1. One important property of a rocket fuel mixture is the large volume of gaseous products formed which provide thrust. Hydrazine, N_2H_4, is often used as a rocket fuel. The combustion of hydrazine is represented by the equation below.

$$N_2H_4(g) + O_2(g) \rightarrow N_2(g) + 2H_2O(g) \qquad \Delta H^0 = -585 \text{ kJ/mol}$$

   a. Hydrazine reacts with fluorine to produced nitrogen and hydrogen fluoride, all in the gaseous state. State an equation for the reaction. [1]
   b. Draw the Lewis structures for hydrazine and nitrogen. [2]
   c. Given the average bond enthalpies given on the front of the exam, determine the enthalpy change for the reaction given in part a. [2]
   d. Based on your answers to part a and c, suggest whether a mixture of hydrazine and fluorine is a better rocket fuel than a mixture of hydrazine and oxygen. [2]
   e. Comment on the environmental safety concerns of the products of both rocket fuel mixtures. [1]
   f. The boiling point of hydrazine is 114^0C. Explain the relative high boiling point of hydrazine in comparison to water (100^0C) and ammonia (-33^0C) under standard conditions. [1]

2. The decomposition of 5.00g solid barium carbonate is given by the following equation:

$$BaCO_3(s) \leftrightarrows BaO(s) + CO_2(g)$$

Compound	$BaCO_3(s)$	$CO_2(g)$	$BaO(s)$
$\Delta H_f^\ominus$ / kJ mol^{-1}	–1219	–394	–558
$S^\ominus$ / JK^{-1} mol^{-1}	+112	+214	+70

   a. Calculate the value of ΔG^0 in kJ mol^{-1} at 25^0C. [2]
   b. State with a reason whether the reaction is spontaneous at 25^0C. [1]
   c. Determine the minimum temperature above which this reaction is spontaneous. [1]
   d. Write the equilibrium expression, K_p, for the above reaction. [1]
   e. Determine the value of the equilibrium constant, K_p, at 1500K. [1]
   f. Determine the equilibrium pressure at 1500K. [1]
   g. The lattice energy for barium oxide is 3054 kJ/mol. Would the lattice energy of calcium oxide be higher, lower, or equal to the value for barium oxide? Justify your response. [2]
   h. Given the information on the front of the exam, calculate the second electron affinity of oxygen through the construction of a Born-Haber cycle. [2]
   i. Discuss the significance of the algebraic sign of the second electron affinity. [1]

3. For each of the following three reactions, write a balanced equation for the reaction in part (i) and answer the question in part (ii). In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solution as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction.
   a. A piece of solid barium carbonate is dropped into a 0.1 M solution of sulfuric acid.
      i. Balanced reaction.
      ii. Indicate one thing that would be observed as the reaction occurs.
   b. Lithium metal is strongly heated in nitrogen gas.
      i. Balanced equation.
      ii. What is the change in oxidation states of lithium as the reaction occurs?
   c. Excess hydrochloric acid is added to a solution of nickel(II) nitrate.
      i. Balanced equation.
      ii. Which species in the reaction acts as a Lewis base?

4. Transition elements form complexes, such as $[Co(NH_3)_6]^{3+}$ or $[Cu(NH_3)_4]^{2+}$. The reactions can be viewed as an equilibrium process, in which the equilibrium constant, K_f, is referred to as the formation constant. The equilibrium expression for the formation of $[Cu(NH_3)_4]^{2+}$ is shown below.

$$\mathbf{Cu^{2+}(aq) + 4NH_3(aq) \leftrightarrows [Cu(NH_3)_4]^{2+} \qquad K_f = 1.1 \times 10^{13}}$$

a. Determine the oxidation state of the cobalt ion in the complex ion shown above. [1]
b. Write the equilibrium expression of the reaction shown above. [1]
c. Is the forward or reverse reaction spontaneous? Justify your response. [2]
d. The formation constant for $[Co(NH_3)_6]^{3+}$ is 4.5×10^{33}. Which of the complex ions is more stable, $[Co(NH_3)_6]^{3+}$ or $[Cu(NH_3)_4]^{2+}$? Justify your response. [2]
e. Identify the geometry of the $[Co(NH_3)_6]^{3+}$ complex ion. [1]
f. The maximum absorbance of the $[Cu(NH_3)_4]^{2+}$ occurs at 610nm. Determine the energy of a photon, in Joules, which corresponds to this maximum absorbance. [1]

A 0.556 gram sample of a copper-containing compound is placed in 50.0 mL of water. The resulting solution is reacted with 10 mL of 12M $NH_3(aq)$ and then diluted to 100.0 mL in a volumetric flask. 10.0 mL of this solution is then diluted to 50.0 mL. 5.0 mL of this solution is placed in a cuvette of length 1.50 cm and the absorbance is measured to be 0.530. Another sample of the copper containing compound is placed in a sample of distilled water. A pipetful of silver nitrate is added to the flask and a white precipitate is observed.

g. Determine the percent composition of copper in the original compound given that the molar absorptivity of the copper solution is 42.7 L cm^{-1} mol^{-1}. [2]
h. Determine the chemical formula of the copper containing compound, assuming that the substance is a binary compound. [2]

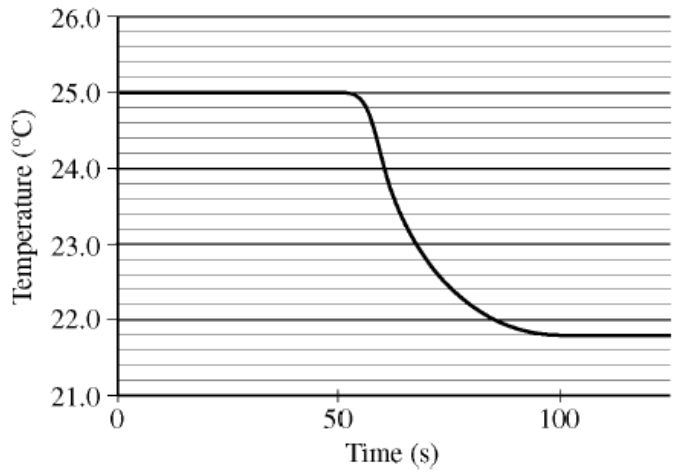
5. A 1.232 gram sample of benzoic acid is placed in a bomb calorimeter at 24.152^0C. After complete combustion of the benzoic acid, the temperature rises to 29.292^0C. If a 1.150 gram sample of sucrose, $C_{12}H_{22}O_{11}$, is burnt in the same calorimeter, the temperature of the calorimeter increases by 3.280^0C.
   a. If the heat of combustion of benzoic acid is -26.42 kJ/g, determine the heat capacity of the calorimeter. [2]
   b. Determine the heat of combustion of sucrose in kJ/mol. [1]

The combustion of sucrose can be represented by the following balanced chemical equation.

$$\mathbf{C_{12}H_{22}O_{11}(s) + 12O_2(g) \rightarrow 12CO_2(g) + 11H_2O(\ell)}$$

   c. If the enthalpies of formation of gaseous carbon dioxide and liquid water are -393.5 kJ/mol and -285.8kJ/mol respectively, determine the enthalpy of formation for sucrose in kJ/mol. [1]
   d. Predict the algebraic sign of the entropy change of the combustion of sucrose. Justify your response. [2]
   e. Under which temperature values will the combustion of sucrose be spontaneous? Justify your response. [2]
   f. The standard molar entropy of liquid water is 69.95 J/Kmol, whereas the standard molar entropy of water vapor is 188.84 J/Kmol under standard conditions. Explain the discrepancy in the entropy values for water. [2]

6. A student performs an experiment to determine the molar enthalpy of solution of urea, H_2NCONH_2. The student places 91.95 grams of water at 25^0C into a coffee-cup calorimeter and immerses a thermometer in the water. After 50 seconds, the student adds 5.13 grams of solid urea, also at 25^0C, to the water and measures the temperature of the solution as the urea dissolves. A plot of the temperature data is shown in the graph below.



a. Determine the change in temperature of the solution that results from the dissolution of the urea. [1]
b. According to the data, is the dissolution of urea in water an endothermic process or an exothermic process? Justify your answer. [2]
c. Assume that the specific heat capacity of the calorimeter is negligible and that the specific heat capacity of the solution of urea and water is 4.2 J g^{-1} C^{-1} throughout the experiment.
    a. Calculate the heat of dissolution of the urea in joules. [1]
    b. Calculate the molar enthalpy of solution, ΔH^0, of urea in kJ mol^{-1}. [1]
d. The student performs a second trial of the experiment, but this time adds urea that has been taken directly from a refrigerator at 5^0C. What effect, if any, would using the cold urea instead of urea at 25^0C have on the experimentally obtained value of ΔH^0. Justify your answer. [2]

Unit 6 Test:
Thermochemistry
AP Chemistry

The following questions require the use of the following thermodynamic values.

Average Bond Enthalpies (kJ/mol)

Single Bonds

C—H	413	N—H	391	O—H	463	F—F	155
C—C	348	N—N	163	O—O	146		
C—N	293	N—O	201	O—F	190	Cl—F	253
C—O	358	N—F	272	O—Cl	203	Cl—Cl	242
C—F	485	N—Cl	200	O—I	234		
C—Cl	328	N—Br	243			Br—F	237
C—Br	276			S—H	339	Br—Cl	218
C—I	240	H—H	436	S—F	327	Br—Br	193
C—S	259	H—F	567	S—Cl	253		
		H—Cl	431	S—Br	218	I—Cl	208
Si—H	323	H—Br	366	S—S	266	I—Br	175
Si—Si	226	H—I	299			I—I	151
Si—C	301						
Si—O	368						

Multiple Bonds

C=C	614	N=N	418	O_2	495
C≡C	839	N≡N	941		
C=N	615			S=O	523
C≡N	891			S=S	418
C=O	799				
C≡O	1072				

First Ionization Energy of Barium	+503 kJ/mol
Second Ionization Energy of Barium	+965 kJ/mol
Atomization Energy of Barium	+180 kJ/mol
First Electron Affinity of Oxygen	-142 kJ/mol
Enthalpy of Formation of BaO(s)	-554 kJ/mol

Grading Scale

Question 1: _____ x 2.222 = _____ (20)

Question 2: _____ x 1.667 = _____ (20)

Question 3: _____ x 1.000 = _____ (15)

Question 4: _____ x 1.667 = _____ (20)

Question 5: _____ x 2.000 = _____ (20)

Question 6: _____ x 2.143 = _____ (15)

Total Score = _____ (110)