02/23/2022

Honors General Chemistry (Chem H2B) Winter 2022
Second Midterm Exam

Instructions

- Answer the questions below in the spaces provided. For full credit, results must be*inside* the answer boxes, rounded exactly to the requested precision, and in the correct units.
- If you need additional space for your work, use separate sheets of paper (provided to you during the exam), and submit them together with the exam. Do not write on the back of any sheet.
- This exam is administered in person and closed book. You may use a calculator, but no other electronic devices, notes, or books are allowed.
- This exam comprises 5 problems on 7 pages (excluding the cover).
- Please use only the molar masses provided in each problem and the exact values of the constants provided in the Appendix. Do not take atomic weights from the periodic table.
- Constants, unit conversions, and useful identities are provided in the appendix.
- Do not round intermediate results.
- Exam time is 50 minutes.

By submitting this exam, you certify under the penalty of an academic integrity violation that all results are your own and were obtained according to the rules above. You consent to be forthcoming to any subsequent questions about your results and how exactly they were obtained, and understand that you may not receive credit if you cannot give a satisfactory answer.

Problems

1. **Entropy** (4 credits)

Does the entropy of the system/reaction mixture increase, decrease, or stay the same in the following processes? Briefly explain your answer in each case.

a) Haber-Bosch synthesis of ammonia

Answer :

b) Isomerization of neopentane (2,2-dimethylpropane) to *n*-pentane

Answer :

c) Isothermal compression of an ideal gas

Answer :

d) Mixing of two ideal gases at constant temperature, total pressure, and total volume

Answer :

2. Essay Question: Gibbs Free Energy (4 credits)

Explain in a few sentences why the Gibbs free energy is a central quantity in chemical thermodynamics. What type(s) of information can be obtained from the Gibbs free energy change of a process? Name at least two methods for determining the Gibbs free energy of a chemical reaction experimentally, computationally, or using tabulated data.

Answer :

3. Equilibrium Constants (4 credits)

Determine the equilibrium constant K_c at 25°C for the reaction

$$\mathrm{N_2(g) + O_2(g) + Cl_2(g) \rightleftharpoons 2\ NOCl(g)}$$

given the following data at 25°C:

$$\mathrm{N_2(g) + 2\ O_2(g) \rightleftharpoons 2\ NO_2(g)} \quad K_p = 1.0 \times 10^{-18} \text{ units?!}$$
$$\mathrm{2\ NOCl(g) + O_2(g) \rightleftharpoons 2\ NO_2Cl(g)} \quad K_p = 1.21 \times 10^{4} \text{ units?!}$$
$$\mathrm{2\ NO_2(g) + Cl_2(g) \rightleftharpoons 2\ NO_2Cl(g)} \quad K_p = 9.0 \times 10^{-2} \text{ units?!}$$

Answer (2 significant figures):

4. Van't Hoff Equation (5 credits)

In the gas phase, nitrosyl chloride NOCl is in chemical equilibrium with its dissociation products, nitrogen monoxide and chlorine gas.

	ΔH_f° (kJ/mol)	S° (J/(mol K))
NO	90.29	210.76
ClNO	51.71	261.68
Cl_2		223.08

Table 1: Thermochemical data at standard conditions.

a) Formulate the balanced chemical equation including states.

Answer :

b) Using the thermochemical data from Table , estimate the temperature T_c at which the equilibrium constant K equals 1.

Answer (3 significant figures):

c) Qualitatively plot $\ln K$ as a function of $1/T$ based on your results from (b).

Answer :

5. Statistical Thermodynamics (6 credits)

2.5 mol of ethyne (a.k.a. acetylene, C_2H_2) gas are kept in a 1 L steel cylinder. Assume ideal behavor.

a) Determine the total enthalpy of the sample at 300 K.

Answer (3 significant figures):

b) The pressure of the sample is doubled by reducing the volume to 0.5 L. The temperature is kept constant. Determine the total enthalpy.

Answer (3 significant figures):

c) Estimate the rms velocity of the ethyne molecules in m/s at 300 K.

Answer (3 significant figures):

d) Determine the entropy change when the original gas sample is heated from 300 K to 800 K.

Answer (3 significant figures):

e) Ethyne has a standard free energy of formation of 209.9 kJ/mol. Why is it not smart to heat a pressurized steel cylinder containing ethyne?

Answer :

Appendix A: Constants and Unit Conversions

Constant	Symbol	Value
Ideal gas constant	R	8.3145 J/(mol K)
Avogadro's constant	N_A	6.022×10^{23} mol^{-1}
Standard temperature (STP)	T_s	273.15 K
Standard pressure (STP)	P_s	101325 Pa = 1 atm
Molar volume of an ideal gas at STP	v_s	22.414 L/mol

Table 2: Physical constants

Quantity	Conversion
Volume	1 gal = 3.7854 L
Temperature	$\theta_C/^\circ C = (\theta_F/F - 32) \times \frac{5}{9}$
Pressure	1 atm = 101325 Pa = 760 torr

Table 3: Unit conversions

Appendix B: Identities

Equilibrium constants:

$$K_p = \left(\frac{1}{P^\circ}\right)^{\Delta\nu} K, \quad K_c = \left(\frac{P^\circ}{c^\circ RT}\right)^{\Delta\nu} K$$

Entropy change of an ideal gas at constant volume:

$$\Delta S = C_v \ln \frac{T_f}{T_i}$$

Van't Hoff Equation:

$$\ln K = -\frac{\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R}$$

Appendix C: Periodic Table of the Elements

Periodic Table of the Elements

Do NOT use the atomic weights given here to answer exam questions!!!

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 **	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
**Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]