Answers: General Stoichiometry

1. (a) m(C) = 1.715 x12.01/44.01 = 0.468 g
%(C) = 0.468 x 100 /1.021 = 45.84% (2)

m(H) = 0.2521 x 2 x 1.008/ 18.016 = 0.0282g
%(H) = 0.0282 x 100 / 1.021 = 2.762% (2)

m(N) = 0.2558 x 14.01 / 46.01 = 0.0779 g
%(N) = 0.0779 x 100 / 1.021 = 7.629% (2)

m(S) = 0.3568 x 32.06 / 64.06 = 0.1786 g
%(S) = 0.1786 x 100 / 1.021 = 17.49% (2)

%(O) = 100 – 45.84 – 2.762 – 7.269 – 17.49 = 26.279% (1)

	C	H	N	S	O	
%	45.84	2.762	7.629	17.49	26.279	
n	3.81	2.74	0.545	0.546	1.642	
ratio	7	5	1	1	3	(3)

EF = $C_7H_5NSO_3$

(b) m = 105.083 - 102.729 = 2.354 g
M = mRT/PV = 2.354 x 8.314 x 573.15 / 102 x 0.6 = 183.3 $gmol^{-1}$
M(EF) = 7 (12.01) + 5(1.008) + 1(14.01) + 1(32.06) + 3(16) =183.18 $gmol^{-1}$

MF = EF = $C_7H_5NSO_3$ (saccharine) (4)

2. **Quick answer : $Sn_2I_4(CO_3)_2.6H_2O$.**
m(H_2O) = 1.6318 – 1.4507 = 0.1811 g
n (H_2O) = 0.01005 moles
n(SnS_2) = 0.2042 / 182.7 = 0.00112 moles
n (Sn) in original sample = 3 x 0.00112 = 0.00335 moles
n (AgI) = 0.5253 / 234.8 = 0.00224 moles
n (I) in the original sample = 3 x 0.00224 = 0.00671 moles
n (CO_2) = 0.0491 / 44.01 = 0.00112 moles
n (C) = n (CO_3^{2-}) = 3 x 0.00112 = 0.00335 moles (8)

	Sn	I	CO_3^{2-}	H_2O
moles	0.00335	0.00667	0.00335	0.01005
Ratio	1	2	1	3

Empirical formula $SnI_2(CO_3).3H_2O$ (3)
M(EF) = 486.5 $gmol^{-1}$
M(MF) / M(EF) = 970 / 486.5 = 1.99
MF = $Sn_2I_4(CO_3)_2.6H_2O$ (3)

3.(a) $SO_2Cl_2 + 2 H_2O \rightarrow H_2SO_4 + 2 HCl$ (2)

(b) $SO_2Cl_2(l) + 2 H_2O(l) \rightarrow 2 H^+(aq) + SO_4^{2-}(aq) + 2 H^+(aq) + 2$ Cl-(aq)

Or more correctly $SO_2Cl_2(l) + 2 H_2O(l) \rightarrow 4 H^+(aq) + SO_4^{2-}(aq) + 2$ Cl-(aq) (2)

(c) Using the equation $SO_2Cl_2(l) + 2 H_2O(l) \rightarrow 4 H^+(aq) + SO_4^{2-}(aq) + 2$ Cl-(aq)

$n(H^+) = 4 \times n(SO_2Cl_2) = 4 \times (0.725/M(SO_2Cl_2))$

$= 4 \times (0.725/134.96)$

$= 0.02149$ moles (2)

$[H^+] = n/V = 0.02149/0.100 = 0.2149$ $molL^{-1}$ (2)

(d) Using the equation $H^+ + OH^- \rightarrow H_2O$

0.2149$molL^{-1}$ 0.0985 $molL^{-1}$

20 ml ? ml

Volume NaOH = (0.2149 x 20)/0.0985 = 43.6 mL. (2)

(e) from the equation in (b) $[SO_4^{2-}] = ¼ \times [H^+] = 0.05373$ $molL^{-1}$ (2)

Using the equation $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$

$n(BaSO_4) = n(SO_4^{2-}) = 40 \times 10^{-3} \times 0.05373 = 0.00215$ moles

$M(BaSO_4) = 233.36$ g

$m(BaSO_4) = n \times M = 0.502$ g (2)

4. (a) Rewrite the equations so they are all balanced.

$4 NH_3(g) + 5 O_2(g) \rightarrow 4 NO(g) + 6 H_2O(g)$

$2 NO(g) + O_2(g) \rightarrow 2 NO_2(g)$

$3 NO_2(g) + H_2O(g) \rightarrow 2 HNO_3(g) + NO(g)$ (3)

(b) Only 2/3 N ends up as acid molecules. (1)

(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%.

From (b) we get a mole statement: $n(HNO_3) = 2/3 \times n(NH_3)$

In 5000g $n(NH_3) = 5000/17 = 294.12$ moles $M(HNO_3) = 63$ $gmol^{-1}$

If 95% yield mass $HNO_3 = 0.95 \times 294.12 \times M(HNO_3) = 1.76 \times 10^4 \times 2/3$ g $= 1.17 \times 10^4$ g (3)

(d) $n = c \times V$ $0.95 \times 294.12 = 11 \times V$

$V = 25.4$ L (2)

(e) Return the NO(g) formed in the third reaction to the reacting chamber where the second reaction is taking place, simply add more oxygen (air) at that time and make more NO_2 (g) out of it as the reaction goes on to the third reaction, this then becomes a continuous recycling process so all N ends up as HNO_3.
(2)

Answers comprehension and Interpretation

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

$3\ CH_4(g) + 6\ H_2O(g) \rightarrow 3\ CO_2(g) + 12\ H_2(g)$ $4\ N_2(g) + 12\ H_2(g) \rightarrow 8\ NH_3(g)$ That is, 3 mol CH_4 produces 8 mol NH_3	1 1
$n(CH_4) = 1/M(CH4) = 1/16.042 = 0.06234$ mol	1
$n(NH_3) = 8/3 \times 0.06342 = 0.1662$ mol	1
$m(NH_3) = n \times M = 0.1662 \times 17.034 = 2.83$ g i.e. at 100% efficiency, 2.83 g of NH_3 is produced for each gram of CH_4 reacted	1
Total	**/5**

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.

$n(CH_4) = 650000/16.042 = 40,518.63$ mol	1
$n(H_2) = 285500/2.016 = 141,617.06$ mol	1
$3\ CH_4(g) + 6\ H_2O(g) \rightarrow 3\ CO_2(g) + 12\ H_2(g)$ From the equation, 1 mol of CH4 produces 4 mol of H2 if completely reacted 141617.06/4 mol of CH4 was reacted = 35,404.3 mol	2
H2O was the LR. To improve the process the n(H2O) must be > 40518.63 x 6/3 mol = 81,037.26 mol So that all of the CH4 is consumed	2
Total	**/6**

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.

From information provided, 1 g of chicken feathers gives 0.26 g NH_4HCO_3	1
$n(NH_4HCO_3) = \dfrac{0.26}{M(NH_4HCO_3)} = \dfrac{0.26}{79.06} = 3.29 \times 10^{-3}$ mol	1
$n(NH_3) = n(NH_4HCO_3) = 3.29 \times 10^{-3}$ mol	1
$m(NH_3) = 17.034 \times 3.29 \times 10^{-3} = 5.604 \times 10^{-2}$ g	1
At 90% efficiency, $m(NH_3) = 0.9 \times 5.604 \times 10^{-2} = 5.04 \times 10^{-2}$ g	1
Total	**/5**

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.

From information provided, 15% by mass of chicken feathers is N. 1g of feathers contains 0.15g of N	1
1g of feathers produces 0.0504 g of NH_3. m(N) = 0.0504 x 14.01/17.034 = 0.04145 g	1
∴ % efficiency = 0.04145/.15 x 100 = 27.6%	1
Total	**/3**

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.

For steam reforming process, common values for efficiency range from 65–75%	1
For the Haber process, at each pass of the gases through the reactor, only about 15% of the nitrogen and hydrogen converts to ammonia. (This figure varies from plant to plant.) By continual recycling of unreacted nitrogen and hydrogen, the overall conversion is about 98%	1
For calculation of overall efficiency, a value of ~70% is realistic (accept any values around this range)	1
At 70% efficiency, $m(NH_3) = 0.7 \times 2.83 = 1.98$ g	1
Reference(s) cited with sufficient detail to allow checking	1
Total	**/5**

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.

$\frac{\text{m(NH3) Haber/ steam reforming}}{\text{m(NH3) feathers}} = \frac{1.98}{0.00504} = 39.28$	1
The steam reforming/Haber process produces approximately 39 times more NH_3 on a gram basis of their starting material	1
Total	**/2**

7. Assuming that all reactions reach a state of equilibrium, 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.

Temperature and pressure conditions for the steam reforming process	
• moderate pressures (~20 atm) for reaction of CH_4 with H_2O – high pressures would favour reverse reaction but low pressures would give too slow a reaction rate	2
• high temperature (~800 °C) for reaction of CH_4 with H_2O – the forward reaction is endothermic, so high temperatures favour the forward reaction	2
• high pressures (~200 atm) for reaction of CO with H_2O – increases the rate of reaction without compromising equilibrium yield	2
• low to moderate temperature for reaction of CO with H_2O – forward reaction is exothermic so high temperatures favour the reverse reaction but too low a temperature slows reaction rate	2
Temperature and pressure conditions for the Haber process	
• high pressures (~200 atm) – favour forward reaction and increase rate of reaction	2
• moderate temperature (~400 °C) – forward reaction is exothermic, so high temperatures favour the reverse reaction but too low a temperature slows reaction rate	2
Total	**/12**

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.)

Temperatures for chicken feather process does not reach as high as for steam reforming process but is higher than for Haber process	1
Estimate of pressure for chicken feather process may be based on the supercritical nature of the CO_2 – CO_2 is supercritical at about 73 atm	1
Pressures for the Haber process and one stage of steam reforming process are very high (in an industrial sense). Whilst the information provided does not state explicit pressures for the chicken feather process, CO_2 is supercritical at about 73 atm, less than half the pressures for the Haber process.	1–2
Total	**/4**

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.

Discussion includes relevant points taken from information provided and researched	1–4
Total	**/4**
Answer could include, but is not limited to:	
Aspects that may be in a discussion include: • high pressures need to be maintained in Haber process and second stage of reforming process which uses a lot of energy • the decomposition of ammonium hydrogencarbonate occurs at low temperature, so reduces energy demands • high temperatures in steam reforming and Haber require high energy • hydrogen for the Haber process is generated from a fossil fuel – a non-renewable resource • feathers are a renewable resource • carbon dioxide generated in the feather process and decomposition of ammonium hydrogencarbonate may be recycled other nitrogen containing compounds that would otherwise go to landfill may be used in the process developed for chicken feathers	