Le Chatelier's Principle

Information for students

- One of the most important discoveries for humanity was made in the first decade of the 20th century. German chemists Fritz Haber and Carl Bosch worked out a way to combine hydrogen (H_2) and nitrogen (N_2) to produce ammonia (NH_3).

$$N_{2\,(g)} + 3\,H_{2\,(g)} \rightleftharpoons 2\,NH_{3\,(g)} + 92\text{ kJ}$$

The Haber-Bosch process

- Nitrogen, the most common gas in our atmosphere, plays a critical role in the biochemistry of every living thing. However, because nitrogen is so unreactive, plants cannot take it directly from the air. This was once a major limiting factor in agriculture, as plants need nitrogen to grow. Today, we use the Haber-Bosch process to artificially produce ammonia (NH_3), which is used to make fertilizers. These fertilizers allow us to grow more and more crops which, in turn, allows us to feed billions of people.
- In this week's challenge, we will use our understanding of ***"Le Chatelier's principle"*** as we think through the Haber-Bosch process, a process in dynamic equilibrium.

1. Consider the reactant nitrogen (N_2). Why is it difficult for nitrogen to react with other elements?
   (Answer in Appendix A)

2. After introducing the reactants into the process, one of the first steps involves pressure. Is the pressure increased or decreased? Why?
   (Answer in Appendix A)

3. The next step involves the use of a catalyst (usually made of iron or ruthenium). What does the catalyst do in this chemical reaction?
   (Answer in Appendix A)

4. The fourth step involves cooling. Why would decreasing the temperature of the system be helpful in increasing the yield of ammonia (NH_3)?
   (Answer in Appendix A)

5. Finally, as the Haber-Bosch process takes place, the ammonia (NH_3) produced is removed from the system. How does its removal increase the yield of ammonia (NH_3) produced overall?
   (Answers in Appendix A)

Congratulations! You have now thought through the 5 steps of the Haber-Bosch process.

To learn more about the discovery, benefits and drawbacks of the Haber process, click: https://ed.ted.com/lessons/the-chemical-reaction-that-feeds-the-world-daniel-d-dulek

For more information on Le Chatelier's principle, click on https://www.chemguide.co.uk/physical/equilibria/lechatelier.html

Did you know?

- About 80% of the nitrogen in our bodies comes from the Haber-Bosch process.
- In 1901, Henry Louis Le Chatelier attempted to produce a reaction between hydrogen and nitrogen, but a horrible explosion occurred, almost killing his assistant. Later, Haber acknowledged that Le Chatelier's failure accelerated his research, leading to the invention of the Haber process.
- Although the Haber-Bosch process is used today to produce ammonia (NH_3) for crop fertilizers, during WWI, it was used to give Germany an advantage in the production of explosives. (As history reminds us over and over again, science itself is neither good nor bad, it is simply science. The people with the best intentions can have the worst impacts while those who only want to kill might end up saving billions of lives.)
- Haber won a Nobel Prize in Chemistry in 1918, almost a decade after he came up with his invention. But this was controversial, as he had also invented chlorine and mustard gas, which killed thousands during WWI.
- The nitrate runoff from farms, a product of synthetic fertilizers, has a devastating effect on water quality. It causes explosive growths of algae in waterways that use up much of the oxygen and result in "dead zones" where aquatic life cannot exist.

Materials required

- Appendix A
- Device with internet connection (optional)

Information for parents

- Review their understanding of Le Chatelier's principle while learning more about one of the top chemistry inventions of the 20th century.

Appendix A: Solutions

Answers

- The two nitrogen atoms in a nitrogen molecule are held together by a triple bond. This bond is not easy to break. In addition, the activation energy barrier to overcome is very high.
- Since the goal of the process is to produce the highest yield of ammonia (NH_3) possible, the gaseous mixture should have its pressure increased. Looking at the equation, we see that pressure drives the equilibrium to the right. Le Chatelier's principle tells us that since one mole of nitrogen and three moles of hydrogen result in 2 moles of ammonia (NH_3), increasing pressure would drive the reaction to the right and thus increase the yield of ammonia (NH_3).).

*** Note: The pressure during the Haber-Bosch process is 200 atmospheres ***

- The catalyst is used to lower the high activation energy of this reaction. This is needed in order to break the strong nitrogen triple bond.

*** Note: Haber noted that uranium would be a better catalyst, but it was too expensive ***

- This reaction is exothermic. We see this since energy is written as one of the products of the forward reaction. Le Chatelier's principle tells us that when heat energy is removed (i.e. the temperature is lowered), the reaction will favor replacing this heat energy and thus the forward reaction will be favored. In this case, this would result in an increase in the production of ammonia (NH_3).

*** Note: The temperature used in the reaction is between 400 °C and 450 °C ***

- By removing the ammonia (NH_3), the forward reaction will be favored. Le Chatelier's principle dictates that when there is less reactant/product the system will move to increase those reactants/products to re-establish equilibrium. So, in removing ammonia (NH_3), the forward reaction will be favored in order to re-establish equilibrium, hence increasing the yield of ammonia (NH_3).

*** Note: Ammonia is the first step in creating many explosives (e.g. nitro. and TNT) ***

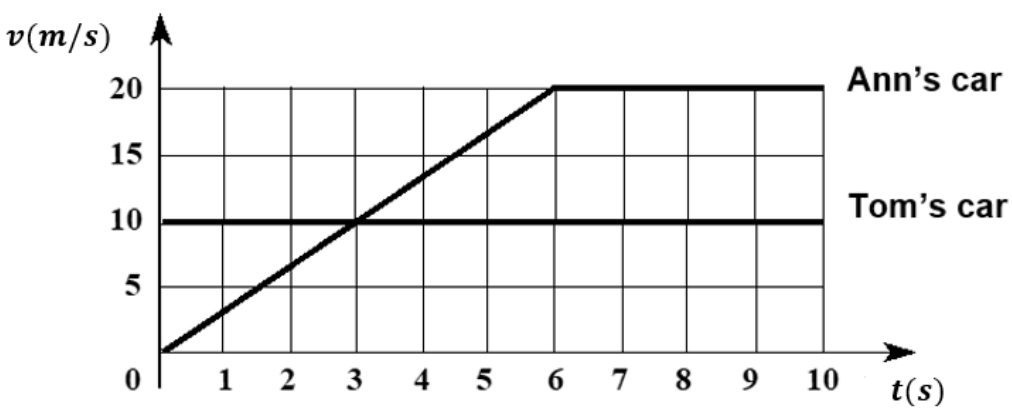
Velocity - Time Graph

Information for students

- $v_2 = v_1 + a\Delta t$
- $\Delta d = \frac{(v_1+v_2)}{2}\Delta t$
- $\Delta d = v_1\Delta t + \frac{1}{2}a\Delta t^2$
- $v_2{}^2 = v_1{}^2 + 2a\Delta d$

where:
$\Delta \boldsymbol{d}$ = change in distance (m)
$\boldsymbol{v_1}$ = initial velocity (m/s)
$\boldsymbol{v_2}$ = final velocity (m/s)
$\boldsymbol{a}$ = acceleration (m/s^2)
$\Delta \boldsymbol{t}$ = change in time (s)

- Describe what is happening in the graph below.



- A science teacher gave the following question to her class.
  Ann is waiting for a red light to change. When the light turns green, Tom, who is travelling in the same direction, at a constant speed, passes Ann just as she starts to move. At what time (in seconds) will Ann pass Tom?

- The graph above represents the velocity of the two cars as a function of time.
- Four students correctly found the answer to be 6 seconds, but each of them used a different strategy.
  - Steven found the solution algebraically
  - Melissa created a displacement vs time graph
  - Peter used trial and error
  - Isabel noticed that the area under the curve equals displacement during a time interval.
- Show how each student might have answered the question.
- At what time will Ann pass Tom, if Tom is travelling at a constant speed of 12 m/s?

Information for parents

- Links to help your child learn more about velocity-time graphs:
  - What are velocity time graphs? https://youtu.be/b1Zd8hUWpw0
  - The Physics Classroom https://www.physicsclassroom.com/class/1DKin/Lesson-4/Meaning-of-Shape-for-a-v-t-Graph
  - Why distance is the area under the velocity-time line. https://youtu.be/d-_eqgj5-K8