THE BOMBARDIER BEETLE

DEFENCE MECHANISM

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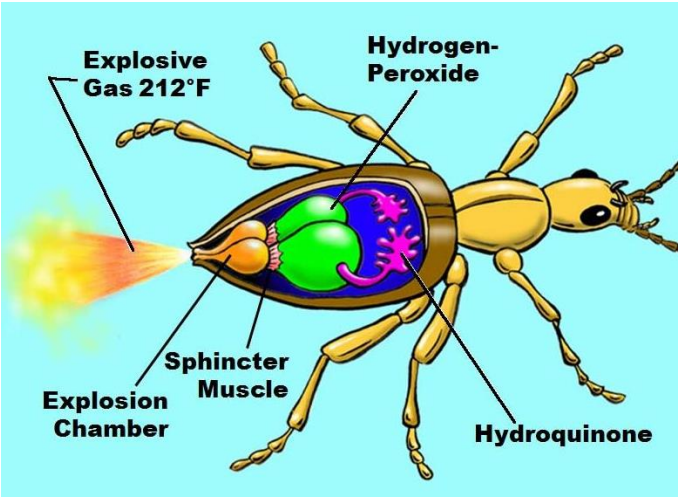
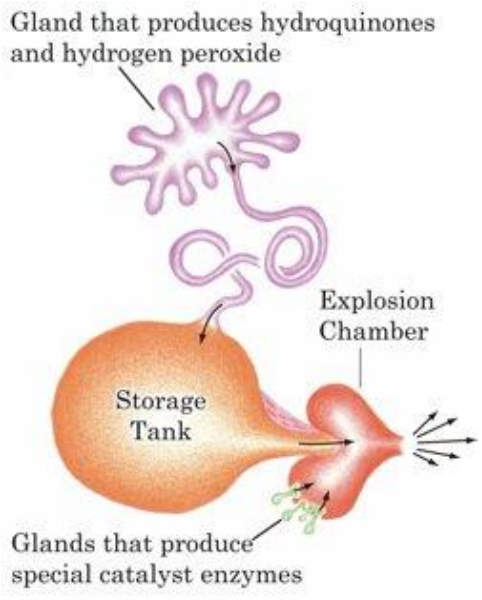
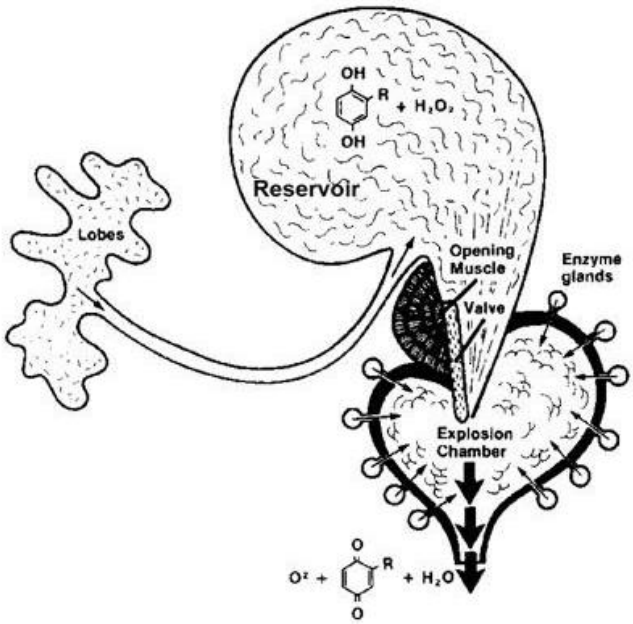
The bombardier beetle received its name from the noxious "bombs" it releases as a defense mechanism. When disturbed, the bombardier beetle ejects a hot, noxious chemical spray from the tip of its abdomen with a popping sound. The spray is produced as a result of a reaction between two chemical compounds, hydroquinone and hydrogen peroxide, which are stored in two separate reservoirs in the beetles abdomen. When triggered, the aqueous solution of hydroquinone and hydrogen peroxide travels to the vestibule where catalysts facilitate the decomposition of the hydrogen peroxide, and the oxidation of the hydroquinone. The heat produced from the reaction causes the mixture to reach a temperature near the boiling point of water, producing gas which drives the ejection. To predators, the damage can be fatal.

ANATOMY



The bombardier beetle has two large glands that open at the tip of the abdomen. Each gland is composed of a thick-walled vestibule which contains a mixture of catalases and peroxides that are produced by the secretory cells which line the vestibule. Both glands are also made up of a thin-walled and compressible reservoir that contains an aqueous solution of hydroquinone and hydrogen peroxide. The reaction doesn't occur in the reservoir because it doesn't provide sufficient energy to fuel the reaction.





MECHANISM OF DEFENCE

When threated, the bombardier beetle opens a valve that allows the aqueous solution of hydrogen peroxide and hydroquinone to travel from the reservoir to the vestibule. Catalases lining the vestibule wall facilitate the decomposition of the hydrogen peroxide into oxygen gas and water in the following reaction:

$$2H_2O_{(aqueous)} \rightarrow 2H_2O_{(liquid)} + O_{2\,(gas)}$$

Peroxidase enzymes facilitate the oxidation of the hydroquinone into p-Quinone and hydrogen gas in the following reaction:

$$C_6H_4(OH)_{2\,(aqueous)} \rightarrow C_6H_4O_{2\,(aqueous)} \rightarrow C_6H_4O_{2\,(aqueous)} + H_{2\,(gas)}$$

Hydroquinone and hydrogen peroxide react to produce paraquinone and water. The net reaction is:

$$C_6H_4(OH)_{2\,(aqueous)} + H_2O_{2\,(aqueous)} \rightarrow C_6H_4O_{2\,(aqueous)} + 2H_2O_{(liquid)}$$

This reaction is highly exothermic. The energy released from the reaction raises the temperature of the mixture to nearly 100° C, causing roughly 1/5 of the mixture to vaporize. The vapor pressure buildup forces the entrance valves from the reactant storage chambers to close, protecting the beetle's internal organs from the explosion. The boiling, foil smelling liquid is expelled explosively through an outlet valve with a loud "pop". The beetle's glands store enough hydroquinone and hydrogen peroxide to allow the beetle to spray roughly 20 times. Sometimes, this is enough to terminate the predator. The main component of the spray, 1, 4-Benzoquinone (paraquinone), is particularly irritating to the eyes and respiratory system. The flow of the reactants into the reaction chamber and consequent ejection occur in a series of 70 pulses, at a rate of 500 pulses/second! These pulsations are caused by micro explosions due to the continuous pressure on the reservoir. This system of pulsations is beneficial for the survival of the beetle because it uses pressure instead of muscles to eject the spray at a constant velocity, thus conserving the beetle's energy.

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The Bombardier Beetle

On the surface, Bombardier Beetles may not appear to be very different from the average ground beetle, or *Carabidae*, but upon closer examination, they are miraculously designed to have the unique ability to stun and deter predators from pursuing them due to a highly-complex internal defense mechanism: a jet stream of boiling hot chemicals.

Bombardier beetles function like a highly complex machine, designed with specific materials for a specific purpose. A research team from the Massachusetts Institute of Technology (MIT) recently examined the internal processes and parts involved in how the beetles produce their chemical weapon jet by using an X-ray camera that recorded the process at 2,000 frames per second. Their observations were as follows:

> "The X-ray images of the explosion . . . show that spray pulsation is controlled by the passageway between two internal chambers; two structures control this process: a flexible membrane and a valve. The opening and closing of this passageway between a chamber holding the precursor liquid and an explosion chamber seems to take place passively; an increase in pressure during the explosion expands the membrane, closing the valve. Then, after the pressure is released when the liquid is ejected, the membrane relaxes back to its original state and the passage reopens, allowing the next pulse to form. This all takes place so rapidly — not to mention inside the insect — that the process had never been directly observed."[1]

Essentially, inside the Bombardier beetle's abdomen there are two connected chambers: the first chamber has hydroquinone and hydrogen peroxide inside, and the second chamber is full of enzymes called peroxidase and catalase.[2] When a Bombardier beetle feels threatened by an enemy it will empty the chemical contents of the first chamber into the second chamber, where the enzymes speed up the reaction of the chemicals, resulting in a deadly chemical expulsion with a temperature of 212º F. Even worse for a foe, the insect can precisely aim its explosive concoction at any being trying to harm it.

In conclusion, the Bombardier beetle has a complex defense mechanism, complete with the machinery to create hydroquinone and hydrogen peroxide, raise the chemicals to a boiling point, and aim them exactly at the desired target. While Bombardier beetle's defensive system will not seriously harm larger predators[3], the boiling expulsion is still capable of burning and staining the skin of the enemy, providing a miraculously designed system of protection for this little beetle.

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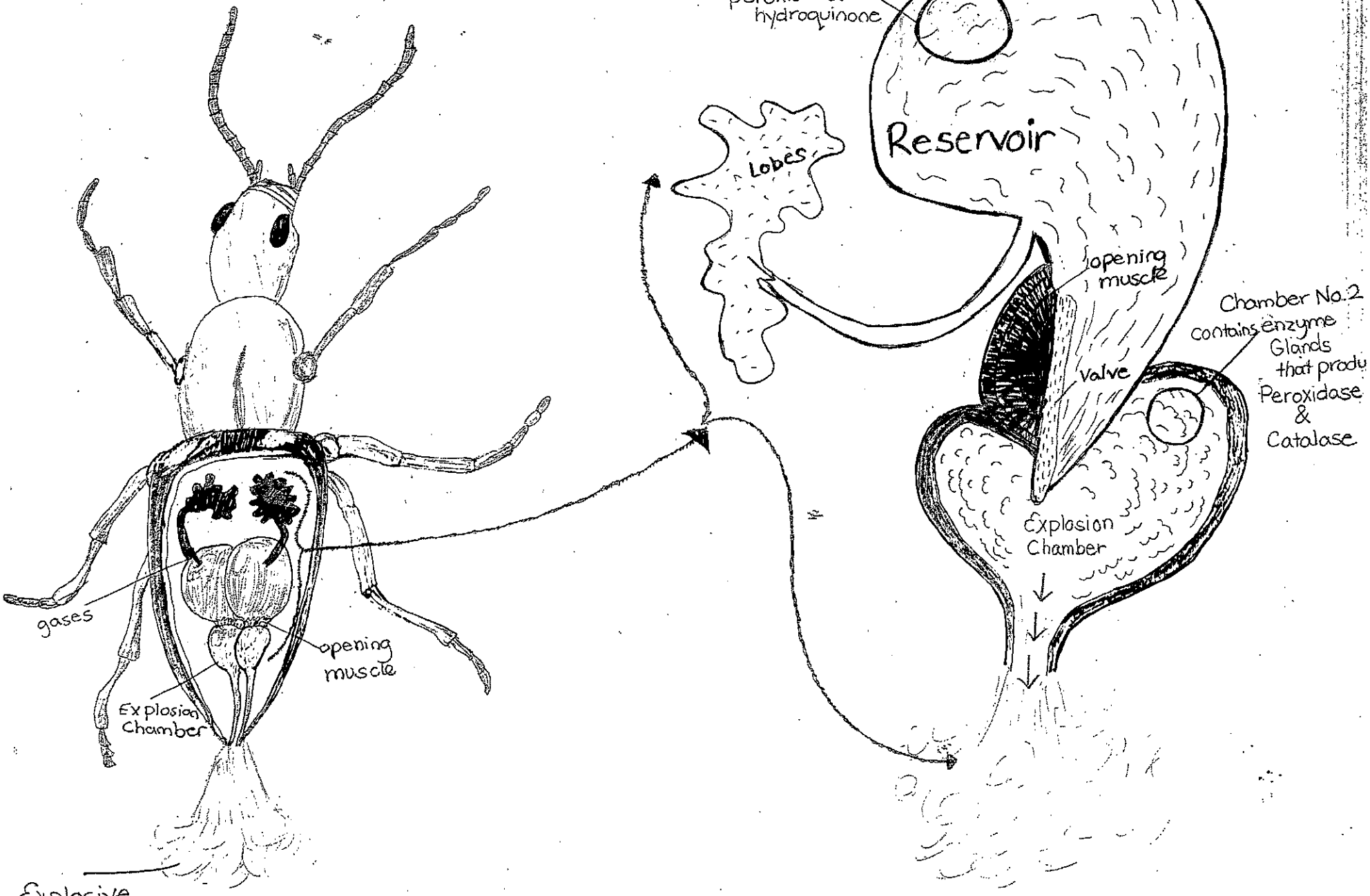
[1] MIT News, David L. Chandler | MIT News Office - http://news.mit.edu/2015/how-bombardier-beetles-produce-defensive-spray-0430 | Accessed: 9/23/16

[2] Things to Ponder about Evolution and Creation
http://www.ichthus.info/Evolution/evol-vs-creation.html Accessed: 9/23/16

[3] About.com Education, Debbie Hadley - http://insects.about.com/od/coolandunusualinsects/a/bombdefenses.htm | Accessed: 9/23/16

THE BOMBARDIER BEETLE CHEMICAL DEFENSE SYSTEM



Emma Trueba

The Defensive Mechanism of the Bombardier Beetle:

Less than one-inch long[1], the slow bombardier beetle seemingly constitutes an easy meal for predators. However, most animals steer clear of it for their own safety. The bombardier beetle has one of the greatest defense mechanisms in the animal kingdom, the ability to spray scalding chemicals, up to 270 degrees Fahrenheit [1], at a distance of 20 cm[3]. That's the equivalent of a human flinging flaming napalm a distance of 46 feet.

This spray is the result of a precise chemical reaction. The beetle has two special chambers, one containing hydrogen peroxide ($2H_2O_2$) and the other containing hydroquinone ($C_6H_4(OH)_2$). When the beetle feels threatened, these two chemicals are combined in a vestibule (larger chamber) along with some catalysts. As the chemicals are combined, the following reaction occurs[4]:

$2H_2O_{2(aq)} \rightarrow 2H_2O_{(l)} + O_{2(g)}$

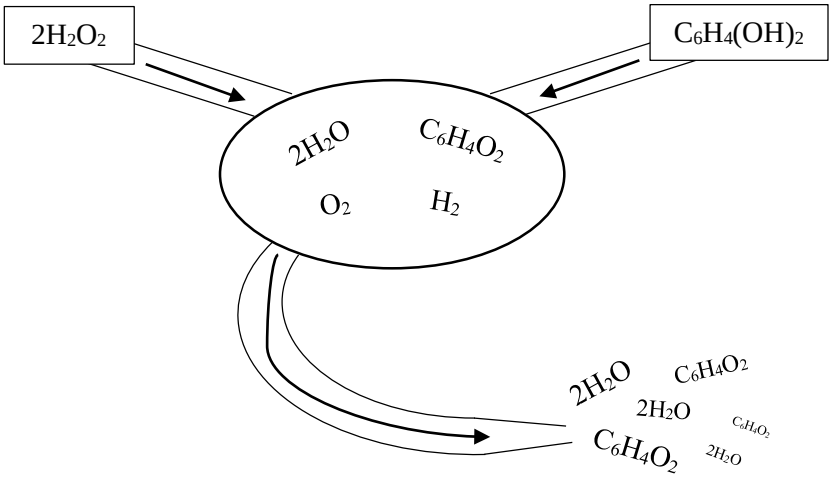
Hydrogen peroxide → *Water* + *Oxygen Gas*

The oxygen gas release from the hydrogen peroxide reacts with the Hydroquinone as follows[4]:

$C_6H_4(OH)_{2(aq)} + O_2 \rightarrow C_6H_4O_{2(aq)} + 2H_2O_{(l)}$

Hydroquinone + Oxygen Gas → *Benzoquinone + Water*

The highly exothermic reaction of hydrogen peroxide and hydroquinone creates Benzoquinone, water, and a *lot* of heat. The mixture instantly heats to 100 degrees Celsius[4] (212 Fahrenheit) and 80% is vaporized. The expanding gas creates pressure, which forces the boiling mixture through an outlet valve. As the mixture is sprayed, deflectors direct it for pin-point accuracy[2]. The entire reaction is roughly diagrammed below.



Benzoquinone is nasty stuff. There are certainly worse things to be sprayed with, but Benzoquinone is pretty bad. According to the IARC (International Agency for Research on Cancer), Benzoquinone causes "local skin discoloration, erythema [rashes], and… [possible] necrosis"[5] when applied to skin. Benzoquinone gas causes "serious vision disturbances… through the entire conjunctiva and cornea."[5] Inhalation "depresses respiration" and, in large doses, "induce[s] local irritation, clonic convulsions, decreased blood pressure and death due to paralysis…"[5]. Fortunately, one bombardier beetle cannot

produce enough Benzoquinone to cause any serious side effects in humans, but to its potential predators, one full-scale attack can be lethal.

The bombardier beetle is a walking time bomb. In two separate vessels, it carries two different chemicals whose combination creates a poisonous gas and a flash of intense heat. This combination only occurs when the beetle wants it to, in a specialized vestibule capable of withstanding high temperature and pressure. Whenever the beetle sprays an enemy, it also covers itself with boiling chemicals. No one knows how it survives unharmed[2]. How could such a complex creature evolve without exploding from rampant chemical reactions or melting itself with its own safety mechanism. Design is a much more satisfactory explanation of this phenomenon. Through this tiny beetle, we see how God has equipped even the smallest creatures with incredibly complex tools. In conclusion, the bombardier beetle may appear small and helpless, but God has armed it with a chemical weapon to deter any predator.

1. National Wildlife Federation, “Bombardier Beetles”
https://www.nwf.org/Wildlife/Wildlife-Library/Invertebrates/Bombardier-Beetles.aspx
2. Rick Steinau, “Bombardier
Beetles” http://www.asktheexterminator.com/Beetles/Bombardier_Beetle.shtml/
3. Institute of Physics, “The Bombardier Beetle, Power Venom, And Spray Technologies”, April 5, 2008,
https://www.sciencedaily.com/releases/2008/04/080401170543.htm
4. Wikipedia, “Bombardier Beetle”
https://en.wikipedia.org/wiki/Bombardier_beetle
5. International Agency for Research on Cancer, “1,4-BENZOQUINONE”, 1977,
http://monographs.iarc.fr/ENG/Monographs/vol71/mono71-63.pdf

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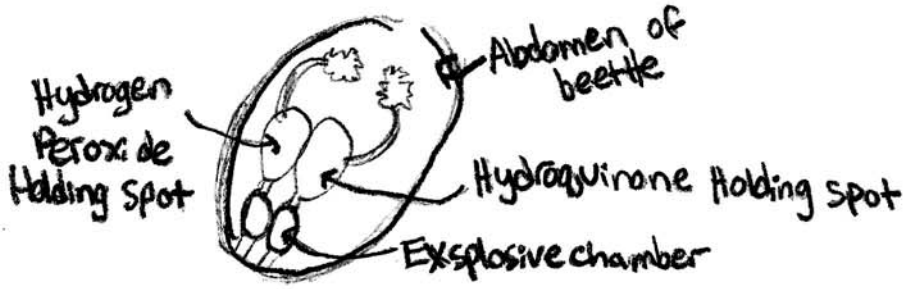
20 September 2016

Research Paper: Bombardier Beetle

The Bombardier Beetle seems harmless at sight but when it goes into defense mode, it is one of the deadliest insects around. Inside their bodies, the beetle detonates explosions that spray out boiling hot chemicals to defend themselves.

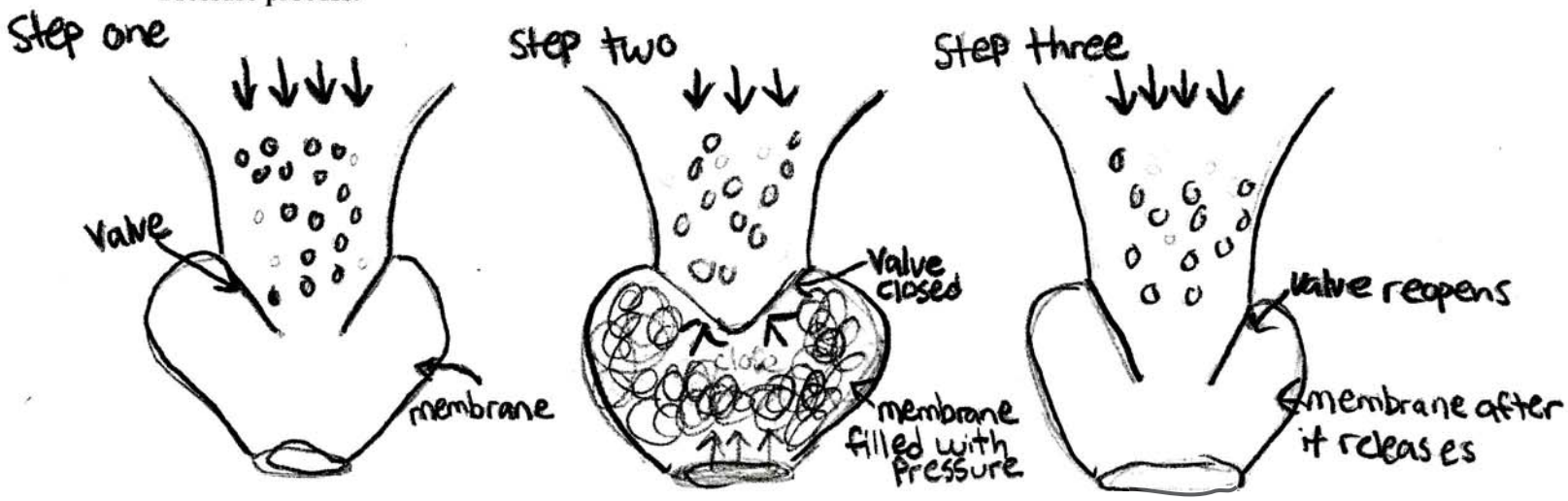
The liquid these beetles spray out is called benzoquinone, which is common in many other insects. The big difference is that the Bombardier Beetle heats up this liquid to a boiling point of 100 degrees Celsius. Hydroquinone and Hydrogen Peroxide are the two chemical compounds that mix together in the beetle's special chamber. These two chemicals are stored in the beetle's abdomen before they mix.

Chambers inside the beetle's body:



When the chemical is sprayed, it comes out in pulses rather than a stream. Part of the explosive chamber deforms to cut off part of the chemical flow; this causes it to start and stop. The pulses are controlled by the flexible membrane and a valve. Within the body of the beetle, pressure increases to expand the membrane, which closes the valve. After the liquid is released, the membrane goes back to its original size.

Pressure process:



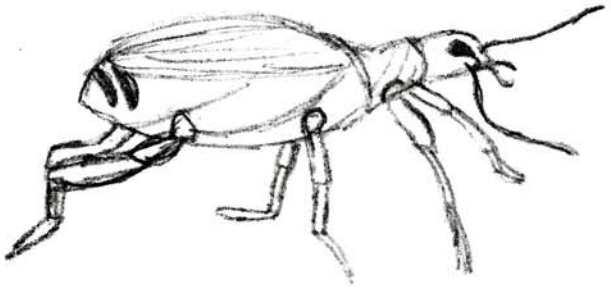
Since the system uses pressure instead of muscles, this saves the beetle's energy and allows him to escape after spraying. The chemical pulses about 500 per second, which is five times faster than any other insect. When the chemicals mix to form the irritant, they begin to heat up to a boiling temperature as they prepare to spray. Bombardier Beetles can swivel the spray 270 degrees with very good aim.

Net reaction:

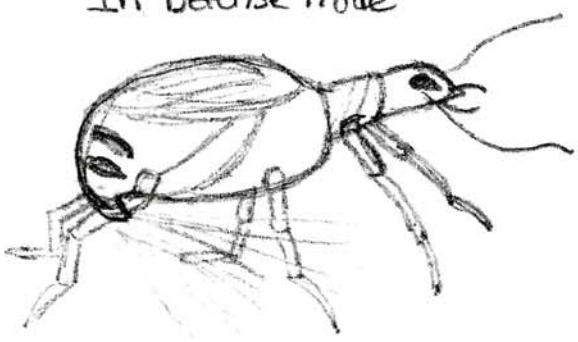
$$C_6H_4(OH)_{2(aq)} + H_2O_{2(aq)} \rightarrow C_6H_4O_{2(aq)} + 2H_2O_{(s)}$$

When threatened this whole process happens within seconds and the liquid sprays its attacker. The predators, such as birds and frogs, are scolded by the spray. Effects could be very fatal depending on where the spray hits. The chemicals spray out like a jet and can travel as far as 20cm. There is no warning except the popping noise that occurs right before they spray. It can affect humans the same way as if you poured boiling water on yourself.

Bombardier Beetle



In Defense mode



Spray