

Synthesis

- (b) An addition of acid to the test tube shifts the equilibrium to the right, dissolving the precipitate. Note: Barium dichromate is much more soluble than barium chromate.

Making Connections

9. (a) The Claus method is one of the most common methods of removing foul-smelling hydrogen sulfide during the processing of crude oil and natural gas. The Claus method occurs in two steps:
1. In the “thermal step,” hydrogen sulfide is burned with oxygen temperatures in excess of 850°C.
 2. During the “catalytic step,” the combustion products from step 1 are cooled and passed over an aluminum oxide catalyst, where the following reaction takes place:
$$2 \text{H}_2\text{S}_{(g)} + \text{SO}_{2(g)} \rightleftharpoons 3 \text{S}_{(s)} + 2 \text{H}_2\text{O}_{(g)}$$

Elemental sulfur is removed as it forms in the process. The remaining gases are passed on to other chambers where more sulfur removal takes place. Step 2 needs to be repeated 2–3 times because equilibrium prevents the reaction from going to completion.
- (b) Immediate removal of sulfur favours the forward reaction in the equilibrium, removing the hydrogen sulfide and sulfur dioxide from the processing plant emissions.
10. The first limitation is the limited oxygen supply on the spacecraft. Secondly, excess carbon dioxide exhaled by the astronauts will consume all the lithium hydroxide in the purification system, forcing the equilibrium to the right and eventually to completion. Without lithium hydroxide, carbon dioxide levels would soon increase, reaching toxic levels.
11. Reducing the pressure of a solution–gas equilibrium (blood and air in the body) reduces the quantity of gas (oxygen) that is dissolved in a solution (blood). At high altitudes, the human body can compensate for the loss of oxygen by increasing the number of red blood cells in the blood. This adaptation to increase the red blood cell count usually takes about three to four weeks, but it can be accelerated by transfusion.
12. Get the victim to fresh air as soon as possible. Administer oxygen with a bottle-fed breathing mask. Breathing 100% oxygen would shift the given equilibrium to the left, displacing carbon monoxide from hemoglobin.

7.4 CASE STUDY: THE HABER PROCESS: AMMONIA FOR FOOD AND BOMBS

PRACTICE

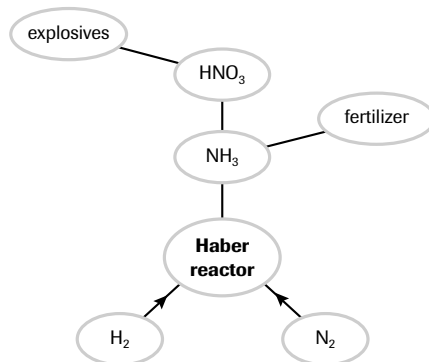
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Understanding Concepts

1. Factors increasing production include:
- removing $\text{NH}_{3(g)}$
 - adding $\text{N}_{2(g)}$
 - adding $\text{H}_{2(g)}$
 - reducing the temperature slightly
 - raising the pressure
 - adding a catalyst (which will have the effect of speeding up both forward and reverse reactions)

Making Connections

2.



PRACTICE

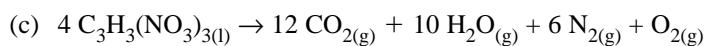
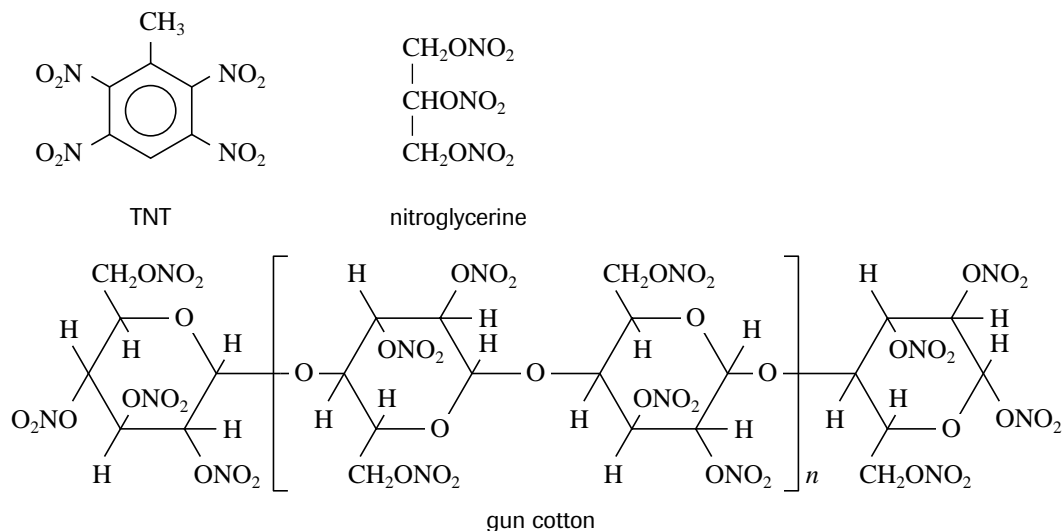
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Understanding Concepts

- Lowering the temperature would have the effect of slowing down the reaction.
- The catalyst does not affect the position of the equilibrium since it lowers the activation energy for both the forward and reverse reactions. However, using a catalyst allows the manufacturer to run the process at a lower temperature and still maintain yield.

Making Connections

- (a) TNT, nitroglycerine, and gun cotton
(b)



This reaction is explosive because it is highly exothermic ($\Delta H = 1415 \text{ kJ/mol}$ nitroglycerine) and converts four moles of liquid nitroglycerine into 29 moles of gaseous products.

- (d) Gun cotton (nitrocellulose) is a highly explosive nitrated cellulose made by soaking cotton (cellulose) in nitric acid and sulfuric acid; used to make smokeless gunpowder.

SECTION 7.4 QUESTIONS

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Making Connections

- (a) Decrease the temperature, increase the pressure, increase $[\text{N}_{2(g)}]$, increase $[\text{H}_{2(g)}]$, and remove ammonia from the system.
(b) Decreasing the temperature will shift the equilibrium to the right but makes the reaction uneconomical because the yield of ammonia decreases.
(c) The heat released by the forward reaction can be used to help maintain the temperature of the reaction chamber. The company should also ensure that the equipment is well maintained so that gas leaks in the system do not reduce pressure. They should keep the system insulated to prevent heat loss, and they should use high-efficiency pumps and heaters to save on energy costs. The system should separate and recycle unreacted $\text{H}_{2(g)}$ and $\text{N}_{2(g)}$.
- (a) Possible sources of these gases are: nitrogen—extraction from the atmosphere, and hydrogen—electrolysis of water.
(b) Hydrogen is produced by reacting methane ($\text{CH}_{4(g)}$, natural gas) with steam ($\text{H}_2\text{O}_{(g)}$), producing carbon dioxide ($\text{CO}_{2(g)}$) and hydrogen ($\text{H}_{2(g)}$). Nitrogen ($\text{N}_{2(g)}$) is obtained by the fractional distillation of air (~78% $\text{N}_{2(g)}$). Fractional distillation is a process by which the components in a chemical mixture are separated according to their different boiling points. Vapours from a boiling solution are passed along a cooled column. The temperature of the column gradually decreases along its length. Components with a higher boiling point condense on the column and return to the solution; components with a lower boiling point pass through the column, are condensed, and are collected in a suitable collecting vessel.
- (a) Bacteria such as *Rhizobium* and *Azotobacter* absorb nitrogen from air and fix it into ammonia through a series of reactions that use an enzyme complex called nitrogenase as a catalyst.

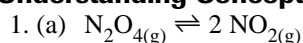
- (b) More nitrogen is fixed naturally (1.75×10^8 tonnes per year) than synthetically (8×10^7 tonnes per year).
- (c) Studies show that high levels of nitrogen fixation caused by nitrogen pollution are likely to cause severe declines in native plant communities by favouring weedy plants that favour high ammonia concentrations in soil. This problem can be reduced by decreasing the use of machines that burn fossil fuels such as automobiles, trucks, buses, planes, leaf blowers, lawn mowers, and jet skis, and by reducing the nitrogen oxide emissions of coal- and oil-burning electricity generating plants and large industries.

7.5 QUANTITATIVE CHANGES IN EQUILIBRIUM SYSTEMS

PRACTICE

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Understanding Concepts



$$[\text{N}_2\text{O}_{4(g)}] = 5.30 \text{ mol/L}$$

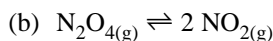
$$[\text{NO}_{2(g)}] = 2.15 \text{ mol/L}$$

$$Q = \frac{[\text{NO}_{2(g)}]^2}{[\text{N}_2\text{O}_{4(g)}]}$$

$$= \frac{[2.15]^2}{[5.30]}$$

$$Q = 0.87$$

Since the value of Q is equal to the value of K (0.87), the reaction is at equilibrium.



$$[\text{N}_2\text{O}_{4(g)}] = 0.80 \text{ mol/L}$$

$$[\text{NO}_{2(g)}] = 1.55 \text{ mol/L}$$

$$Q = \frac{[\text{NO}_{2(g)}]^2}{[\text{N}_2\text{O}_{4(g)}]}$$

$$= \frac{[1.15]^2}{[0.80]}$$

$$Q = 3.0$$

Since the value of Q is larger than the value of K (0.87), the reaction is not at equilibrium. In order to attain equilibrium, the reaction will shift to the left (as written). The concentration of the reactants will increase and the concentration of the products will decrease.

2. $[\text{Cl}_{2(g)}]_{\text{initial}} = \frac{3.20 \text{ mol}}{1.00 \text{ L}}$

$$[\text{Cl}_{2(g)}]_{\text{initial}} = 3.20 \text{ mol/L}$$

$$[\text{PCl}_{3(g)}]_{\text{initial}} = \frac{1.5 \text{ mol}}{1.0 \text{ L}}$$

$$[\text{PCl}_{3(g)}]_{\text{initial}} = 1.5 \text{ mol/L}$$

$$[\text{PCl}_{5(g)}]_{\text{initial}} = \frac{2.0 \text{ mol}}{1.0 \text{ L}}$$

$$[\text{PCl}_{5(g)}]_{\text{initial}} = 2.0 \text{ mol/L}$$

$$Q = \frac{[\text{PCl}_{3(g)}][\text{Cl}_{2(g)}]}{[\text{PCl}_{5(g)}]}$$

$$= \frac{[1.5][3.20]}{[2.0]}$$

$$Q = 2.4$$