



ATAR CHEMISTRY UNITS 3 & 4

NAME: _____

Extended Response: Chemical Synthesis

Weighting: 5%

Waste chicken feathers as a potential source of ammonia

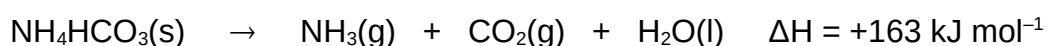
Introduction

Chicken feathers are composed of approximately 90–92% keratin proteins. 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.

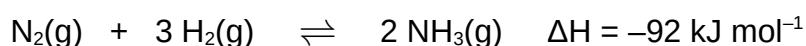
The researchers placed 1 g of chicken feathers and 12 g of solid carbon dioxide in a 25 mL autoclave. The autoclave was maintained at a temperature of 600 °C and a pressure of 73 atm. Reactions took place in the autoclave and after cooling to room temperature, 0.26 g of ammonium hydrogencarbonate and 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.

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

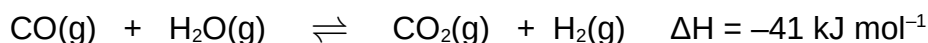
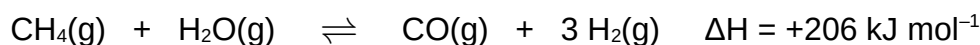
The thermal decomposition of ammonium hydrogencarbonate gives it potential as a source of ammonia which, in turn, is used for a range of industrial processes, including the production of the fertiliser urea. Ammonium hydrogencarbonate decomposes in the range 36-60 °C to ammonia, carbon dioxide and water,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



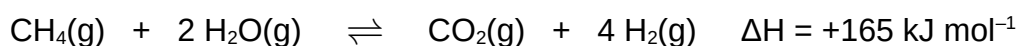
Typically, ammonia is produced industrially by the Haber process in which nitrogen and hydrogen gases react to produce ammonia. The equation for this reaction is represented below.



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.



The sum of these reactions is



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

What to do

Prepare a report based on 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. a) Ammonia is a very important chemical and is used widely. It ranks second to sulphuric acid in the quantity produced worldwide per year. List 5 uses of ammonia. (5 marks)

b) Ammonia is regarded as an alkaline cleaner. Discuss why ammonia is regarded as alkaline and give equations to support your answer. (3 marks)
 2. Assuming 70% efficiency in the steam reforming process and 95% efficiency in the Haber process, determine the mass of ammonia produced per gram of methane reacted. (5 marks)
 3. Determine the mass of ammonia produced per gram of chicken feathers in the feather process. Note: The decomposition of the ammonium hydrogencarbonate is typically about 90% efficient. (5 marks)
 4. 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)
 5. Based on the researchers' analysis of the efficiency with which the nitrogen in the feathers 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. (2 marks)
 6. Describe the typical temperature and pressure conditions for steam reforming and Haber processes. Explain the choice (based on the appropriate chemistry concepts and other relevant factors) of temperature and pressure conditions for the reactions. (12 marks)
 7. At one point during the production of ammonia using the Haber process, there were 1.63×10^7 mol nitrogen gas, 3.78×10^7 mol hydrogen gas and 3.52×10^7 mol ammonia gas present inside the reaction chamber. The temperature in the chamber was 476 K and the volume was 9.25×10^6 L. Determine the pressure inside the chamber.
 8. Compare and contrast the temperature and pressure conditions for the steam reforming and Haber processes to those used in the production of ammonia from chicken feathers. (3 marks)
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9. Despite the ratio of ammonia produced on a gram of starting material basis being much greater in the steam reforming and Haber processes than in the chicken feather process (Q3), 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. (8 marks)
10. Keratin proteins in chicken feathers are formed from α - amino acids linked in a chain called a peptide chain. Draw the peptide chain for the following sequence of α -amino acids: Ser- Gly- Tyr- Ala- Leu
11. Compare polypeptide chains in α -helix and β -pleated sheet structures. Use diagrams to aid your description. (7 marks)
12. Draw a labelled energy profile diagram for the decomposition reaction of ammonium hydrogencarbonate. (5 marks)
13. You must include correctly referenced sources that you have used to get information (you must use at least three sources). (3 marks)

References

1. Onifade, A.A., Al-Sane, N.A., Al-Musallam, A.A., & Al-Zarban, S. *Bioresource Technology*, **66**(1), 1–11.
 2. Salminen, E. & Rintala, J. *Bioresource Technology*, **83**(1), 13–26.
 3. Gao, L., Hu, H., Sui, X., Chen, C., & Chen, Q. *Environmental Science and Technology*, **48**(11), 6500–6507.
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