Name **ANSWER KEY** Slayter Box **007**

Hour Examination 6 April 17, 2003

General Chemistry (CHEM 122-01)

Thermochemistry & Thermodynamics

Dr. Bennett

Please do not open until instructed

Thermochemistry & Thermodynamics

Notes:

* This exam consists of answering **3 questions on 6 pages** (the first question has five shorter questions). Please check to make sure that you have a complete copy of the exam.
** Please do not simply give me answers. Give me well-supported answers. Numerical answers that are not backed by supporting calculations will receive minimal credit.*
* Please write clearly; if I can't read your answer, I can't give you credit for your answer.
* Please note that different questions are worth different numbers of points. Plan your time accordingly.
* Remember to include units and significant figures where appropriate.
* No books or notes are to be used on this exam.
* Please do NOT share calculators; if you need a calculator but do not have one, please let me know!

** If you feel that you would be better able to answer **any** question if you had additional information, please do not hesitate to ask for it.* I will happily provide any information that I feel will help you answer the question without compromising the efficacy and fairness of the test.

Question	Possible	Score
1	25	
2	20	
3	25	
TOTAL	70	
	percent:	

$R = 8.314\ J \cdot mol^{-1} \cdot K^{-1}$ | $0\ ^\circ C = 273.15\ K$ | $k = 1.381 \times 10^{-23}\ J \cdot K^{-1}$

$\Delta E = q + w$ | $w = -P_{ex}\Delta V$ | $\Delta H = \Delta E + P\Delta V$

$q = m \times s \times \Delta T$ | $\Delta S = q_{rev}/T$ | $\Delta S = \Delta H/T$

$\Delta S = C_p \cdot \ln(T_2/T_1)$ | $S = k \cdot \ln(W)$ | $\Delta G = \Delta G^\circ + RT\ln Q$

$\Delta G = \Delta H - T\Delta S$ | $\Delta G^\circ = -RT\ln K$ | $q = C_{cal}(\Delta T)$

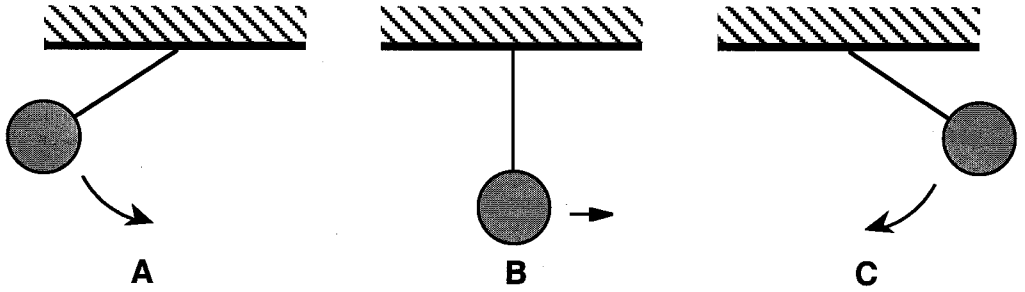
$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

The last page contains selected thermodynamic data

1.

(a) A pendulum swings back and forth as shown. Assume no energy is lost due to friction. At what point in its path does the pendulum have ***the most potential energy***? At which point does it have ***the most kinetic energy***?

4



most potential

most kinetic

most potential

(b) You observe an eccentric professor combine some chemicals in a bottle, place a 1.0 kg mass on top of the bottle., and then use a spark to initiate a reaction.

There is a sudden loud bang, and the 1.0 kg mass is propelled to a position 15 meters away. Slightly dazed, the professor feels the reaction vessel and informs you that it has become very warm.

4

Being a student of chemistry, you realize that a chemical reaction has taken place. Both heat (q) and work (w) were involved. Treating the reaction as the system, tell what the signs of q and w were for the reaction. Explain briefly.

the system

$q_{sys} = \ominus$ b/c it gave heat to its surroundings

$w_{sys} = \ominus$ b/c it did work on its surroundings

(c) For each of the following reactions, predict whether the entropy change for the system is positive or negative. Give a brief explanation for each answer.

6

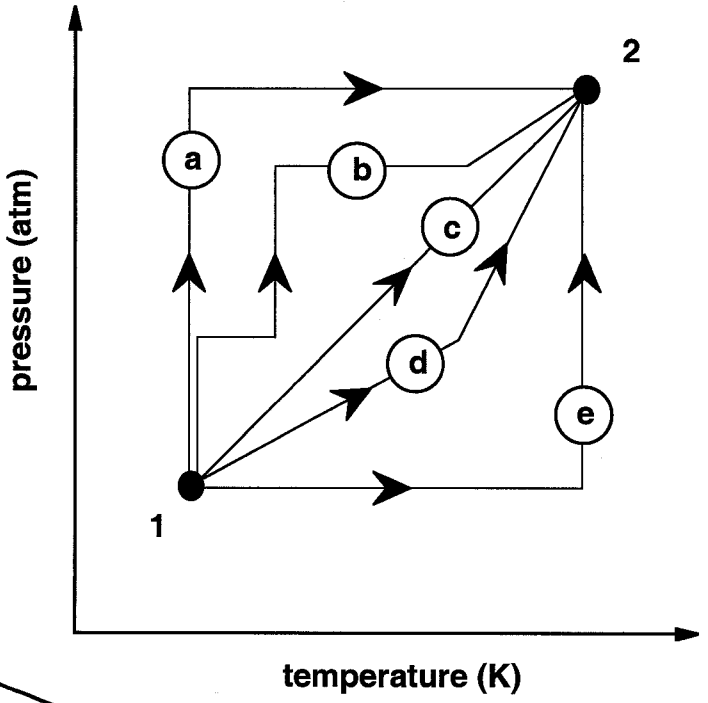
$N_{2(g)} + 3\,Cl_{2(g)} \rightarrow 2\,NCl_{3(l)}$ (−) gases → liq

$PCl_{5(g)} \rightarrow PCl_{3(g)} + Cl_{2(g)}$ (+) 1 gas → 2 gas

$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)}$ (−) s & l → just s

(d) Consider the following diagram for a gas changing from one temperature and pressure to another temperature and pressure. Complete this sentence by choosing one of the choices A — D:

3



A state function

"The change in entropy ΔS in going from **state 1** to **state 2** is...

(A) ...the same for paths (a) through (e)."
(B) ...different for each of the paths."
(C) ...smallest for path (c) because it is the shortest path."
(D) ...the same for paths (a) and (e) but different for the other paths."

(e) Monoclinic and rhombic are different elemental forms of sulfur. From these data:

$S_{(rhombic)} + O_{2(g)} \rightarrow SO_{2(g)}$ $\Delta H = -296.06$ kJ

$S_{(monoclinic)} + O_{2(g)} \rightarrow SO_{2(g)}$ $\Delta H = -296.36$ kJ

8 calculate the enthalpy change for the following transformation.

$S_{(rhombic)} \rightarrow S_{(monoclinic)}$

-3 pts for sign

$S_{(rhombic)} + O_{2(g)} \rightarrow SO_{2(g)}$ $\Delta H = -296.06$ kJ

$SO_{2(g)} \rightarrow S_{(monoclinic)} + O_{2(g)}$ $\Delta H = +296.36$ kJ

-2 for units

$S_{(rhombic)} \rightarrow S_{(monoclinic)}$ $\Delta H_{rxn} = 0.30$ kJ

2. A 7.51 g sample of NH_4NO_3 (ammonium nitrate) is placed into 100.0 g of water in a calorimeter. The temperature of the water drops from 24.8 °C to 19.0 °C. Assume no heat is transferred to the calorimeter. The specific heat of water is $s_{H_2O} = 4.184\ J/g{\cdot}°C$.

(a) Calculate the heat released by the water (q_{H_2O}).

5 $q_{H_2O} = m_{H_2O}\, s_{H_2O} (T_{f,H_2O} - T_{i,H_2O})$

$= (100.0g)(4.184 \frac{J}{g \cdot °C})(19.0 - 24.8)C°$

$= -2427\ J$

(b) Calculate the heat absorbed by the reaction (q_{rxn}).

5 $q_{H_2O} + q_{rxn} = 0$ (or) $2.427\ kJ$

$q_{rxn} = -q_{H_2O} =$ **+ 2427 J**

(c) What is ΔH_{rxn} for $NH_4NO_{3(s)} \rightarrow NH_4NO_{3(aq)}$ ***(in units of kJ/mol)***?

5 $7.51\,g\ NH_4NO_3 \left(\frac{1\,mol\ NH_4NO_3}{80\,g\ NH_4NO_3}\right) = 0.09387\ mol\ NH_4NO_3$

$\Delta H_{rxn} = \frac{2.427\,kJ}{0.09387\,mol} =$ **25.8 kJ/mol**

(d) This reaction is spontaneous. What is the sign of ΔH_{rxn} that you found in (c)? Based on this, can you tell what the sign of ΔS_{rxn} must be? If so, what is it?

5 spont means ΔG_{rxn} must be (−)

to obtain $\Delta G_{rxn} = (-)$, it must be that $\Delta S_{rxn} = (+)$

b/c $\Delta G = \Delta H - T\Delta S$

3. Carbon disulfide reacts with hydrogen at 25.0 °C to form methane gas and hydrogen sulfide vapor according to the following balanced equation.

$$CS_{2(g)} + 4\,H_{2(g)} \rightarrow CH_{4(g)} + 2\,H_2S_{(g)}$$

(a) Calculate the enthalpy change ($\Delta H°$) for this reaction.

7

$\Delta H° = [-74.9 + 2(-20.2)] - [117 + 4(0)]$

$= \underline{-232.3\ kJ/mol}$

(b) Calculate the entropy change ($\Delta S°$) for this reaction.

7

$\Delta S° = [186.1 + 2(205.6)] - [237.8 + 4(130.6)]$

$= -162.9\ J/(mol \cdot K)$

(c) Using the Gibbs Free Energy equation ($\Delta G° = \Delta H° - T\Delta S°$) determine whether this reaction is spontaneous or not.

7

$\Delta G° = (-232.3\ kJ/mol) - \left[(298\ K)\left(-0.1629\ \frac{kJ}{mol \cdot K}\right)\right]$

$= -184\ kJ/mol$ yes, spont

(d) Which thermodynamic term ($\Delta H°$ or $\Delta S°$) would cause the reaction to tend to be spontaneous? Explain.

2

$\Delta H°$, not $\Delta S°$ → $\Delta H°$ ⊖ means increase in entropy (of surroundings)

$\Delta S°$ ⊖ means decrease in entropy (of system)

(e) Estimate the temperature at which the spontaneity of this reaction changes.

2

$\Delta G = 0 = -232\ \frac{kJ}{mol} - (T)(-0.1629\ kJ/mol \cdot k)$

$T = 1424\ K$

or $1152\ °C$

Table of selected thermodynamic data:

compound	$\Delta H°_f$ (kJ/mol)	$S°_f$ (J/mol·K)
$O_{2(g)}$	0	205.0
$H_{2(g)}$	0	130.6
$Cl_{2(g)}$	0	223
$HCl_{(g)}$	-92.3	186.8
$HCl_{(aq)}$	-167.5	55.1
$H_2S_{(g)}$	-20.2	205.6
$H_2O_{(g)}$	-241.8	188.7
$H_2O_{(l)}$	-285.8	69.9
$CO_{2(g)}$	-393.5	213.7
$CS_{2(g)}$	117	237.8
$CH_{4(g)}$	-74.9	186.1
$C_2H_{6(g)}$	-84.7	229.5
$C_2H_5OH_{(l)}$	-277.6	161

$R = 8.314\ J\cdot mol^{-1}\cdot K^{-1}$

$\Delta E = q + w$

$q = m \times s \times \Delta T$

$\Delta S = C_p \cdot \ln(T_2/T_1)$

$\Delta G = \Delta H - T\Delta S$

$\Delta G° = \Delta H° - T\Delta S°$

$0\ °C = 273.15\ K$

$w = -P_{ex}\Delta V$

$\Delta S = q_{rev}/T$

$S = k\cdot\ln(W)$

$\Delta G° = -RT\ln K$

$k = 1.381 \times 10^{-23}\ J\cdot K^{-1}$

$\Delta H = \Delta E + P\Delta V$

$\Delta S = \Delta H/T$

$\Delta G = \Delta G° + RT\ln Q$

$q = C_{cal}(\Delta T)$