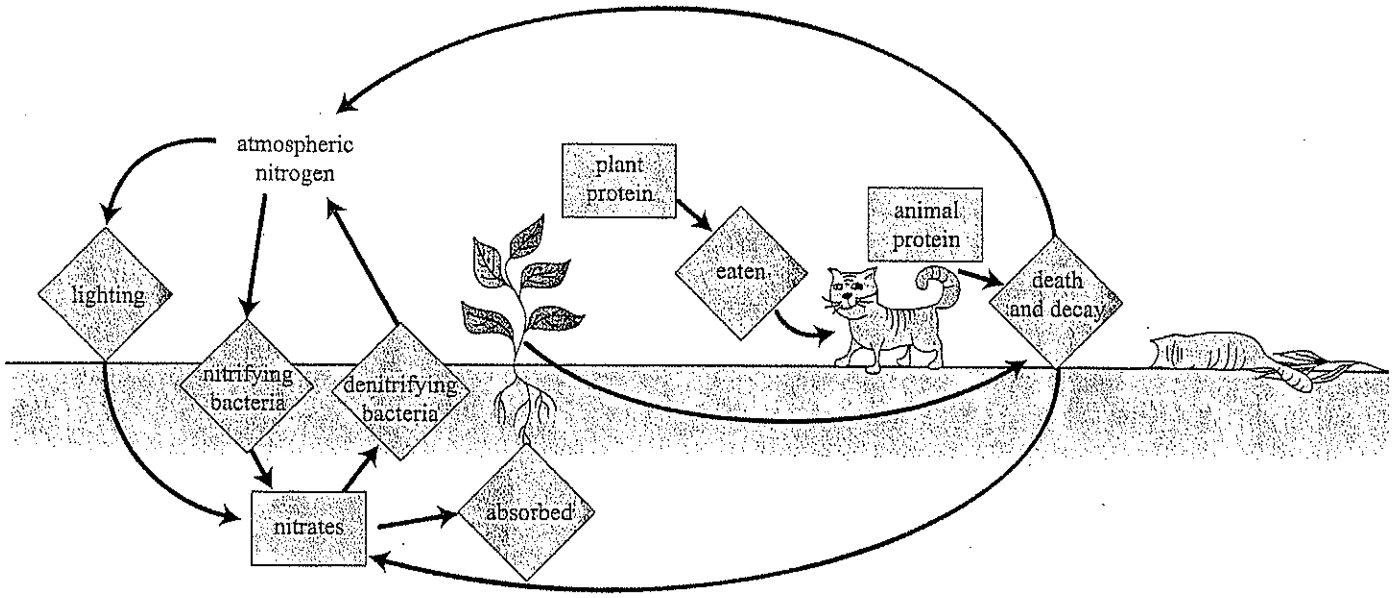
ANSWERS

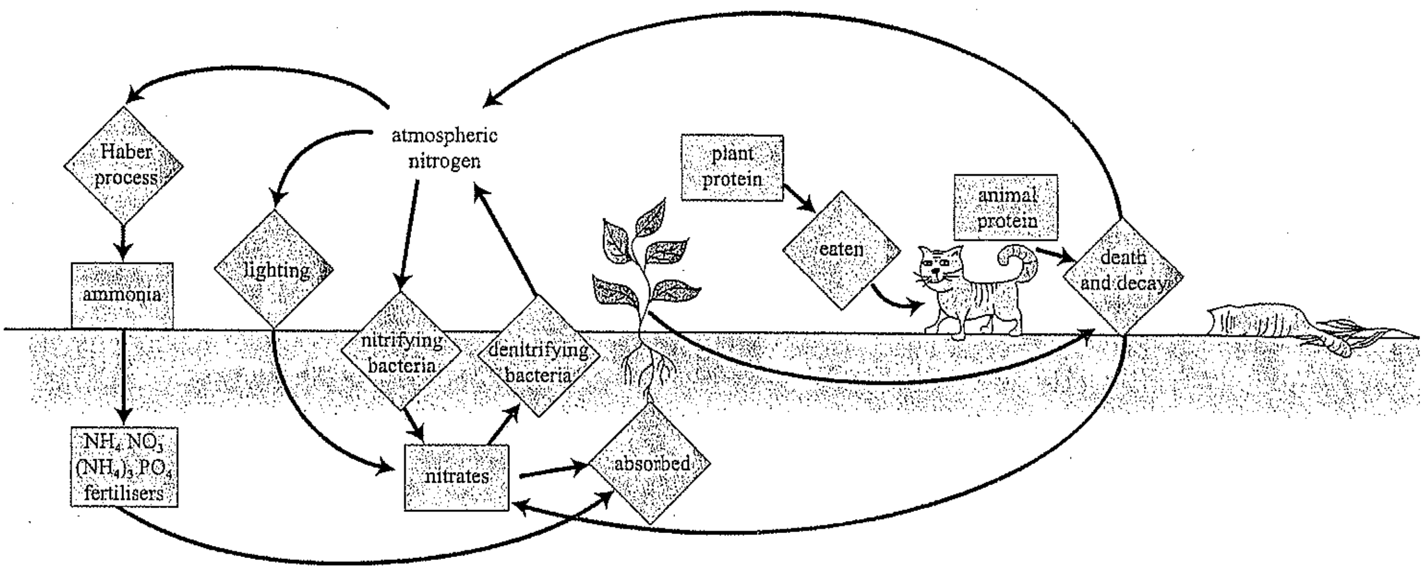
History of the Haber Process

1. (b) sea bird droppings
   (c) $N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g)$, $\Delta H = -92$ kJ mol^{-1}
   (d) (i) ammonia
   (ii) nitric acid and nitrates
   (e) (i) Early in World War I the powerful British navy prevented saltpetre being shipped to Germany.
   (ii) needed ammonia to make fertilisers, explosives and dyes
   (f) Haber process to make ammonia from hydrogen and atmospheric nitrogen. Then Ostwald process to convert ammonia into nitric acid and nitrates.
   (g) allowed them to make explosives and continue war
   (h) catalysts and high pressure equipment and technology
2. A
3. C
4. (a) NH_3
   (b) NH_4Cl
   (c) NH_4^+
   (d) $(NH_4)_2CO_3$
   (e) HNO_3
   (f) NH_4NO_3
5. a–iii; b–iv; c–i; d–v; e–ii
6. See diagram on the next page.
7. See diagram on the next page.
8. allowed Germany to continue WWI; decreased importance of saltpetre from Chile so affected their exports; allowed development of fertiliser, explosive and dye industries
9. (a) Haber
   (b) Bosch
   (c) guano and Chile saltpetre
   (d) make plant protein
   (e) manufacture of explosives, synthetic dyes, fertiliser
   (f) nitrogen
11. (i) $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$
   (ii) $4NO(g) + 2H_2O(g) + 3O_2(g) \rightarrow 4HNO_3(l)$
   (iii) $HNO_3(l) + NH_3(g) \rightarrow NH_4NO_3(s)$
12. (a) $N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g)$, $\Delta H = -92$ kJ mol L^{-1}
   (b) 3.0 kg
   (c) 0.9 kg
13. Maintain optimum conditions for maximum yield and the least possible waste.
   Getting maximum yield of ammonia from the Haber process involves balancing reaction energy, reaction rate and equilibrium. A compromise is reached, and the reaction is monitored, maintaining the following conditions in the reaction vessels to ensure optimum yield:
   - nitrogen and hydrogen are fed in at a ratio of 1:3
   - a pressure of 250–350 atmospheres
   - a temperature of 400°C to 500°C
   - iron oxide (Fe_3O_4) catalyst lowers the activation energy
   - unused gases are returned to the reaction vessel
   - ammonia is constantly removed as a liquid.
14. (a) (i) As temperature increases, % yield of ammonia increases.
   (ii) As pressure increases, % yield of ammonia increases.
   (b) (i) ~~50%~~ 30% (ii) 8% (iii) ~~75%~~ 65%
   (c) (i) 2941.18 mol (ii) 24 kg
15. See the flow chart on this page.
16. (a) ammonia
   (b) colourless, toxic gas, pungent odour
   (c) ammonium nitrate and phosphate
   (d) nitrogen and hydrogen
   (e) Carl Bosch
   (f) $CH_4(g)$ and $H_2O(g)$
   (g) $N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g)$, $\Delta H = -92$ kJ
   (h) lowering temperature
   (i) increasing temperature
   (j) iron or iron oxide
   (k) increasing pressure
   (l) ammonia
   (m) explosives, fertiliser, nitric acid, synthetic fibres, sodium carbonate, soaps

ANSWERS



Answer to Question 3.6



Answer to Question 3.7

4 The Haber Process

1. A 2. D 3. B 4. C 5. C
6. nitrogen, hydrogen
   $N_2(g) + 3H_2(g) \leftrightarrow 2NH_3(g)$, $\Delta H = -92$ kJ mol L^{-1}
7. (a) $CH_4(g) + 2H_2O(g) \xrightarrow{750^\circ C,\ Ni\ catalyst} 4H_2(g) + CO_2(g)$
   (b) fire extinguishers, fizzy drinks
8. (a) Reaction proceeds in both directions at the same time.
   (b) Energy is released to the environment.
9. (a) cool and liquefy
   (b) Equilibrium moves right to make more ammonia so yield of ammonia increases.
10. (a) Higher temperature causes particles to move faster so more collisions so faster rate of reaction.
    (b) Exothermic reaction so increasing temperature pushes equilibrium to left to use up the extra heat. Le Chatelier's principle states that when an equilibrium system is disturbed, it moves to minimise the disturbance. This shift left favours reactants, not products.
    (c) High enough to have good reaction rate, low enough to still get a good yield. Compromise between (a) and (b).