Extended Response 1
Chemical Synthesis and Analysis

Name____

Due date & Validation Test: Monday 18th February

Section 1 General Stoichiometry

1. A soft drink manufacturer of a produces a diet version of the drink containing artificial sweetener. The quality assurance procedures of the manufacturer require that incoming batches of the artificial sweetener be analysed to ensure compliance with standards.

(a) A combustion analysis of a 1.021 g sample of sweetener produced 1.715 g CO_2, 0.2521 g H_2O, 0.2558 g NO_2 and 0.3568 g SO_2. The sweetener contains the elements C, H, O, N and S. Determine its empirical formula. (12 marks)

(b) If a flask of 600 mL volume is evacuated and weighed, then filled with the vapour of the compound and reweighed we get these experimental results:

Mass of empty flask	102.729g
Mass of flask + vapour	105.083g
Pressure of the vapour	102 kPa
Temperature of system	300 °C

(i) What is the mass of the vapour being tested?
(ii) What is the molar mass of the compound?
(iii) What is the molecular formula of the compound?

(4 marks)

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2. A compound was analysed to determine its empirical formula. The compound has tin, iodine, carbonate ions and water of crystallisation with a general formula $Sn_wI_x(CO_3)_y.zH_2O$.

1.6318 g of the compound was heated to drive off the water. The mass of compound was determined a number of times during the heating and the following data was obtained:

Time (hours)	Mass (g)
0	1.6318
1	1.4843
2	1.4509
3	1.4507

One third of the anhydrous compound was dissolved in water and then H_2S gas was bubbled through the solution. 0.2042 g of tin (IV) sulphide was precipitated.
Another one third of the anhydrous compound was treated with silver nitrate solution and produced 0.5253 g of silver iodide.
The remaining third of the anhydrous compound was analysed by combustion and 0.0491 g of carbon dioxide was produced.
Determine the values of w, x, y and z in the general formula above if the molecular mass is known to be about 970. (14 marks)

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3. Sulfuryl chloride, SO_2Cl_2 , is a liquid which reacts with water to form a mixture of sulphuric and hydrochloric acids. 0.725 g of this substance was added to excess water and made up to exactly 100.0 ml in a flask.

(a) Write a molecular equation for the reaction described.
(b) Write an ionic equation for the same reaction.
(c) What is the concentration of $H^+(aq)$ in the flask?
(d) If 20.00 mL of the solution in the flask is neutralised by a 0.0985 $molL^{-1}$ NaOH solution what volume of the base is required?
(e) If 40.00 mL of the solution in the flask is added to excess $BaCl_2$ solution what mass of precipitate is expected to from? (14 marks)

4. The **unbalanced** equations below represent the basic reactions that occur in the production of nitric acid from ammonia.

$$NH_3 (g) + O_2 (g) \rightarrow NO (g) + H_2O (g)$$

$$NO (g) + O_2 (g) \rightarrow NO_2 (g)$$

$$NO_2 (g) + H_2O (g) \rightarrow HNO_3 (g) + NO (g)$$

(a) Rewrite the above equations so they are all balanced.
(b) It appears even from the unbalanced equations that not all the nitrogen in the ammonia is converted to nitric acid. What fraction ends up in the acid according to the balanced equations?
(c) Calculate the mass of HNO_3 that could be produced if 5.00 kg of ammonia was reacted according to these steps and the yield was 95%.
(d) HNO_3 is commonly stored as an approximately 11 $molL^{-1}$ solution, what volume of water would be required for the HNO_3 made in the process described in (b). You may assume the HNO_3 (g) has no significant volume contribution once dissolved.
(e) Suggest how you could ensure nearly all the nitrogen atoms end up as useful HNO_3 product.

(9 marks)

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Section 2 Comprehension and Interpretation

Waste chicken feathers as a potential source of ammonia **(46 marks)**

Chicken feathers are composed of approximately 90–92% keratin proteins (1, 2). Keratin is a group of fibrous structural proteins and is chemically stable, most likely as a result of the tight coiling of its polypeptide chain in α-helix and β-pleated sheet structures. Recent research has shown that the carbon and nitrogen in feathers can be converted to carbon microspheres and ammonium hydrogencarbonate, two useful products (3).

The researchers placed 1 g of chicken feathers and 12 g of solid carbon dioxide in a 25 mL autoclave that was heated to 600 °C, at which temperature it was maintained for 3 hours. Reactions took place at the pressure generated in the sealed autoclave, which reached levels to make the carbon dioxide supercritical. After cooling the autoclave to room temperature, 0.26 g of ammonium hydrogencarbonate and 0.25 g of carbon microspheres were recovered. Analysis indicated approximately 30.6% and 21.1% by mass of the nitrogen from the feathers was transferred to the ammonium hydrogencarbonate and carbon microspheres, respectively. Analysis also showed the nitrogen content of the carbon microspheres was 12.8% by mass. When the autoclave was opened, carbon dioxide gas rushed out, accompanied by an odour strongly suggestive of ammonia gas. The researchers also found other nitrogen-containing substances, such as amino acids and the polymer nylon-6, react to produce ammonium hydrogencarbonate and carbon microspheres using this method. This could divert these substances from landfill which is where they often end up.

The elemental composition (mass %) of chicken feathers is approximately 47.5% carbon, 15% nitrogen, 7% hydrogen and 30.5% other elements (1).

The thermal decomposition of ammonium hydrogencarbonate gives it potential as a source of ammonia which, in turn, is used for a range of industrial processes, including the production of the fertiliser urea. Ammonium hydrogencarbonate decomposes in the range 36-60 °C to ammonia, carbon dioxide and water, as represented by the equation below.

$$NH_4HCO_3(s) \rightarrow NH_3(g) + CO_2 + H_2O(l) \quad \Delta H = 163 \text{ kJ mol}^{-1}$$

Typically, ammonia is produced industrially by the Haber process in which nitrogen and hydrogen gases react to produce ammonia. The equation for this reaction is represented below.

$$N_2(g) + 3 H_2(g) \rightarrow 2 NH_3(g) \quad \Delta H = -92 \text{ kJ mol}^{-1}$$

The nitrogen comes from air and the hydrogen generally comes from methane through the steam reforming process. Methane is reacted with steam to give hydrogen and carbon monoxide. The carbon monoxide is then further reacted with more steam to give hydrogen and carbon dioxide. The equations for the production of hydrogen in the steam reforming process are represented below.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3 H_2(g) \quad \Delta H = 206 \text{ kJ mol}^{-1}$$

$$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g) \quad \Delta H = -41 \text{ kJ mol}^{-1}$$

The sum of these reactions is

$$CH_4(g) + 2 H_2O(g) \rightarrow CO_2(g) + 4 H_2(g) \quad \Delta H = 165 \text{ kJ mol}^{-1}$$

It has been estimated that the Haber Process accounts for 1–2% of the world's annual energy consumption (3).

References

1. Gao, L., Hu, H., Sui, X., Chen, C., & Chen, Q. (2014, April). One for two: Conversion of waste chicken feathers to carbon microspheres and (NH4)HCO3. *Environmental Science and Technology*, *48*(11), pp. 6500–6507.

2. Onifade, A.A., Al-Sane, N.A., Al-Musallam, A.A., & Al-Zarban, S. (1998, October). A review: Potentials for biotechnological applications of keratin-degrading microorganisms and their enzymes for nutritional improvement of feathers and other keratins as livestock feed resources. *Bioresource Technology, 66*(1), pp. 1–11.

3. Salminen, E. & Rintala, J. (2002, May). Anaerobic digestion of organic solid poultry slaughterhouse waste—a review. *Bioresource Technology*, *83*(1), pp. 13–26.

Questions

Answer the following questions about the production of ammonia from chicken feathers, and from the steam reforming and Haber processes. Where calculations are required, show clear working to support your answer.

1. Assuming 100% efficiency in the steam reforming and Haber processes, determine the mass of ammonia produced per gram of methane reacted. (5 marks)

2. In one particular steam reforming process 650 kg of methane was reacted with steam and 285.5 kg of hydrogen was produced. Assuming that the steam reforming reaction goes to completion, what would you recommend the chemist do to improve the output of the process. (6 marks)

3. Based on the information above, determine the mass of ammonia produced per gram of chicken feather in the feather process. Note: The decomposition of the ammonium hydrogencarbonate is typically about 90% efficient. (5 marks)

4. Based on amount of nitrogen in the feathers that is converted to ammonium hydrogencarbonate, determine the efficiency of the process for converting the nitrogen in feathers to ammonia. Note again, the decomposition of the ammonium hydrogencarbonate is about 90% efficient. (3 marks)

5. Research and briefly discuss the typical efficiencies for the steam reforming process and Haber process. Determine the mass of ammonia produced per gram of methane based on the typical efficiencies. Cite the source of your information for the efficiency of the process. (5 marks)

6. Compare the ratio of ammonia produced on a gram of starting material basis in the steam reforming/Haber processes to the chicken feather process. (2 marks)

7. In actual fact, all reactions in the steam reforming and Haber processes reach a state of equilibrium, describe the typical temperature and pressure conditions that would be used in each process. Explain the choice (based on the appropriate chemistry concepts and other relevant factors) of temperature and pressure conditions for the reactions. (12 marks)

8. Compare and contrast the temperature and pressure conditions for steam reforming/Haber processes to those used in the production of ammonia from chicken feathers. (You will need to consider how the information provided may allow a pressure for the chicken process to be estimated.) (3 marks)

9. The researchers suggest that producing ammonia from feathers (via decomposition of ammonium hydrogencarbonate) may be more sustainable than through the steam reforming and Haber processes. Discuss this suggestion. (4 marks)