Chemistry 2740 Spring 2020 Test 1

Time: 50 minutes
Marks: 29
Aids allowed: calculator, 8.5×11-inch formula sheet
Useful data is found on page 3.
Instructions: You can answer the questions in any order, but make sure that you clearly label each of your answers with the question number in your exam booklet(s).

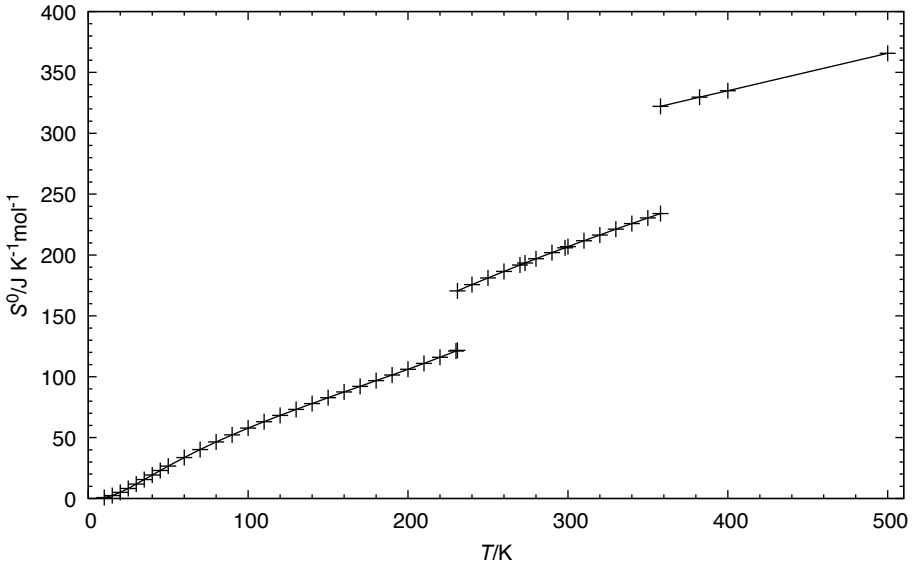
1. Polymerization reactions are typically exothermic. Consider for instance the polymerization of ethylene (systematic name: ethene, C_2H_4, molar mass 28.054 g/mol) to polyethylene $[(C_2H_4)_n]$, which has a polymerization enthalpy of $-96.7\,\mathrm{kJ/mol}$ of monomer. The heat capacity of solid polyethylene per mole of monomers is $46.2\,\mathrm{J\,K^{-1}mol^{-1}}$. Typical industrial processes produce solid polyethylene, and so it is important to keep the temperature well below the melting point (115–135 °C). **10 marks**

   (a) Suppose that the product has a target final temperature of 50 °C, starting from reactants at 25 °C. A large polyethylene plant makes 30 000 kg of polyethylene per hour. How much heat must be removed per hour? [6 marks]

   (b) Usually, the heat is removed by a heat exchanger, often using water as the coolant. Given a supply of water at 30 °C, if the desired temperature of the water on exiting the heat exchanger is 120 °C,[1] what is the flow rate of water through the heat exchanger (in kg/h) required to remove the heat produced by the polymerization process described above? The specific heat capacity of water is $4.184\,\mathrm{J\,K^{-1}g^{-1}}$. [4 marks]

[1] Because pressurized water lines are used, the water can be superheated, i.e. it remains a liquid even at this temperature.

2. The following graph shows the entropy of fluorobenzene as a function of temperature at a pressure of 1 bar:[2] **8 marks**



Use this graph to estimate the following quantities. In some cases, you may need to do a simple calculation:

(a) Freezing point [1 mark]

(b) Boiling point[3] [1 mark]

(c) Entropy of fusion [1 mark]

(d) Entropy of vaporization [1 mark]

(e) Standard entropy—indicate the phase of matter corresponding to your answer [2 marks]

(f) Enthalpy of vaporization [2 marks]

[2]Data from D. W. Scott et al., *J. Am. Chem. Soc.* **78**, 5457 (1956) converted to SI units and adjusted to the new standard state. Crosses are the experimental data. Lines connect the experimental points to aid the eye.

[3]Normal boiling points are measured at 1 atm, but for the purpose of this question, neglect the difference between 1 atm and 1 bar.

3. (a) Write down the formation reaction for $Li_2CO_{3(s)}$. [2 marks] **11 marks**

   (b) Calculate the standard entropy of formation for $Li_2CO_{3(s)}$, i.e. the entropy change for the reaction from part (a). [2 marks]

   (c) Calculate the standard free energy of formation of $Li_2CO_{3(s)}$. [2 marks]

   (d) A promising new rechargeable battery technology is the lithium–carbon-dioxide battery. The overall reaction in this battery is thought to be[4]

$$4\,Li_{(s)} + 3\,CO_{2(g)} \longrightarrow 2\,Li_2CO_{3(s)} + C_{(s)}.$$

   What is the maximum electrical work a battery based on this chemistry could perform at 298.15 K **per mole of lithium** if the pressure of CO_2 in the cell is 1.2 bar? [5 marks]

Useful data

Constants and conversion factors

$0\,K = -273.15\,°C$
$R = 8.314\,472\,J\,K^{-1}mol^{-1}$

Standard thermodynamic data at 298.15 K

Species	$\Delta_f H^\circ$ / kJ mol^{-1}	S° / J K^{-1}mol^{-1}	$\Delta_f G^\circ$ / kJ mol^{-1}	$C_{p,m}$ / J K^{-1}mol^{-1}
$C_{(s)}$ (graphite)	0	5.74	0	8.53
$CO_{2(g)}$	−393.51	213.785	−394.37	37.1
$Li_{(s)}$	0	29.09	0	24.62
$Li_2CO_{3(s)}$	−1216.04	90.31		96.25
$O_{2(g)}$	0	205.152	0	29.35

[4] A. Ahmadiparidari et al., *Adv. Mater.* **31**, 1902518 (2019)