SASTA OLIPHANT SCIENCE AWARDS

Prize Winner

Science Writing

Year 7-8

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BIOLUMINESCENCE

What is bioluminescence?

Bioluminescence, a type of chemiluminescence that emits light energy from a chemical reaction, is a natural phenomenon that allows living things to produce and emit light. Bioluminescence is considered as "cold light" because less than 20% of the light produces thermal radiation or heat (education.nationalgeographic.org, n.d.). In fact, many bioluminescent organisms can regulate when light is produced, what colour to produce and how bright the colour is by controlling their internal chemistry. These abilities are beneficial for bioluminescent organisms to survive in different situations such as when a predator is approaching. Bioluminescence and biofluorescence is completely different. Biofluorescence occurs only when an organism absorbs short-wavelength light and then re-emits the light to a longer wavelength light. Whereas, bioluminescence does not absorb light but produces light **(Figure 1)**.

Figure 1. Bioluminescence
(Jordan Robins Photography, n.d.)

What causes bioluminescence?

Most bioluminescent organisms require two chemicals which are luciferin and luciferase. In an enzymatic chemical reaction, luciferin is the substrate to allow bioluminescence takes place. Whereas, luciferase is an enzyme which catalyses the oxidation of luciferase, accelerates the chemical reaction and allows sudden bursts of light to be generated **(education.nationalgeographic.org, n.d.) (Figure 2)**. When luciferin is catalytically oxidised with oxygen by luciferase, the products are oxyluciferin, adenosine monophosphate (AMP), carbon dioxide (CO_2) and light **(Figure 3)**. An oxidised luciferin is called oxyluciferin. Luciferase is the enzyme which is a biological catalyst that speeds up the rate of reaction of oxidising luciferin by lowering activation energy to achieve bioluminescence **(Figure 4)**. In other words, luciferase allows luciferin releases light energy more quickly. Co-substrates are often required for full activity of bioluminescence. For instance, for fireflies, the required co-substrates are adenosine triphosphate (ATP), magnesium (Mg^{2+}) and Oxygen (O_2), and the end products are oxyluciferin, adenosine monophosphate (AMP), carbon dioxide (CO_2), green photons of 562 nm wavelength and inorganic pyrophosphate (PPi).

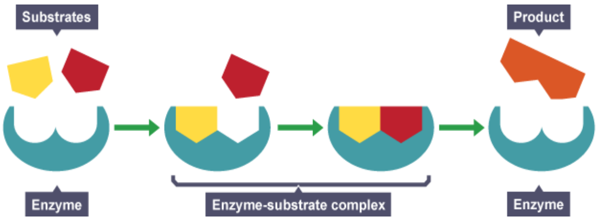


Figure 2. Substrate-Enzyme Reaction
(Amazing World of Science with Mr. Green, n.d.)

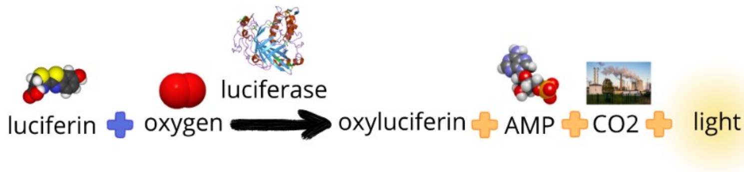


Figure 3. Basic bioluminescence

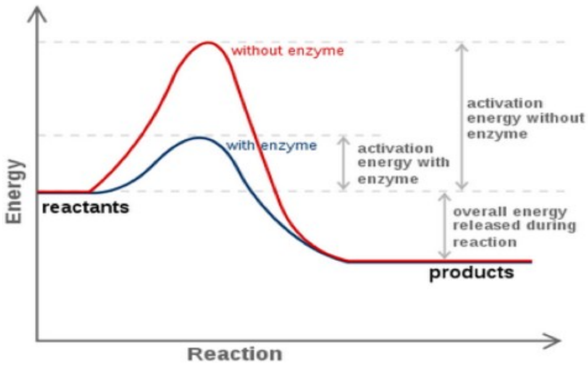


Figure 4.1. Differences in activation energy between reactions with and without enzyme
(www.dynamicscience.com.au, n.d.)

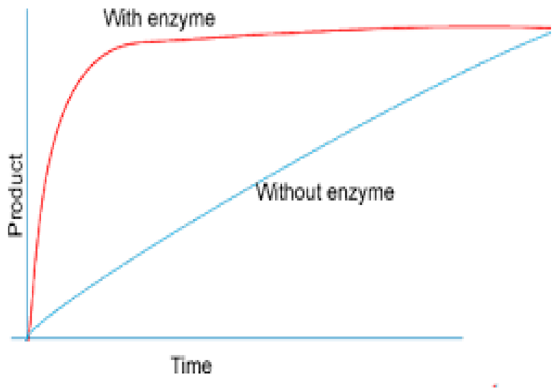


Figure 4.2. Differences in the rate of reactions between catalysed and uncatalyzed reactions.
(www2.nau.edu, n.d.)

Most bioluminescent reactions involve luciferin and luciferase; however, some reactions do not require luciferase but involve photoprotein. Photoprotein is sometimes thought of a luciferase. It is a type of enzyme made up of protein. Photoprotein binds luciferin and oxygen together, often with addition of other required cofactors to produce light **(education.nationalgeographic.org, n.d.)**. It is found in coelenterates, ctenophores, and radiolarians.

Some bioluminescent organisms do not synthesise but absorb luciferin through their diet or symbiotic relationship luciferin from other organisms. For example, midshipman fish absorbs luciferin through seed shrimps. Bioluminescent bacteria species Aliivibrio Fischeri and Bobtail squid share a symbiotic relationship. The bacteria allow the squid to produce light which protects the squid from predators, while the squid supplies nutrients such as sugars and amino acids for the bacteria **(Science in the News, 2021)**.

Colour of bioluminescence

Most bioluminescent organisms in the ocean produce blue-green light. Blue-green light is the colour that transmits best through ocean water due to its short wavelength, high frequency and high photon energy. The shorter the wavelength is and the higher the photon energy is, the deeper the colour that travels through the ocean; therefore, the most unusual colour that bioluminescent organisms produce is red light, for instance, dragonfish (Scripps Institution of Oceanography, n.d.) (Table 1).

Table 1. Colour's wavelength, frequency, and photon energy.

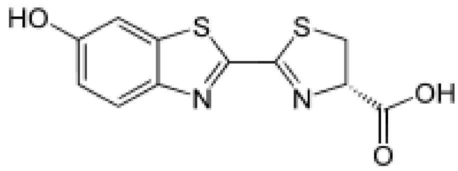
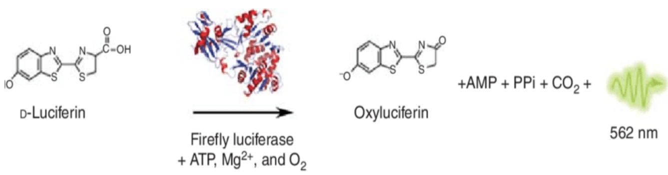
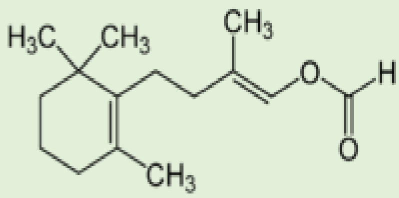
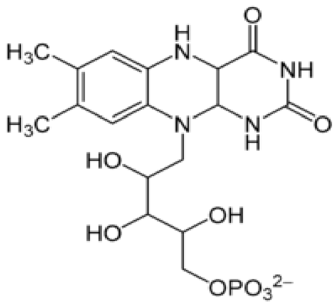
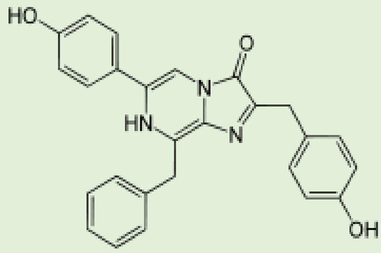
Colour	Wavelength	Frequency	Photon energy
Violet	380-450 nm	668-789 THz	2.75-3.26 eV
Blue	450-495 nm	606-668 THz	2.50-2.75 eV
Green	495-570 nm	526-606 THz	2.17-2.75 eV
Yellow	570-590 nm	508-526 THz	2.10-2.17 eV
Orange	590-620 nm	484-508 THz	2.00-2.10 eV
Red	620-650 nm	400-484 THz	1.65-2.00 eV

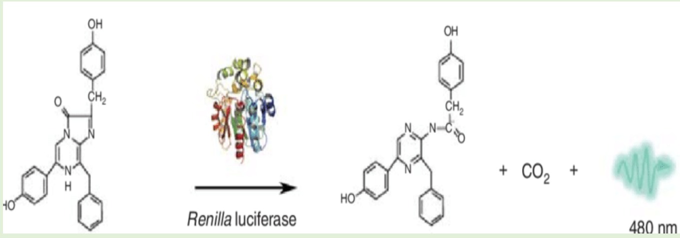
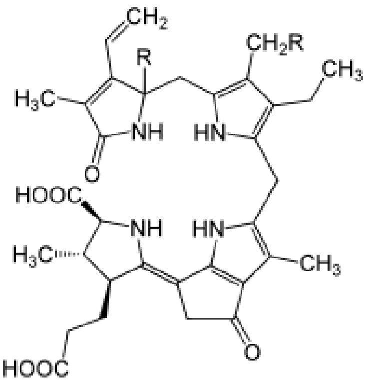
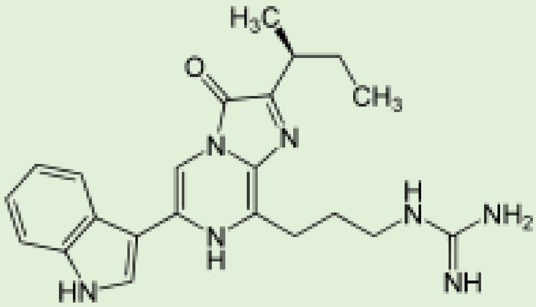
The light produced by bioluminescent organisms depends on the structure of luciferin molecules. There are many types of luciferins, but it is unknown of how many types of luciferins there are. There are five basic luciferin-luciferase systems (Moreira, 2017) (Table 2). Some well-studied luciferins are shown below (Table 3).

Table 2. Five basic luciferin-luciferase systems.

Luciferase Origin	Organism (Family)	Substrate (luciferin)	Co-Substrate	Composition (mass, kDa)	Peak Emission (nm)
Photinus pyralis	Firefly (Lampyridae)	Benzothiazoylthiazole	O_2, ATP	Monomer (62)	560 (610 at 37°C)
Pyrophorus plagiophthalamus	Click beetle (Elateridae)	Benzothiazoylthiazole	O_2, ATP	Monomer (62)	546–593
Renilla reniformis	Sea pansy (Renillidae)	Benzylimidazopyrazinone coelenterazine	O_2	Monomer (35)	480
Gaussia princeps	Copepod (Metridinidae)	Benzylimidazopyrazinone coelenterazine	O_2	Monomer (19)	480
Photorhabdus	Bacteria (Enterobacteriaceae)	Long-chain aliphatic aldehyde	O_2, FMNH2	Heterodimer (77)	490
Vibrio	Bacteria (Vibrionaceae)	Long-chain aliphatic aldehyde	O_2, FMNH2	Heterodimer (77)	490

Table 3. Well-studied luciferins.

Luciferins	Descriptions	Pictures
Firefly luciferin (D-luciferin)	Produce yellow-green light for Lampyridae species	 Molecular structure of firefly luciferin (Wikipedia, 2020)  Chemical reaction of firefly bioluminescence (Lyons, 2013)
Latia luciferin	Produce bright green light for small limpet-like snails	 Molecular structure of Latia luciferin (Wikipedia, 2020)
Bacterial luciferin	Consist of flavin mononucleotide and a fatty aldehyde	 Molecular structure of bacterial luciferin (Wikipedia, 2020)
Coelenterazine	A luciferin discovered in ctenophores, cnidarians, radiolarians, chaetognaths, copepods, brittle stars, fishes, squids, and shrimps	 Molecular structure of coelenterazine (Wikipedia, 2020)

		 Chemical reaction of Renilla (jellyfish) bioluminescence (Lyons, 2013)
Dinoflagellate luciferin	Produce bluish-green light for dinoflagellates to glow in the waves of the ocean	 Molecular structure of dinoflagellate luciferin (Wikipedia, 2020)
Vargulin (Cypridina luciferin)	Produce blue light for Cyprinidae species	 Molecular structure of Vargulin (Cypridina luciferin) (Wikipedia, 2020)

What are the advantages of using bioluminescence by animals?

Animals use bioluminescence to communicate with others, lure preys, defend against predators or signal to others including finding a mate (Table 4). Sometimes counterillumination is used as a method to camouflage in which animals use bioluminescence to blend in the colour of the light of the surrounding and hide themselves from predators (Figure 6).

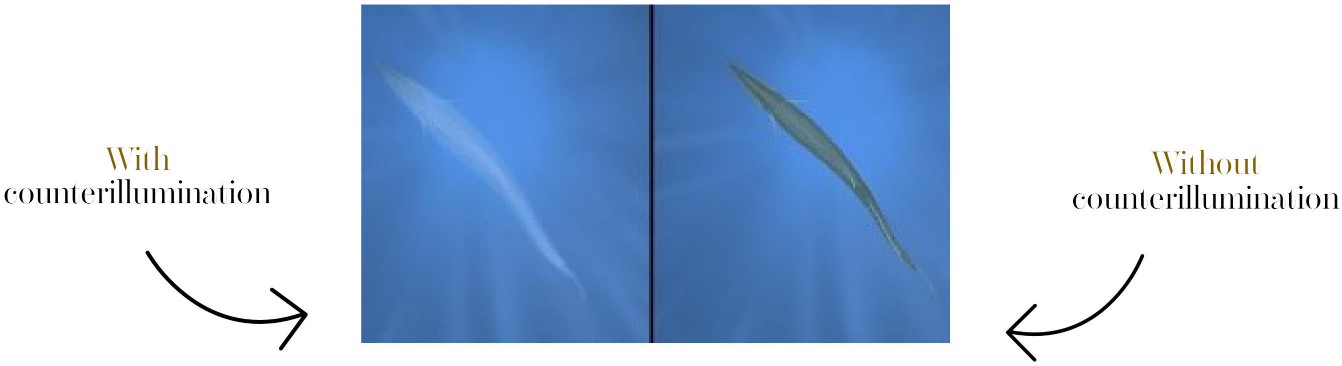
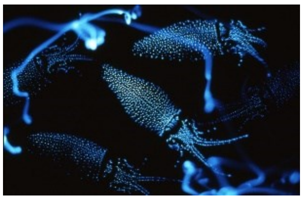
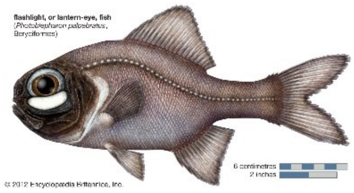


Figure 6. Difference between a fish using counterillumination and another fish using no counterillumination.
(https://www.facebook.com/OceanPortal, 2018)

Table 4. Examples of animals using bioluminescence.

EXAMPLES OF ANIMALS USING BIOLUMINESCENCE:

New Zealand earthworm (Octochaetus multiporus)  (Science Learning Hub, n.d.)	It squirts out bioluminescent bright yellow-orange fluid to indicate it is disturbed.  (Science Learning Hub, n.d.)
Firefly squid (Watasenia scintillans)  (bioGraphic, 2018)	It is covered in tiny glowing photophores to attract preys or confuse predators.  (bioGraphic, 2018b)
Green bomber (Swima bombiviridis)  (Glowing 'bomber worms' discovered, 2009)	It releases bioluminescent sacs to distract predators.  (NBC News, n.d.)
Flashlight fish (Anomalopidae)	It has bioluminescent bacteria under their eyes for finding preys and confusing predators by playing a game of blink-and-run.

 (The Editors of Encyclopaedia Britannica, 2018)	 (Bray, D.J, 2017)
Female anglerfish (Lophius piscatorius)  (Tech2, 2020)	It lives in the midnight zone. It has bioluminescent bacteria in the anglerfish's esca which the anglerfish used to lure preys.  (The Evolution of Planet Earth, 2018)
Firefly (Lampyridae)  (Hadley, 2019)	It has bioluminescence in their bodies at night to attract female fireflies.  (Awale, 2021)
Jellyfish: Siphonophores, Medusae, Sea pens, Ctenophores, etc.  (Rocky Mountain Hospital for Children, 2018)	It uses bioluminescence for defence against predators.  (Nemo, 2021)

Is Bioluminescence safe?

It is advised to view bioluminescence at a fair distance and leave bioluminescent organisms by themselves. It is unsafe to swim in bioluminescent water as organisms can produce toxins that are harmful and cause severe health effects to humans. Swimming is prohibited at the widely known bioluminescent Mosquito Bay at Puerto Rico. Bioluminescent algae can harm marine animals and humans to be sick if contacted. If fishes consume high concentrated toxic bioluminescent algae, they can transmit toxins to other marine life or humans when being consumed. The toxin can cause marine animals and humans to have skin irritations, sickness or even death.

Where is bioluminescence found? When does bioluminescence usually occur? How long does bioluminescence last? Where can you see Bioluminescence in Australia and around the world?

Eighty percent of bioluminescence is found throughout marine habitats, mostly in the ocean. There are the places you can see bioluminescence in Australia and around the world, to name a few (Table 5). Summer months and around new moons where there is no moonlight reflecting on the water are considered the best time to see bioluminescence happening. Bioluminescent organisms light up at various times such as comb jellies luminesce in winter and dinoflagellates luminesce in summer (Figure 7). Nevertheless, bioluminescence is unpredictable of when to happen and it can happen at any time of the year. Bioluminescence lasts a few weeks but some lasts for a few days. According to Florida Department of Health, bioluminescent algal blooms can last for three to five months.

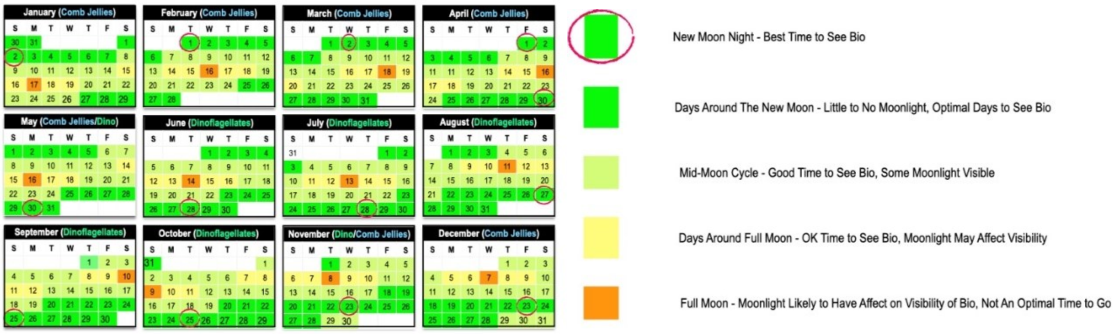


Figure 7. Bioluminescence 2022 Calendar (Comb Jellies and Dinoflagellates)
(BK, 2022)

Table 5. Places of which bioluminescence can be seen in Australia and around the world.

The World:

Toyama Bay, Japan
Mosquito Bay, Puerto Rico
Matsu Islands, Taiwan
Luminous Lagoon, Jamaica
Vaadhoo Island, Maldives
Waitomo Caves, New Zealand
The Blue Grotto, Malta
Halong Bay, Vietnam
San Juan Island, United States
Titusville and Merritt Island, United States
Manialtepec Lagoon, Mexico
Isla Holbox, Mexico
Golfo Dulce, Costa Rica
Jersey, United Kingdom
Mission Bay, California

Australia:

Jervis Bay, New South Wales
Preservation Bay, Tasmania
Port Lincoln, South Australia
Mindarie Marina, Western Australia
The Gippsland Lakes, Victoria
Springbrook National Park, Queensland

The impact of bioluminescence on human

Bioluminescence is found to have significant advantages to human throughout history. Bioluminescence has been used to light up pathways through jungles including India's Western Ghats, all the way to underground mining. Miners used fireflies as an early safety lamp. In the future, streetlights may be replaced by bioluminescent algae in a long glass tube of salted water to create an ecosystem, which can create a better environment, safe electricity and economically safe money (Konica Minolta Sensing, n.d.).

Currently, the bioluminescent bacteria species Aliivibrio Fischeri is used to detect water toxicity. When the bacteria are exposed to a toxic substance, its respiration process will be disrupted leading to decreased light output from the bacteria which signals that the water is contaminated (Microtox M500 ® Industry-leading toxicity detection, n.d.).

Marine bioluminescence has made submarines difficult to hide in the ocean. During World War I in 1918, while attempting to sneak through the Strait of Gibraltar, the last German U-boat disturbed bioluminescent organisms causing the boat to reveal itself to a nearby major military base and subsequently sunk by Allied forces (Mizokami, 2018).

In addition, bioluminescence plays a role in medicine. At the Battle of Shiloh in the American Civil War, on the night of April 7, 1862, the wounds of soldiers began to glow with a greenish-blue colour in the dark. Not after 139 years, in 2001, High schoolers, Bill Martin and Jonathan Curtis, and microbiologist, Phyllis Martin investigated the cause of the glow. The bizarre glow was caused by a bioluminescent bacterium species Photorhabdus luminescens that made the wounds of the soldiers to have a higher survival rate and healing rate, and lower rate of infection than the unilluminated wound of their counterparts. This mysterious phenomenon was called the "Angel's Glow". The cool night temperature and wet conditions by the river had made the soldiers' body temperature to be low enough to experience hypothermia which allowed the bacteria invading the open wound through the soil. The bacteria produced antibiotics that killed off potential pathogens including pernicious bacteria that would have caused lethal infections to open wounds. This investigation led Martin and Curtis won the first place in the 2001 Intel International Science and Engineering Fair (Kuroski, 2018).

Bioluminescence imaging has increased tremendously in the past decades. Bioluminescence imaging monitors and tracks gene and protein interactions, cells or small organisms by the emission of visible light. It is mostly used as a monitoring and detecting technology including tracking cancer cells (www.sciencedirect.com, n.d.). Specialised cameras and machines with sensitive detection systems are employed to detect light emitted by luciferase which oxidises either D-luciferin or Coelenterazine. Continuous research is warranted to explore further developments and applications of bioluminescence.

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