

# Bask in the Glow: Luminescence in Life



Photo courtesy of Barcroft Media

A research paper by Indë Francis

Imagine it is late at night, and the stars are shining brightly. You are at the beach in Puerto Rico and the water is beckoning to you. As your toes touch the cool water the shore lights up in glorious shades of blue and green, and you find yourself swimming in an aurora of ocean light. What is this beautiful phenomenon?

This beautiful phenomenon is the emission of cold light, known as luminescence. Luminescence is found in many different forms. The best known are chemiluminescence and bioluminescence. I have written this paper to explain luminescence and how it affects plant, wild animal, and human life. Luminescence is a function used by millions of organisms, and it is used to find mates, protect prey from their predators, and lure prey. Fungi appear to use their luminosity to attract animals which spread its spores. Plants cannot naturally bioluminesce, but thanks to skilled engineers, we humans may someday light our homes with them. In human culture, we use things like neon lights and glow-sticks to add atmosphere to events, and we are constantly inspired by cold light to write poems and portray the beauty through arts. Luminous life has woven itself strongly into our planet. Documentations of luminescence have been found from B.C.E., and between then and now humans have learned much more about how and why luminescence exists on Earth. Between now and then we have learned to make our *own* luminescence. The discoveries and inventions of the past years are numerous and valuable, and for that reason I have updated the summary of luminescence.

I will lead you through the many aspects of luminescence, starting with background (definition, scientific explanation, sub-categories), and moving on to historical references, uses, defensive and offensive, difference between uses, difference between chemical reactions, and finishing with my conclusion.

### **Background Part A: Definition**

Luminescence is used in both natural and artificial ways. Primarily used in marine life, luminescence in nature is manipulated into various defense and offense mechanisms. In human culture, chemiluminescence is best known in the form of a glow-stick. These glow-sticks are commonly sold in band concerts for the fans to wave to the beat. The science behind these party favors is actually very interesting.

### **Background Part B: Scientific Explanation**

Cold light is exhibited by a very large group of materials and organisms including beetles, cephalopods (squid), and rocks. As different as these subjects undoubtedly are, they actually rely on nearly identical chemical reactions. This process must include oxygen and luciferin as the bare minimum of materials. However, without the third chemical, luciferase, the expression of light appears very slowly and in the infrared layer, which humans cannot see without specific equipment. When luciferase is added to the equation the electrons in the luciferin and oxygen switch to an excited state. Immediately after the energy level calms, light appears from the compound chemical (suite101, Articlesbase & HowStuffWorks). This is the process at its simplest, but the chemicals in fireflies and glow sticks have several unique properties. Adenosine triphosphate (ATP) is the energy that allows fireflies to glow.

ATP is the energy that is in all living cells. For example, when you eat food, the

energy it contains has to be used to make ATP before your cells can use the energy to function. The proteins of ATP are arranged in groups of three phosphates on a chain. After receiving the command to release energy, the last phosphate on a chain of the three must break away. This triggers an energy generator and turns the phosphate chain to ADP (adenosine diphosphate). ADP is ATP after it has released its energy. Immediately after releasing its energy, ADP has two phosphates. ADP can break off another phosphate to supply more energy to the cell or travel to the ribosomes and get a new phosphate so it may become ATP again (suite101). Biologist Abner Lall explained to me the relationship between oxygen and bioluminescence, "The emission of photons in bioluminescence is a by product of a reaction that utilizes luciferin, ATP, luciferase enzyme in the presence of oxygen. Hence bioluminescent reactions cause a reduction (or depletion) in the ambient concentration of oxygen. Therefore when the concentration of oxygen is high (i.e., oxygen toxicity) in an ecological niche, the presence of bacterial bioluminescence reduces the ambient concentration of oxygen, i.e., bacterial glow thereby reducing oxygen toxicity."

Glow sticks are an example of chemiluminescence. The chemicals used in glow sticks are color dye, hydrogen peroxide, and phenyl oxalate ester. The peroxide oxidizes the oxalate ester creating the chemical phenol as well as peroxyacid ester. The new ester dissolves into more phenol and a peroxy compound. The decomposition of the peroxyacid ester energizes the fluorescent dye; causing it to glow (ArticlesBase & science.HowStuffWorks).

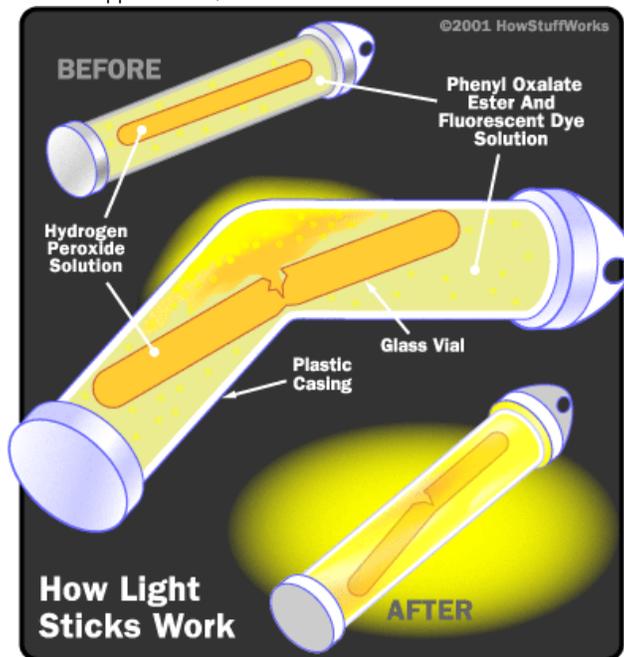


Image courtesy of HowStuffWorks

### Background Part C: Sub-Categories

There are fourteen noteworthy subcategories of luminescence as a whole, and each of them is characterized by the different initiations of their light output (Wikipedia, Luminescence). Below I have compiled definitions of all fourteen and how they luminesce.

- o Electrochemiluminescence is chemiluminescence caused by an electrochemical reaction. To reach a state of excitation, so that it they may produce light,

the electrochemical intermediates must have an exergonic reaction (a reaction with a negative change in energy levels) to create a light upon returning to a relaxed state.

- Crystalloluminescence is luminescence when created during crystallization (the natural creation of crystals).
- Electroluminescence is the light produced when a substance passes through an electrical current or electric and/or magnetic field. Electroluminescence was also used to backlight the gauges on car panels from 1960-1967.
- Cathodoluminescence is the name of the reaction in which the electrons of an atom contact a luminescent substance and cause it to glow.
- Mechanoluminescence is light caused by the actions of a mechanical object upon a different object (when a quartz rock is struck by steel or another quartz stone, it sparks luminescently). There are four subcategories; tribo, piezo, sono, and fractoluminescence. Fractoluminescence is very specifically the fracturing of crystals that emit light.
- When light is emitted due to the breaking of chemical compounds it is called triboluminescence. The chemical bonds in various materials can break from many actions such as crushing, rubbing, ripping, or scratching. An example of triboluminescence, and tribology, is the light emitted when one crunches a (specifically Wint-O-Green) Life Saver® candy.
- Piezoluminescence is light emitted by certain solids when subjected to pressure. Piezoelectric crystals, as well as cigarette lighters when the button is pressed, express piezoluminescence when they are under pressure.
- Sonoluminescence is light emitted by a bubble that has imploded as a reaction to sound. The glowing gas from the bubble often molds to the bubble's original shape. Certain complex equations can approximate "dynamics of motion". The following Rayleigh-Plesset equation is used to measure the dynamics of a sonoluminescent bubble:

$$R\ddot{R} + \frac{3}{2}\dot{R}^2 = \frac{1}{\rho} \left( p_g - P_0 - P(t) - 4\mu\frac{\dot{R}}{R} - \frac{2\gamma}{R} \right)$$

In this equation, R is the radius of the bubble, t is time,  $\mu$  is viscosity, P is the pressure, t represents time, the over-dots represent "time derivatives", and  $\gamma$  represents surface tension.

- Photoluminescence is the release of light after any substance absorbs photons. The time span between absorption (of photons) and release is usually very brief; lasting femtoseconds (billionths of a second) or milliseconds. However, the intermission has been prolonged to minutes or even hours.

- Fluorescence is the luminescence of a material or organism that has been subjected to electromagnetic radiation or ultraviolet light. Popular examples of fluorescence are uranium glass, aragonite, and pyronite highlighters. Even diamonds display slight red light when under an x-ray!
- Phosphorescence is similar to fluorescence except for that phosphorescent substances do not immediately release the radiation they take in. The electromagnetic radiation absorbed can be stored in the substance for multiple hours before expressing light.
- Radioluminescence is the display of light by an object or material that has been exposed to beta particle rays or ionizing radiation. This technology, in the form of radioluminescence paint, is used in some watch faces to make them glow.
- Thermoluminescence is the phenomenon of light being emitted by a crystalline object that has undergone electromagnetic or ionizing radiation. Thermoluminescence is used as a way to date things that have been buried for a long time, but were ionized by radioactive “elements” in the earth around them. The amount of ionizing the object has undergone is equal to its age.
- Lyoluminescence is displayed when solids dissolve into a liquid solvent. Depending on the radiation dose of the solid, the light can last as long as the saturation value (amount of radiation. Most irradiated substances (paper, powdered milk, etc.) have the ability to lyoluminesce (Wikipedia).

### **Background Part D: Appearances in Organisms**

Naturally, there are no bioluminescent mammals in documented history. Most bioluminescent creatures are marine life. In fact, ninety percent of deep sea life is bioluminescent! Other bioluminescent species include microorganisms like dinoflagellates, bacteria, fungi, annelids (worms), land-dwelling snails (molluscs), and insects and beetles like fireflies (Wikipedia, List of Bioluminescent Organisms and Simon, 14).

Where does the light of bioluminescent emanate from? The answer to this frequently asked question is that there are organs for making light! Also called photophores, these organs are most prominent on a vast variety of squid (Simon, 80). According to Hilda Simon’s book, Living Lanterns, some squids have incredible numbers of photophores all over their bodies, “One four-inch species from New Zealand has no fewer than ninety photophores, seventy of them on its long tentacles and arms.” (Simon, 81).

Some organisms create light without creating photoproteins. However, these organisms also have light organs. These organs are home to light-producing bacteria. This is called a symbiotic relationship. The bacteria produce light consistently, so in order to stop their glow the host lifeform must retract the light organ into itself or cover the organ with skin, like an eyelid (science.HowStuffWorks, 5).

Some bioluminescence, like that of many corals, is only visible under ultraviolet light, and when it is viewed from underwater, in its natural habitat (Simon, 106-107). Until about

1956, it was assumed that coral had very few self-luminescent species. The Pacific was being surveyed by divers, and the divers came across corals luminescing in a variety of different colors: greens, oranges, golds, yellows, blue, violet, red, and the rarest sorts of light: beiges and grays (Simon, 100-106). However, because the corals only shine visibly under ultraviolet light, the most beautiful way to witness their rainbow orchestra is to see them in their natural habitat.

The *Vampyroteuthis Infernalis*, translating literally to “vampire squid of Hell” is an extremely interesting bioluminescent deep-sea cephalopod (squid) that lives in the midnight zone at about 2,000 to 3,000 feet or more. This squid, commonly known as the vampire squid, is about one foot long and has eight webbed tentacles that are lined with cerata (bony spikes) on the inside. It gets its name from its dark color and cloak-like tentacles paired with its large red eyes which are, proportionally, the largest in the animal kingdom. Adult vampire squid have fins extending from both sides of their head, thus providing means of propulsion. Almost entirely covered in photophores, a type of light organ, these squid have extreme control over their luminescence. They are capable of manipulating their photophores to create flashes of light that span from disorienting bursts of light for fractions of a second to minutes of light in the aphotic depths at which it lives (Wikipedia, Vampire Squid).

### Luminescence Historically Part A: Recordings

Luminescence has been the subject of texts and poems by humble observers and renowned philosophers alike. Below are two of many poems that were inspired, sparked, and illuminated by luminescence and the feelings it evokes.

#### Phosphorus

by Samuel Dickinson

What place luminescent  
joy has in a winter storm  
I know not, but between  
the labored breaths and  
windy retaliation, it  
shines.

#### Outing into Darkness

by Pradipto Chattopadhyay

Sinking low in fathomless misery  
The poet seeks an escape vent.  
Takes this as an outing into darkness  
A free fall in a gliding motion  
Into the depth of the ocean  
Away from the surface storm  
Knowing he can't be down beneath bottom,

And even there would be swimming  
With all the life that make it their abode  
Wrapped in blackness yet luminescent  
In the filtered glow up from above  
Dreaming one day to find their way back  
To the warm hug of sunlight.  
This affords him a survival, belief-driven,  
Alike the last breath that hopes a heaven!

The Greek philosopher Aristotle, in the fourth century B.C.E., recorded his observation of fireflies as such: "some things, though they are not in their nature fire, nor any species of fire, yet seem to produce light." (Simon, 19, [Guides.library.Harvard](#), & [ChemistryExplained](#)). According to [PhotoBiology](#), Aristotle recorded as many as one hundred eighty different luminous marine species.

In the first century C.E., a Roman naturalist known as Pliny the Elder mentioned a variety of bioluminescent animals. Notably the *Pholus Dactylus* clam and *Lucerna Piscis* lanternfish (Simon, 19, [Guides.library.Harvard](#), & [ChemistryExplained](#)). In the fifteenth century, explorers such as Christopher Columbus noted the marine luminescence as a "burning sea" (Columbus, cited from [PhotoBiology](#)).

The Waitomo Caves are a popular tourist attraction in New Zealand. The caves were first explored in 1887 by Maori Chief Tane Tinorau and the English explorer Fred Mace. This subterranean caves are filled with water and thousands of glowworms. The glowworms live on the ceiling and glow green over the boats that traverse the caves. Today the caves are owned by the descendants of Tane Tinorau and his wife Huti (Waitomo). Glowworm is the generic name for a group of insects that glow through bioluminescence. The most well known form of glowworm is the adult wingless female. The males have wings but cannot glow ([Wikipedia](#), [Glowworm](#)).

### Luminescence Historically Part Two B: Experiments

Hennig Brand, a German scientist, conducted an experiment in 1669 which concluded in chemiluminescence. He had hoped that by superheating human urine he would create gold. What he did get was phosphorus in its elemental form. Phosphorus is a waxy white material that glows when exposed to oxygen ([ArticlesBase](#)).

Following his appointment as director of the McCollum-Pratt institute, Dr. William McElroy (a biochemist who lived from 1917-1999) sought to understand the secrets of luminescence. He discovered that he needed a sum of greater than two million fireflies to extract one gram of luciferin. According to [Living Lanterns](#) by Hilda Simon, "In those years fireflies were caught and killed for experimental use in incredible numbers- sometimes nearly a million in a single summer season!" This is extremely unfortunate because firefly larvae are important predators in the food chain. They use their mandibles to bite into prey like slugs and snails, and then they liquify their prey with acid so that they can digest them. The results of McElroy's experiments proved that ATP (adenosine triphosphate) is necessary and present in a firefly's light organs which are located in its tail. It was discovered that adding extra ATP results in a brighter glow. This relates ATP to adrenaline because

adrenaline sharpens a firefly's light as well (Simon, 118-119).

### Uses Part A: Human

Humans use luminescence too, but not so much in our bodies as in our culture. Chemiluminescence is the most common kind of luminescence in an average American's life because it is found in neon lights, which can be found in nearly every town and city.

Neon lights are an example of chemiluminescence in its gaseous form. Neon lights are lit by electrified gases, most often red neon, inside a glass tube or bulb that has a metal electrode at each end. Several thousand volts are charged into the electrodes; ionizing the gas inside the bulb or tube. The light produced is a form of fluorescence (Wikipedia, Neon Lighting).

During 1923, a man named Earle C. Anthony bought two neon lights from Claude Neon Lights, a neon light company, to advertise his car company, Packard. Placed in Los Angeles, California, the signs "literally stopped traffic". Inspired by the publicity Anthony's signs had brought him, other companies flocked to Claude, among other companies that began to pop up, to buy the incredible neon lights (Wikipedia, Neon Lighting).

Neon lights are an example of the use of cold cathodes in light caused by a gas discharge. A cold cathode is an electron that creates electrodes without being heated through a filament (a wire, usually pressed tungsten, that is made to conduct electricity). (Wikipedia, Cold Cathode).

Some people have developed ways to prevent light pollution with bioluminescence. Antony Evans, the founder and CEO of Genome Compiler, started growing glowing plants to replace electric lights. Imagine: lighting your home with plants! This project, successfully funded by Kickstarter on June 7, 2013, safely genetically enhances plants to cause bioluminescence using firefly and bacteria genes as a base (Kickstarter and Inhabitat).

### Uses Part B: Nature

While the process of bioluminescence is beautiful, it doesn't seem to have a point at first. Why does it exist in the first place? One use that animals have for luminescence is to attract a mate. You can imagine it would be a lot easier to find other tiny fireflies if they glow. Some mushrooms glow too. The reason they glow is to attract animals to spread their spores (suite101).

Mushrooms, as well as dinoflagellates, which are tiny creatures that live in the ocean, also glow to attract larger animals to eat the animals that want to eat them! (suite101).

Fireflies are perhaps the most well known bioluminescent terrestrial creatures in the world. These tiny beetles can be found in every part of the world except in desert and arctic climates (Simon, 23). Firefly larvae are carnivorous, "Feeding mainly on snails and slugs." Simon, 24. They use their mandibles to tear at and paralyze their prey, and some seem to be semi-aquatic (Simon, 24). The luminosity and winglessness of the adult fireflies varies greatly from species to species. The majority of adult females are wingless, but glow more brightly than their male counterparts. "They are the "glowworms" of poetry." (Simon, 25). It is believed that fireflies (which are slightly poisonous) glow to dismay predators from eating them (Wikipedia, Glowworm). There are a few other luminous beetles, many of them sharing the swamp ecosystem with frogs and toads; predators. In the past, people have reported sightings of bioluminescent frogs. However these frogs and toads are only temporarily luminous after eating a meal of luminescent beetles. These beetles glow

continuously until they have been completely digested (Simon, 44).

Most bioluminescent animals live in the ocean, concentrating in the twilight zone (the area between 660 to 3,300 ft deep). Above the twilight zone is the euphoric zone, and below it is the midnight zone. Some of the bioluminescent creatures that live in this area are shrimp, krill, fish, squid, and jellyfish. The glow from these animals can travel very far, so sometimes the only source of light deep in the sea is from bioluminescence. In fact, ninety percent of deep sea life can make light. Most bioluminescence in marine life is blue or green because blue light reaches farthest through the water with a wavelength of 440-479 nanometers (science.HowStuffWorks 2 and DrScience.wcp.MuOhio).

One of the most famous bioluminescent fish is the terrifying anglerfish which uses bioluminescence to lure prey. Some animals, specifically squid and crustaceans, use bioluminescence to scare predators away by spitting chemiluminescent compounds at them (suite101).

One family of fish known as malacosteus, or loosejaws, emits red light, which normally isn't visible in the twilight or midnight zones. This fish uses its infrared light to see its prey, but no other species can see the light it emits (DrScience.wcp.MuOhio).

Dinoflagellates are a type of unicellular marine plankton, but what makes them special is that they light up. Because they have condensed chromosomes they are classified as dinokaryotic. When dinoflagellates feel movement in the water they light up. One dinoflagellate's glow lasts between 0.1 or 0.5 seconds. The brightness and length of most luminescent organisms depends on the sunlight absorbed from the previous day. These microscopic "fire plants" swim using two flagella, one is longitudinal (meaning lengthwise) and the other is flat. The longitudinal flagella moves the dinoflagellates forward, and the flat flagella directs it. This means that dinoflagellates spiral while they swim (DrScience.wcp.MuOhio).

In Puerto Rico, the dinoflagellates are well known. The bioluminescent bays are a popular tourist attraction. During certain phases of the moon, such as the new moon, the waning gibbous phase, the waning crescent phase, and the last quarter phase, the dinoflagellates are especially prominent and react brightly to even slight disturbances. People love to kayak in the bright bay when the dinoflagellates are glowing beautifully (BioBayPuertoRico).

"Fairy-tale garden in the dark," is how Hilda Simon describes the array of glowing structures on the seafloor in her book, Living Lanterns (Simon, 97). The plantlike structures are reminiscent of skeletons, feathers, and glorious branches. These bodies host "colonies" of tiny bioluminescent organisms and root themselves to the sea floor, largely unable to move. Among all the immobile organisms of the sea, the sea pens are the most remarkable. Most sea pens, which strongly resemble quills, are luminous, and can grow up to five feet high in some species. Sea pens use luminescence as a response to touch, and will light up at the base, and spread up the stem, and along the fronds, until the entire feather is alight with oceanic fire (Simon, 98).

### **Defense vs. Offense Part A: Defense**

There are many uses for bioluminescence in the depths of the ocean. There are six defensive uses: startling a predator, counterillumination to hide from predators, misdirection/smokescreens can be used to distract and escape a predator, distractive body parts glow and separate from the main body to distract a predator. The last two are

alarms, which small organisms use to attract second degree predators to eat their predators, and sacrificial tags which stick to predators to attract *that* predator's predator (Biolum.eemb.ucsb).

### Defense vs. Offense Part B: Offense

There are also four offensive uses of bioluminescence. These include luring prey, stunning prey, attracting prey with external (in some cases) light, and illuminating prey (Biolum.eemb.ucsb). One rare shark, known as the megamouth shark, is thought to have bioluminescent tissue dangling from its upper jaw that it uses to attract shrimp, jellyfish, and various planktons. If this hypothesis is correct then the megamouth shark is the largest bioluminescent organism in documented history (Elasmo-Research)



DEFENSE		startle	dinoflagellates, squid, stern-chaser myctophid
		counterillumination	<b>many:</b> crustaceans, fish, squid
		misdirection: smoke screen	<b>many:</b> crustaceans, polychaetes scyphozoans, chaetognaths, squids, tube-shoulder fishes, ctenophores, siphonophores, larvaceans?
		distractive body parts	<i>Octopoteuthis</i> squid, brittle stars, polychaetes, siphonophores
		burglar alarm	dinoflagellates, jellies, other?
		sacrificial tag	pelagic sea cucumbers, jellies, polychaetes
		warning coloration (deter settlers)	jellies, brittle stars? (tube worms, clam)

OFFENSE		lure prey (attract host: bacteria)	anglerfishes, siphonophores, cookie cutter shark, squid?
		lure with external light (evaluate habitat?)	sperm whale? megamouth shark?
		stun or confuse prey	squid, headlamp myctophid?
		illuminate prey	flashlight fish, dragonfishes

	mate attraction/ recognition (swarming cue)	ostracods, <i>Japetella</i> octopus? lanternfish, flashlight fish, anglerfish? syllid polychaetes, others?
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Illustrations from <http://biolum.eemb.ucsb.edu/functions.html>

## Conclusion

I have written this paper to explain luminescence and how it affects plant, wild animal, and human life. We humans have discovered much more about how luminescence works, where it takes place, and how we can use it since its earliest recordings in BCE. Luminescence is important in the wild as a way to evade predators and lure prey, but it could become the way we light our homes. If we can innovate through bioluminescence, we could put a lid on light pollution as a whole. Imagine how beautiful a bioluminescent Earth would be from space.

“What is luminescence, and how has it affected life and history on Earth?”

Luminescence is the emission of cold light by a subjects ranging from bubbles to rocks to squid, and and this function supplies millions of organisms with ways to protect themselves, feed themselves, and find mates. Fungi appear to use its luminosity to attract animals which spread its spores. Plants cannot naturally bioluminesce, but thanks to skilled engineers, we humans may someday light our homes with them. In human culture, we use things like neon lights and glow-sticks to add atmosphere to events, and we are constantly inspired by cold light to write poems and portray the beauty through arts. This phenomenon has rooted itself into our culture, our poetry, and our history. This awesome ability is luminescence.

## Bibliography

"Bioluminescence." *Chemistry Explained*. Advameg, n.d. Web. 10 Apr. 2014.  
<<http://www.chemistryexplained.com/Ar-Bo/Bioluminescence.html#b>>.

"Bioluminescence." *Wikipedia The Free Online Encyclopedia*. Wikimedia Foundation, 1 Apr. 2014. Web. 3 Apr. 2014. <<http://en.wikipedia.org/wiki/Bioluminescence>>.

"Bioluminescent Bay and Other Things to do in Puerto Rico." *Bioluminescent Bay Puerto Rico*. WordPress, n.d. Web. 10 Apr. 2014.  
<<http://biobaypuertorico.com/>>.

"Bioluminescent Bay – Puerto Rico Moon Phase Calendar." *Bioluminescent Bay Puerto Rico*. Bioluminescent Bay Puerto Rico, n.d. Web. 10 Apr. 2014.  
<<http://biobaypuertorico.com/bioluminescent-bay-moon-calendar/>>.

"Bio/Chemi- Luminescence." *Andor*. Oxford Instruments, n.d. Web. 3 Mar. 2014.  
<<http://www.andor.com/learning-academy/bio-chemi-luminescence-an-overview-of-andor%27s-solutions>>.

"Bioluminescence: History." *Harvard Library*. U. Harvard, 19 Dec. 2013. Web. 10 Apr. 2014. <<http://guides.library.harvard.edu/content.php?pid=419040&sid=3493478>>.

"Cathodoluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 14 Mar. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Cathodoluminescence>>.

Chattopadhyay, Pradip. "Outing into Darkness." *Hello Poetry*. Hello Poetry, 3 July 2013. Web. 22 Apr. 2014. <<http://hellopoetry.com/poem/407502/outing-into-darkness/>>.

"Chemiluminescence." *Wikipedia The Free Online Encyclopedia*. Wikimedia Foundation, 26 Feb. 2014. Web. 3 Mar. 2014. <<http://en.wikipedia.org/wiki/Chemiluminescence>>.

"Chemistry of Bioluminescence." *The Bioluminescence Web Page*. U of California, 1997. Web. 4 Apr. 2014. <<http://biolum.eemb.ucsb.edu/chem/>>

Coila, Bridget. "A Simple Explanation of Adenosine Triphosphate." *Suite 101*. N.p., 19 Sept. 2012. Web. 10 Apr. 2014. <<https://suite101.com/a/2dv4274>>.

Coila, Bridget. "How Bioluminescence and Chemiluminescence Work." *Suite 101*. N.p., 19 Sept. 2012. Web. 3 Mar. 2014. <<https://suite101.com/a/how-bioluminescence-and-chemiluminescence-work-a163212>>.

"Cold Cathode." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 22 Feb. 2014. Web. 10 Apr. 2014. <[http://en.wikipedia.org/wiki/Cold\\_cathode](http://en.wikipedia.org/wiki/Cold_cathode)>.

"Crystalloluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 24 Nov. 2013. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Crystalloluminescence>>.

Dickinson, Samuel. "Phosphorus." *Hello Poetry*. Hello Poetry, 22 Oct. 2011. Web. 22 Apr. 2014. <<http://hellopoetry.com/poem/140722/phosphorus/>>.

Dubuisson, M, Marchand, C, Rees, JF., 2004. Firefly luciferin as antioxidant and light emitter: the evolution of insect bioluminescence. *Journal of Bioluminescence and Chemiluminescence*. Volume 19 Issue 6, Pages 339 - 344

"Electrochemiluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 23 Mar. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Electrochemiluminescence>>.

"Electroluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 7 Apr. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Electroluminescence>>.

Evans, Antony. "Glowing Plants: Natural Lighting with No Electricity." *Kickstarter*. Kickstarter, 23 Mar. 2013. Web. 10 Apr. 2014. <<https://www.kickstarter.com/projects/antonyevans/glowing-plants-natural-lighting-with-no-electricit>>.

"Fluorescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 29 Mar. 2013. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Fluorescence>>.

"Functions of Bioluminescence." *The Bioluminescence Web Page*. U of California, 1997. Web. 3 Apr. 2014. <<http://biolum.eemb.ucsb.edu/functions.html>>.

"Glowworm." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 2 Apr. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Glowworm>>.

Harris, Tom. "How Light Sticks Work" 02 November 2001. HowStuffWorks.com. <<http://science.howstuffworks.com/innovation/everyday-innovations/light-stick.htm>> 10 April 2014.

"History of the Waitomo Glowworm Caves." *Waitomo*. Tourism Holdings, 2013. Web. 10 Apr. 2014. <<http://www.waitomo.com/glowworm-caves-history.aspx>>.

Khan, Badruddin. "Importance of Chemiluminescence and Bioluminescence." *Articlesbase*. Articlesbase, 30 Mar. 2010. Web. 3 Mar. 2014. <<http://www.articlesbase.com/education-articles/importance-of-chemiluminescence-and-bioluminescence-2075376.html>>.

Lall, Abner. E-mail interview by Inde Francis. 12 May 2014.

Lee, John. "A History of Bioluminescence." *Photo Biology*. N.p., 2008. Web. 10 Apr. 2014. <<http://www.photobiology.info/HistBiolum.html>>.

"List of Bioluminescent Organisms." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 3 Apr. 2014. Web. 10 Apr. 2014. <[http://en.wikipedia.org/wiki/List\\_of\\_bioluminescent\\_organisms](http://en.wikipedia.org/wiki/List_of_bioluminescent_organisms)>.

"Luciferase." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 31 Mar. 2014. Web. 3 Apr. 2014. <<http://en.wikipedia.org/wiki/Luciferase>>.

"Luminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 7 Nov. 2013. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Luminescence>>.

"Luminol: The Glowing Reaction." *Carolina: World Class Support for Science & Math*. Carolina Biological Supply Company, 2014. Web. 30 Apr. 2014. <<http://www.carolina.com/teacher-resources/Interactive/luminol-glowing-reaction/tr10786.tr>>.

"Luminol." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 29 Mar. 2014. Web. 3 Apr. 2014. <<http://en.wikipedia.org/wiki/Luminol>>.

"Lyoluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 10 Jul. 2012. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Lyoluminescence>>.

Martin, R. Aidan "Biology of the Megamouth Shark." *ReefQuest Centre for Shark Research*. ReefQuest Centre for Shark Research, 2003. Web. 10 Apr. 2014. <[http://www.elasmo-research.org/education/shark\\_profiles/m\\_pelagios.htm](http://www.elasmo-research.org/education/shark_profiles/m_pelagios.htm)>.

Matus, Morgana. "Glowing Plant Project Creates Bioluminescent Plants for Natural Lighting." *Inhabit*. Inhabit, 13 May 2013. Web. 10 Apr. 2014. <<http://inhabitat.com/glowing-plant-project-kickstarter-campaign-creates-bioluminescent-plants-for-natural-lighting/>>.

"Mechanoluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 13 Mar. 2013. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Mechanoluminescence>>

Miller, Allison. "What's Glowing in the Water? Bioluminescent Dinoflagellates." *JrScience*. JrScience, 23 Sept. 2002. Web. 3 Apr. 2014. <<http://jrscience.wcp.muohio.edu/FieldCourses00/PapersMarineEcologyArticles/WhatsGlowingintheWaterBio.html>>.

"Neon Lighting." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 10 Dec. 2013. Web. 10 Apr. 2014. <[http://en.wikipedia.org/wiki/Neon\\_lighting](http://en.wikipedia.org/wiki/Neon_lighting)>.

"Omphalotus Olearius." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 16 Sep. 2013. Web. 10 Apr. 2014. <[http://en.wikipedia.org/wiki/Omphalotus\\_olearius](http://en.wikipedia.org/wiki/Omphalotus_olearius)>.

"Phosphorescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 1 Mar. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Phosphorescence>>.

"Photoluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 18 Mar. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Photoluminescence>>.

"Piezoluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 3 Feb. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Piezoluminescence>>.

"Radioluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 18 Mar. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Radioluminescence>>.

Simon, Hilda. *Living Lanterns: Luminescence in Animals*. Illus. Hilda Simon. New York: Viking, 1971. Print.

"Sonoluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 27 Jan. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Sonoluminescence>>.

"Thermoluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 10 Mar. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Thermoluminescence>>.

"Triboluminescence." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 7 Feb. 2014. Web. 10 Apr. 2014. <<http://en.wikipedia.org/wiki/Triboluminescence>>.

"Vampire Squid." *Wikipedia The Free Encyclopedia*. Wikimedia Foundation, 3 Apr. 2014. Web. 10 Apr. 2014. <[http://en.wikipedia.org/wiki/Vampire\\_squid](http://en.wikipedia.org/wiki/Vampire_squid)>.

Wilson, Tracy V. "How Bioluminescence Works." *HowStuffWorks*. HowStuffWorks, 10 July 2007. Web. 3 Apr. 2014. <<http://animals.howstuffworks.com/animal-facts/bioluminescence.htm>>.