,NO + b\,N_2 + c\,O_2 + d\,Ar$

Solution:

stoichiometric reaction $\frac{1}{2} N_2 + \frac{1}{2} O_2 \rightarrow NO$

From Table A-27, $\log_{10} K = -1.305$ $K = 0.0495$

Atom balance for the actual reaction:

N: $6 = a + 2b$ $b = 3 - 0.5a$

O: $2 = a + 2c$ $c = 1 - 0.5a$

Ar: $0.1 = d$ $d = 0.1$

$n_T = a + b + c + 0.1 = 4.1$

$$K = \frac{\prod_{prod} n_i^{\nu_i}}{\prod_{react} n_i^{\nu_i}} \left(\frac{P}{n_T P_{ref}} \right)^{\Delta\nu}$$

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$$K = \frac{n_{NO}^{\nu_{NO}}}{n_{N_2}^{\nu_{N_2}}\, n_{O_2}^{\nu_{O_2}}} \left(\frac{P}{n_T P_{ref}}\right)^{\nu_{NO}-\nu_{N_2}-\nu_{O_2}}$$

$$= \frac{a^1}{b^{0.5}\, c^{0.5}} \left(\frac{P}{n_T P_{ref}}\right)^{1-0.5-0.5}$$

$$0.0495 = \frac{a}{(3-0.5a)^{0.5}(1-0.5a)^{0.5}} \Rightarrow \boxed{a = 0.0835}$$

(b)

$$\boxed{\begin{aligned} a &= 0.0835 \\ b &= 2.958 \\ c &= 0.958 \\ d &= 0.1 \end{aligned}}$$