The Chemistry of the Bombardier Beetle[1]

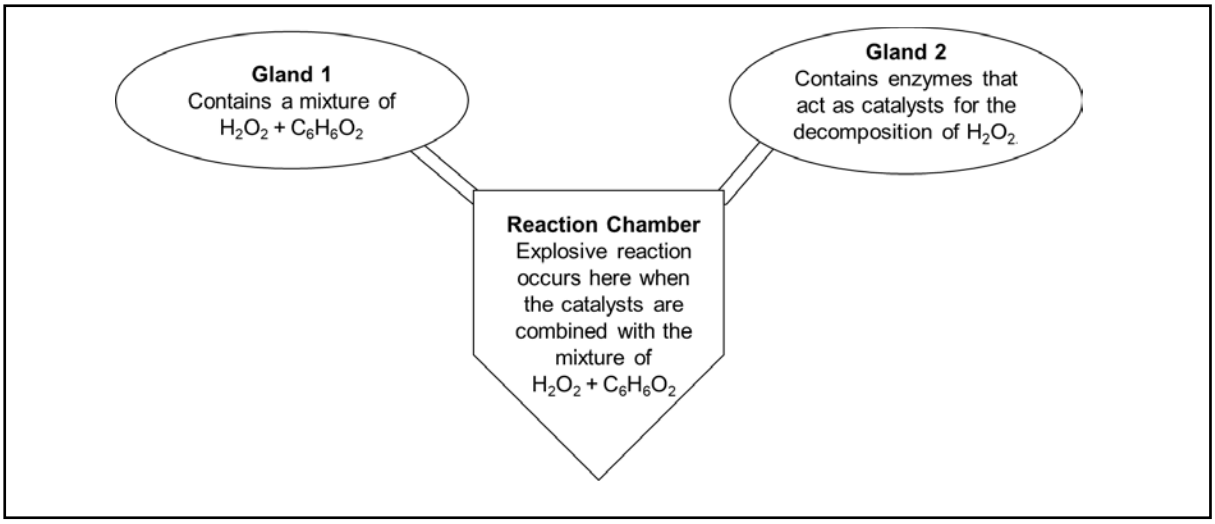
Information for students

- The Bombardier Beetle gets its name from how it defends itself. When threatened, this beetle releases a toxic mixture that is produced by an explosive reaction inside its abdomen.
- Read about the Bombardier Beetle's defense mechanism below and then answer the questions to explain the chemistry behind this phenomenon.

The Bombardier Beetle's Defense Mechanism

Scientists have been curious about how this defense mechanism works and are still learning about it. Below is a simplified description of some of the chemistry behind one of the ways in which the Bombardier Beetle may defend itself from attackers.

- Two glands and a reaction chamber inside the abdomen of the beetle are involved in this defense mechanism.
- When the contents of the glands are emptied into the reaction chamber, an extremely fast reaction occurs.
- Below is a simplified model of the glands and the reaction chamber.



[1] Image:
Patrick Coin, 2006. Bombardier Beetle, Brachininae sp., Orange County, North Carolina, United States. Length 13 mm. CC BY-SA 2.5, https://en.wikipedia.org/wiki/Bombardier_beetle#/media/File:Brachinus_spPCCA20060328-2821B.jpg. Accessed 5/8/2020.

References:
Muzzi, M., & Di Giulio, A. (2019). The ant nest "bomber": explosive defensive system of the flanged bombardier beetle paussus favieri (coleoptera, carabidae). *Arthropod Structure and Development*, *50*, 24–42.
Plumb, R. C., & Erickson, K. L. (1972). The bombardier beetle. *Journal of Chemical Education*, *49*(10), 705–705.
Schwarcz,J. (2017). Do Not Mess With a Bombardier Beetle, McGill Office for Science and Society, https://www.mcgill.ca/oss/article/environment/do-not-mess-bombardier-beetle. Accessed 5/8/2020.

- Gland 1 contains a mixture of hydrogen peroxide (H2O2), and hydroquinone (C6H6O2).
  - This mixture is relatively stable.
  - Hydrogen peroxide can decompose to produce oxygen and water. This reaction occurs very slowly in the gland.
- Gland 2 contains a mixtures of enzymes.
  - These enzymes are catalysts for the decomposition of hydrogen peroxide.

In the Reaction Chamber:

- When the contents of the glands combine in the reaction chamber, an explosive reaction occurs and a mixture of water and benzoquinone is produced. Benzoquinone is the toxic chemical that irritates the beetle's attackers. This reaction happens in two steps:
  - The enzyme mixture catalyzes the decomposition of hydrogen peroxide (H_2O_2), rapidly producing water and oxygen gas: hydrogen peroxide → water + oxygen gas
  - Then, the oxygen gas produced reacts with the hydroquinone, to produce benzoquinone.
- As the reactions occur:
  - Valves seal off the ducts between the glands and the reaction chamber.
  - The mixture in the reaction chamber heats up and can reach temperatures as high as 100 °C.
  - The pressure in the reaction chamber increases and, as a result, the mixture of water and benzoquinone is expelled out of the chamber and onto the beetle's attackers.

You can see a Bombardier Beetle in action by watching this video.

Questions

Answers are provided in the Appendix.

- 1. Is the reaction that occurs in the reaction chamber endothermic or exothermic? Explain.

- 2. Explain why the decomposition of hydrogen peroxide (H_2O_2), occurs very slowly in Gland 1 but very quickly in the reaction chamber.

- 3. Draw and compare the energy diagrams for the decomposition of hydrogen peroxide (H_2O_2) in gland 1 and in the reaction chamber. Include a comparison of the activation energy and the change in enthalpy for the reactions in each location.

- 4. Why do you think the pressure builds up in the reaction chamber? Explain your answer.

Materials required

- Paper and writing materials
- Device with Internet access (optional)

Information for parents

Children should:

- apply their chemistry knowledge to explain the chemistry behind a natural phenomena

Parents could:

- read the task to their child if necessary
- discuss the task with their child

Appendix – Chemistry of the Bombardier Beetle

Answers

- 1. The reaction that occurs in the reaction chamber is exothermic. The temperature in the reaction chamber increases during the reaction, which means the reaction releases heat. (Exothermic reactions release heat.)
- 2. The reaction rate depends on the number of effective collisions between reactants (with correct orientation, sufficient energy). The decomposition of hydrogen peroxide is slower in Gland 1 because there are relatively fewer effective collisions per unit of time than in the Reaction Chamber.
- 3. The decomposition of hydrogen peroxide is faster in the Reaction Chamber because there are more effective collisions between reactants per unit of time. This can be explained by the presence of the catalysts (from Gland 2) in the Reaction Chamber. A catalyst lowers the activation energy of the reaction. As such, a greater number of reactant particles have sufficient energy to react.
- 4. The comparison of your energy diagrams should illustrate the following characteristics:
  - The reaction is exothermic (energy of reactants is greater than the energy of the products
  - The change in enthalpy is the same for both reactions
  - The activation energy is lower for the catalyzed reaction in the reaction chamber.
- 5. One of the possible explanations for the increase in pressure in the reaction chamber is that oxygen gas is produced when the hydrogen peroxide decomposes. An increase in the quantity of gas in the vessel increases the pressure (assuming that the volume of the Reaction Chamber is constant). The increase in temperature can also contribute to the increase in pressure.

Roller Coaster Physics

Imagine you are on your bike[2] and you are:

- A) at the **bottom** of a very steep hill.
- B) at the **top** of a very steep hill.

What factors affect:

- velocity
- the amount of effort/energy required to
  - pedal
  - break

Research

- Describe in your own words what conservation of mechanical energy means
- Identify one way you can increase potential energy
- Identify one way you can increase kinetic energy

Click on the link below to ***Energy in a Roller Coaster Ride*** and choose the "***STEP"*** option. Describe what happens at each position in terms of

- height and velocity
- potential and kinetic energy

Link to ***Energy in a Roller Coaster Ride:*** https://www.pbslearningmedia.org/resource/hew06.sci.phys.maf.rollercoaster/energy-in-a-roller-coaster-ride/

Information for students

The formula for conservation of mechanical energy (disregard friction)

$$PE_1 + KE_1 = PE_2 + KE_2$$

Where:

- $PE = mgh$
- $KE = \frac{1}{2}mv^2$
- $m = mass\ (kg)$
- $h = height\ (m)$
- $v = velocity\ (m/s)$
- $g = acceleration\ due\ to\ gravity\ on\ earth = 9.8\ m/s^2$

[2] Image from: https://www.piqsels.com/en/public-domain-photo-fjkzp, retrieved on May 11, 2020

Problem 1

Most roller coasters use an electric winch to pull the cars up to the top of the first high point. In the example below, the roller coaster is pulled to the top of the hill where the speed of the rollercoaster is 2 m/s (point A). The mass of the roller coaster is 1000 kg.

- A) Identify the potential energy, kinetic energy, total energy and the velocity at points A, B, C, D and complete Table 1.
- B) What is the maximum height the roller coaster reaches when it stops (point E)? ($v = 0\ m/s$)

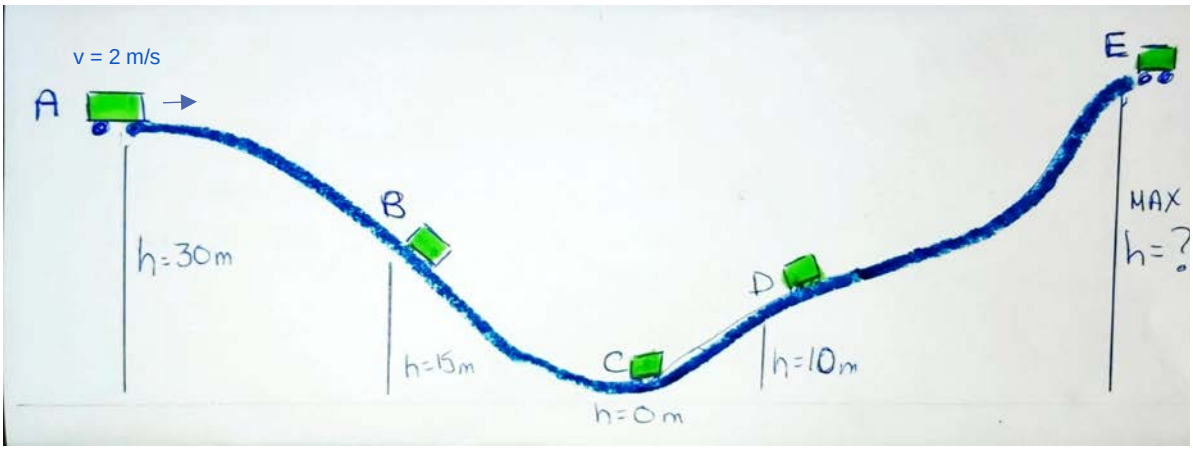


Table 1

	Point A	Point B	Point C	Point D	Point E
Height (m)	30	15	0	10	?
Mass (kg)					
Potential Energy (J)					
Kinetic Energy (J)					
Total Energy (J)					
Velocity (m/s)					

Problem 2

Design a new track for the same roller coaster (m = 1000 kg).

- The roller coaster must have 4 hills and each hill must be a different height
- The speed of your roller coaster should not exceed 100 km/hr
- Air breaks will be used at the end of the ride, once it is at ground level (height = 0 m)
- Complete Table 2

Table 2

	Hill A	Hill B	Hill C	Hill D	End - before the breaks are applied
Height (m)					0
Velocity (m/s)					
Mass (Kg)					
Potential Energy (J)					
Kinetic Energy (J)					
Total Energy (J)					

Materials required:

- Calculator
- Internet device (optional)

Information for parents

Answer key to Table 1 can be found in the Appendix

Helpful link: https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/v/conservation-of-energy

Appendix A: Solutions

Answer Key for Table 1

	Point A	Point B	Point C	Point D	Point E
Height (m)	30	15	0	10	PE - mgh $296\,000 = 1000(9.8)h$ 30.2
Mass (kg)	1000	1000	1000	1000	1000
Potential Energy (J) $PE = mgh$	294 000	147 000	0	98 000	296 000
Kinetic Energy (J) $KE = \frac{1}{2}mv^2$	2 000	296000 – 147000= 149 000	296000 – 0 = 296 000	296000 – 98000 = 198 000	0
Total Energy (J)	296 000	296 000	296 000	296 000	296 000
Velocity (m/s) $KE = \frac{1}{2}mv^2$	2	149 000=$\frac{1}{2}1000v^2$ 17.26	296 000=$\frac{1}{2}1000v^2$ 24.33	198 000=$\frac{1}{2}1000v^2$ 19.90	0