The HABER PROCESS

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The Haber process is a method used to make ammonia directly from nitrogen and hydrogen. The nitrogen is obtained from fractional distillation of liquefied air while the hydrogen is derived from natural gas and water in steam reforming

$CH_{4(g)} + H_2O \rightarrow CO_{(g)} + 3H_{2(g)}$

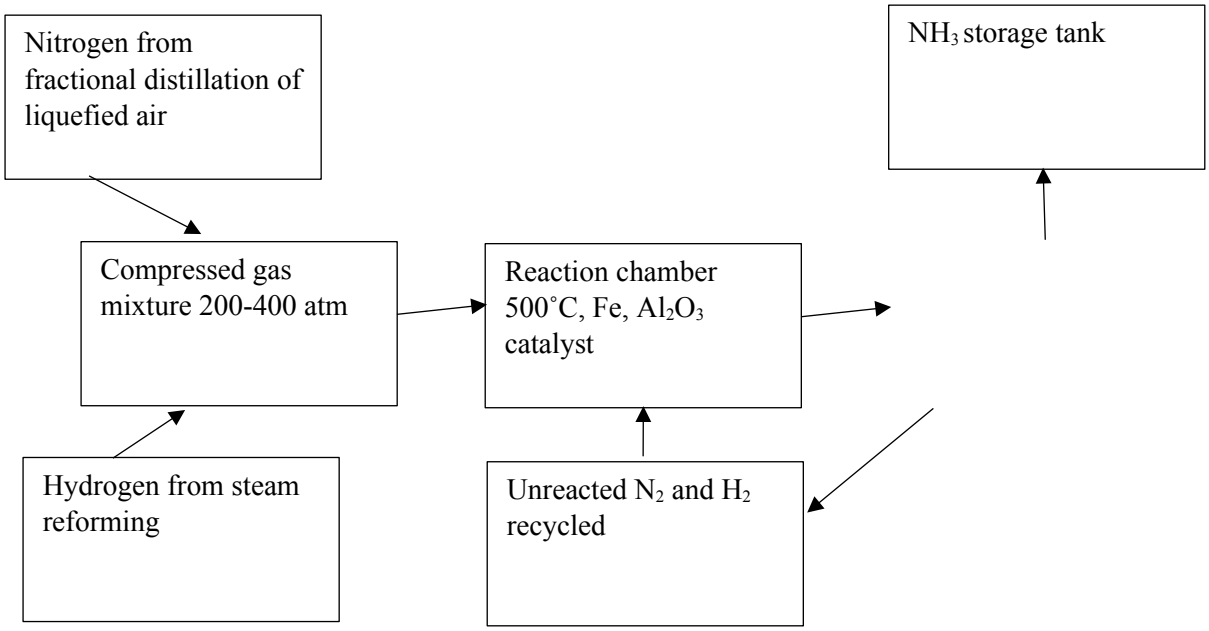
The carbon monoxide produced is combined with more steam to from hydrogen and carbon dioxide.

$CO_{(g)} + H_2O_{(g)} \rightarrow CO_{2(g)} + H_{2(g)}$

The combination of nitrogen and hydrogen into ammonia is a reversible reaction. The forward reaction is exothermic and results in a decrease in volume.

$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$ $\quad\quad$ $\triangle H = -92 KJ\ mol^{-1}$

Flow Diagram of the Haber Process



ACTIVITY 1

Directions: Use the words given to label the diagram below

Liquid ammonia	Iron catalyst	Unreacted nitrogen and hydrogen
Compressor	Nitrogen and hydrogen	

Activity 2

Directions: Fill in the blank with the words given.

Nitrogen is an important _____which is needed for plants to grow. Plants can get nitrogen from the _____process. In this process a reversible reaction between nitrogen and _____ is used to produce ammonia. An _____catalyst is used to increase the _____ of the reaction. The reaction is exothermic, so a moderate temperature of _____˚C is used. This gives a reasonable yield of ammonia at a reasonable rate. A pressure of _____atmosphere is used to give a good yield of ammonia.

rate	element	compound	450
Haber	hydrogen	200	iron

ACTIVITY 3

Instructions: Answer the following questions given below.

1) The reaction of 381.2 kg of nitrogen with 86.1 kg of hydrogen in the Haber process results in a yield of 75.0%. Calculate the mass of product in this reaction.

2) Which feature of a typical reactor in the Haber process allows very high maximum percentage yields to be achieved?
   a) Drying of the reaction mixture
   b) Recycling of reactants
   c) Compression of the reaction mixture
   d) Heating of the reaction mixture
   e) The presence of a catalyst

3) What is the main reason for removing the product from the reaction mixture during the Haber process?
   a) To lower the pressure of the reaction mixture
   b) To increase the reaction yield
   c) To prevent degradation of the catalyst
   d) To increase the reaction rate
   e) To prevent the formation of unwanted side products

4) Which of the following changes could lower the reaction rate in the Haber process?
   a) Increasing the pressure of the reaction mixture
   b) Increasing the reaction temperature
   c) Increasing the mass of the catalyst
   d) Increasing the flow rate over the catalyst
   e) Reducing the size of catalyst particles

5) A sample of nitrogen is reacted with excess hydrogen to produce 2.80 metric tons of product via the Haber process. The yield of the reaction is 41.0%. Calculate the mass of the nitrogen sample.

6) The Haber process is a gas-phase reaction involving hydrogen gas (H_2).A major source of hydrogen gas is the reaction of methane (CH_4) with steam. This process is known as steam reforming.

Give a balanced chemical equation for the steam reforming of methane gas, which generates carbon monoxide as a gaseous by-product.

   a) $CH_4+2H_2O \rightarrow CO_2+8H_2$
   b) $CH_4+H_2O \rightarrow CO+2H_2$
   c) $CH_4+2H_2O \rightarrow 2CO+4H_2$
   d) $CH_4+2H_2O \rightarrow CO_2+4H_2$
   e) $CH_4+H_2O \rightarrow CO+3H_2$

Steam reforming involves a reversible reaction. How do the reaction rate and percentage yield change if the pressure of the reacting gases is increased?

a) The reaction rate increases, and the percentage yield decreases.
b) The reaction rate increases, and the percentage yield is approximately constant.
c) The reaction rate and percentage yield both increases.
d) The reaction rate and percentage yield both decreases.
e) The reaction rate decreases, and the percentage yield increases.

Additional hydrogen can be produced by reacting carbon monoxide from steam reforming with additional water, in a process known as the water-gas shift reaction. There is only one other product. Give a balanced chemical equation for this reaction.

a) $CO+2H_2O \rightarrow CO_3+2H_2$
b) $CO+H_2O \rightarrow CO_2+H_2$
c) $CO+2H_2O \rightarrow H_2CO_3+H_2$
d) $CO+H_2O \rightarrow C+O_2+H_2$
e) $2CO+4H_2O \rightarrow 2HCO_3+3H_2$

The water-gas shift reaction is reversible. How do the reaction rate and percentage yield change if the pressure of the reacting gases is increased?

a) The reaction rate increases, and the percentage yield decreases.
b) The reaction rate decreases, and the percentage yield increases.
c) The reaction rate and percentage yield both decreases.
d) The reaction rate increases, and the percentage yield is approximately constant.
e) The reaction rate and percentage yield both increases.

7) The reaction of 30.0 kg of hydrogen with excess nitrogen generates 93.5 kg of product via the Haber process. Calculate the percentage yield of this reaction.

8) The Haber process involves the reversible reaction of two gaseous reactants. What is the main disadvantage of increasing the pressure at which the reaction is performed?
   a) Condensation of the gaseous reactants
   b) Reduced reaction rate
   c) Reduced maximum percentage yield
   d) Increased equipment and running costs
   e) Increased formation of unwanted side products

9) The Haber process involves the reversible reaction of two gaseous reactants. What is the main disadvantage of increasing the temperature at which the reaction is performed?
   a) Increased formation of unwanted side products
   b) Increased equipment and running costs
   c) Reduced reaction rate
   d) Reduced maximum percentage yield
   e) Melting of the solid catalyst

10) The Haber process is a gas-phase reaction involving nitrogen gas (N_2).Pure nitrogen can be produced by reacting air with hydrogen gas and removing the products.

Besides nitrogen, what are the two most abundant components of dry air?

a) Carbon dioxide and water
b) Oxygen and argon
c) Oxygen and water
d) Oxygen and carbon dioxide
e) Water and argon

Give a balanced chemical equation for the reaction of air with hydrogen.

a) $N_2+3H_2 \rightarrow 2NH_3$
b) $N_2+2H_2 \rightarrow 2NH_2$
c) $N_2+3O_2+H_2 \rightarrow 2HNO_3$
d) $O_2+H_2 \rightarrow H_2O_2$
e) $O_2+2H_2 \rightarrow 2H_2O$

The reaction of air with hydrogen is an example of an irreversible reaction. What is meant by this term?

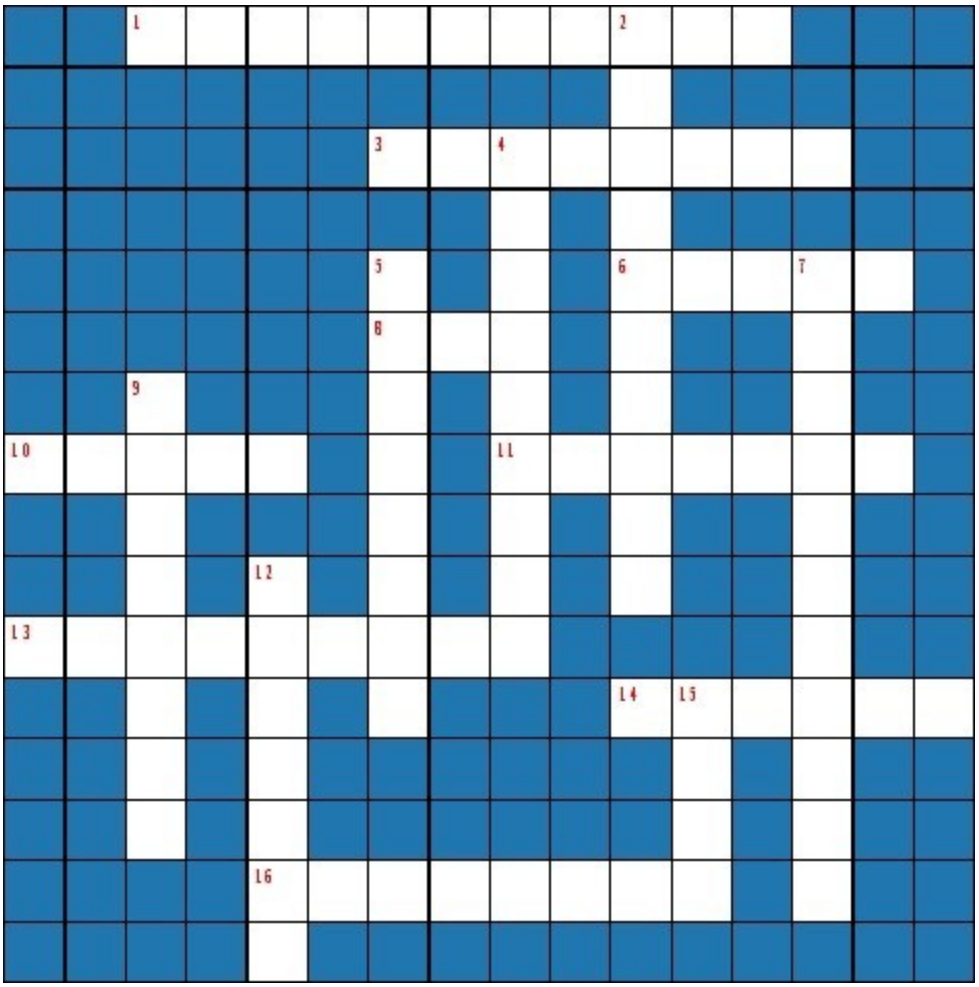
a) The products of the reaction are much more stable than the reactants.
b) The products of the reaction can never be converted back to the original reactants under the reaction conditions.
c) The amount of product that converts back to the original reactants is very close to zero under the reaction conditions.
d) The reaction is highly exothermic.
e) The product of the reaction is removed as it forms, preventing it from converting back to the original reactants.

Which method can be used to separate the product of this reaction from the nitrogen gas?

a) Heating and distilling
b) Cooling and drying
c) Heating and filtering
d) Filtering and distilling
e) Cooling and distilling

ACTIVITY 4

Directions: Use the clue provided to fill out Haber process crossword puzzle.



Across

1 Helping crops to grow, these substances are a major use of ammonia (11)

3 One of the two reactants needed, obtained from natural gas (8)

6 The Fritz who invented the process (5)

8 Nitrogen is obtained by the fractional distillation of this atmospheric mixture of gases (3)

10 An anagram of mates, this reacts with natural gas or coke to produce hydrogen (5)

11 The product of the Haber process (7)

13 The yield of ammonia does this when the pressure is increased (9)

14 An acid produced by the oxidation of ammonia (6)

16 One of the two reactants needed, it is between carbon and oxygen in the periodic table (8)

Down

2 This type of reaction transfers energy to the surroundings, usually by heating (10)

4 The yield of ammonia does this when the temperature is increased (9)

5 A type of substance that increases the rate of a reaction without being used up (8)

7 Reversible reactions like the Haber process can reach a dynamic one of these in a closed system (11)

9 This happens to unreacted nitrogen and hydrogen (8)

12 Rearrange 'the name' - the main compound found in natural gas (7)

15 The metallic catalyst used in the Haber process (4)

ACTIVITY 5

Instructions: Answer the following questions given below.

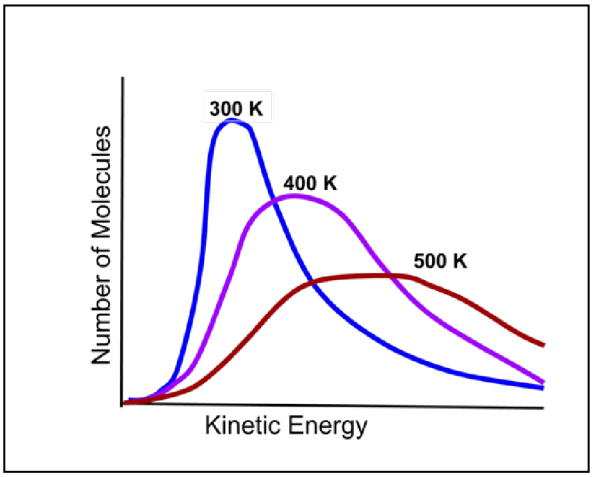
1) The Haber process for the formation of ammonia from hydrogen and nitrogen gasses is given by the equation below.

$3H_2(g) + N_2(g) \rightarrow 2NH_3\,(g)$ ($\Delta H = -92$ kJ/mol)

a) What conditions would maximise yield ? Describe how these conditions are at odds with the rate of the reaction above ?

b) Explain how an increase in temperature maximises the rate of the reaction. Use the chart on the right

c) Explain how a catalyst increases the rate of the reaction. Refer to the diagram on the right.



d) 2.15 litres of hydrogen gas completely react with nitrogen gas to form ammonia at STP. The energy given out is used to heat 200.0 grams of water at 20.0 ^{O}C. Assuming no energy is lost what is the final temperature of the water?

e) In a 1.00 litre vessel 1.00 mol of H_2 gas and 1.00 mol of N_2 gas were mixed, at a given temperature and allowed to reach equilibrium. Two minutes after the gases were mixed the reaction mixture had reached equilibrium and it was found that 0.400 mol of NH_3 was present.

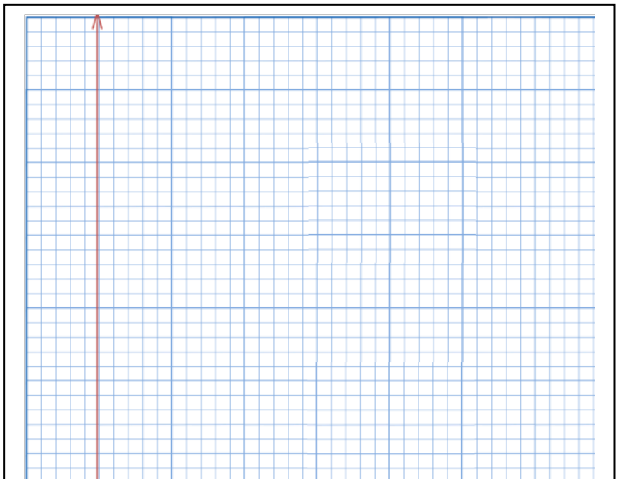
At the 6-minute mark the volume was suddenly doubled, and the system allowed to reach equilibrium once again. At the 10-minute mark the temperature of the reaction vessel was increased slightly.

i. What is the equilibrium expression for this reaction?

ii. Calculate the value of the equilibrium expression at the 2-minute mark

iii. What is the value of the equilibrium expression at the 8-minute mark

iv. Use the set of axis, on the right, to graph the concentration vs time graph of each gas present in the mixture. Sketch the graphs and show the general trends of $[H_2]$, $[N_2]$ and $[NH_3]$.



ACTIVITY 6

1. The sentences describe how ammonia is produced in the Haber process.

The sentences are in the wrong order.

P Ammonia is separated as a liquid.

Q Nitrogen and hydrogen are mixed.

R A mixture of gases enters the condenser.

S Nitrogen and hydrogen react to produce ammonia.

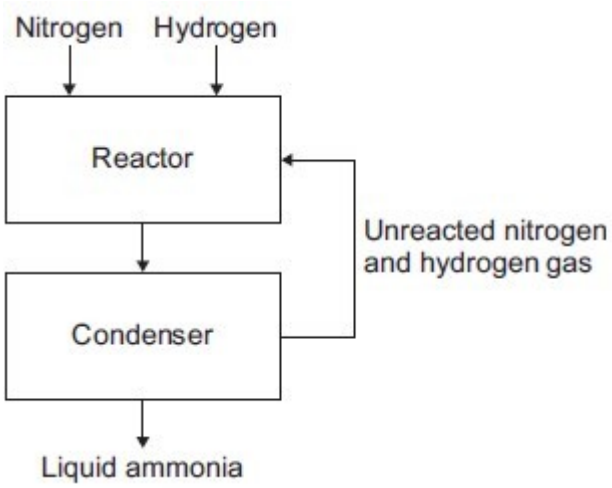
Complete the boxes below to show the correct order of the sentences.

2. Nitrogen gas and hydrogen gas are obtained from different sources. Draw one line from each gas to its source.

GAS	**SOURCE**
	Air
Nitrogen	
	Iron Ore
Hydrogen	Limestone
	Natural gas

3. A flow diagram of the Haber process is shown below.

The Haber process produces ammonia from nitrogen and hydrogen.



(a) Use the correct answer from the box to complete the sentence.

air	limestone	natural gas

Hydrogen is obtained from ..... .

(b) In the reactor, nitrogen and hydrogen at a high pressure are heated and passed over a catalyst.

(i) Use the correct answer from the box to complete the sentence.

25	100	450

The temperature in the reactor is ..... °C

(ii) Use the correct answer from the box to complete the sentence.

copper	iron	nickel

The catalyst used in the reactor is ..... .

(iii) How does a catalyst speed up a reaction?

Tick (✓) **one** box.

The catalyst lowers the activation energy. ☐

The catalyst gives the reactants extra energy. ☐

The catalyst increases the pressure in the reactor. ☐