UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATIONS, APRIL 2001

Second Year

CHE 231S – THERMODYNAMICS I

Examiner - F.R. Foulkes

Time allowed: 2.5 hours

PLEASE BE SURE TO PRINT YOUR NAME ON EVERY PAGE OF THE SPECIAL ANSWER BOOK PROVIDED!

General Instructions:

1. All calculations are to be made in the special answer book, which is to be handed in.
2. One question and solution per page as indicated. No marks will be assigned for material on other pages.
3. If more space is required, use the back of the same page, if necessary.
4. Write all final answers in the rectangular answer boxes provided.
5. Marks will be deducted for unreasonable rounding off of answers and for failure to report answers in the units requested.
6. Programmable calculators are **not** permitted.
7. Marks for each question are indicated in square brackets.

Physical Constants, Conversion Factors, and Miscellaneous Information:

$R = 8.314\ \mathrm{J\ mol^{-1}\ K^{-1}}$	1 cal = 4.184 J	1 atm = 1.01325 bar = 101 325 Pa
0°C = 273.15 K	1 funt = 96 solotnik	$g = 9.81\ \mathrm{m\ s^{-2}}$
1 BTU = 1054.5 J	1 hp = 746 W	$\Delta G_{T,P} = -nFE_{cell}$

Marks

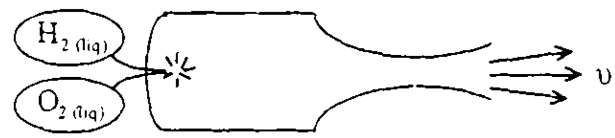
[4] 1. On a hot summer day, it is estimated that 20.0 kJ s^{-1} of heat will leak into a building. A 3.00 horsepower Carnot engine is available for use as part of an air conditioning unit. What is the maximum permissible temperature outside the building for which a temperature of 25.0°C can be maintained inside the building if the unit can achieve 35.0% of the maximum coefficient of performance?

[4] 2. 2.50 kJ of work is used to compress 1.00 mol of an ideal gas isothermally at 35.0°C from 0.50 bar pressure to 1.00 bar pressure. A 10.0°C temperature drop is provided between the gas and the surroundings to facilitate the heat transfer. Calculate the minimum entropy change in the "universe" for the compression under these conditions.

[4] 3. Using one mole of an ideal gas, prove that Pv-work is not a state function.

4. Calculate the vapour pressure of water at 90.0°C if the enthalpy of vaporization at the normal
[4] boiling point is 40.66 kJ mol^{-1}.

5. A rocket is a device in which a fuel and an oxidant are fed under high pressure into an insulated combustion chamber. The hot gaseous combustion products formed are then adiabatically expanded through a nozzle to a



very high exit velocity υ, thereby producing a momentum thrust, $\dot{m}\,\upsilon$, where $\dot{m}$ is the mass flow rate leaving the exhaust nozzle. Because a rocket does not depend on atmospheric oxygen for the combustion, and the thrust generated is independent of the environment, such engines can power flight in the vacuum of outer space. Chemically powered rockets are the only known means for
[5] getting from the Earth's surface to outer space, and rockets powered by the combustion of liquid hydrogen with liquid oxygen to produce gaseous steam generate the highest energy per unit mass of combined fuel + oxidant of any rocket propellents in current use.

The combustion chamber of a certain rocket powered by liquid hydrogen and liquid oxygen operates at a pressure of 100 bar and a combustion temperature of 3000 K, and the hot steam expands to an exhaust jet pressure of one bar. Using the steady state energy equation, estimate the exhaust jet velocity υ. Be sure to state any assumptions you make. Steam may be assumed to behave as an ideal gas with a constant isentropic coefficient of $\gamma = c_p/c_v = 1.22$ over the complete temperature range encountered. The molar mass of water is 18.015 g mol^{-1}.

6. The electrode reactions in a hydrogen–oxygen fuel cell are as follows:

Anode: $H_{2\,(g)} \rightarrow 2H^+ + 2e^-$

Cathode: $\frac{1}{2}O_{2(g)} + 2H^+ + 2e^- \rightarrow H_2O_{(liq)}$

Overall Cell: $H_{2\,(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_2O_{(liq)}$ $\qquad \Delta G^\circ_{298.15} = -237.129$ kJ mol^{-1}

$\Delta H^\circ_{298.15} = -285.830$ kJ mol^{-1}

At one bar (standard) pressure the standard molar heat capacities of hydrogen gas and oxygen gas vary with temperature (T in kelvin) according to $c_p(H_2) = 27.2 + 0.0038\,T$ J mol^{-1} K^{-1} and $c_p(O_2) = 27.2 + 0.0048\,T$ J mol^{-1} K^{-1}. The molar heat capacity of liquid water may be taken to be independent of temperature with a value of $c_p(H_2O_{(liq)}) = 75.48$ J mol^{-1} K^{-1}.

[4] (a) (i) Derive a numerical expression which gives ΔH°_T for the overall cell reaction as a function of the absolute temperature T.

[1] (ii) What is the numerical value of ΔH°_T at 80.0°C?

[3] (b) (i) Derive a numerical expression which gives ΔG°_T for the overall cell reaction as a function of the absolute temperature T.

$$\boxed{\left[\frac{\partial}{\partial T}\left(\frac{\Delta G^\circ}{T}\right)\right]_P = -\frac{\Delta H^\circ}{T^2}}$$

[1] (ii) What is the numerical value of ΔG°_T at 80.0°C?

[1] (c) (i) What is the reversible cell voltage at 25.0°C and one bar pressure?

[4] (ii) What is the reversible cell voltage at 25.0°C and 1000 bar pressure?

[35]

Have a nice summer break! :-)